AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY

Batch 46

1. SUBJECT CLASSIFICATION

A. PRIMARY: TEMPORARY

B. SECONDARY:

2. TITLE AND SUBTITLE

Population, health, nutrition and development: theory and planning

3. AUTHOR(S)

Correa, Hector

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1974	429 p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS

Johns Hopkins

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT

A treatise on quantitative analytic models for studying relationships between population, health, nutrition, and development. The only reasonable approach to the study of the interaction between population, health, nutrition, and development is a general model of the process of development. To construct such a model, several successive approximations are needed, beginning with intuitively accepted concepts and their relationships, and proceeding towards the precise definition and measurement of the concepts and relationships involved. Development is defined as an increment in the personal wellbeing of all the members of a community. It is equivalent to what economists call "welfare" or "quality of life" or "standard of living." A static model of individual wellbeing is presented in Chapter 1. In Chapter 2 a method for estimating social welfare functions is presented. Chapter 3 presents a study of the influence of population size and growth, health, and nutritional conditions on physical and mental capacities. Chapter 4 considers interactions among determinants of wellbeing--population, health, nutrition, and education. Chapter 5 substitutes employment for education, and Chapter 6 considers all five determinants together. Chapter 7 considers interactions of population and economic growth. Chapter 8 considers interactions among population, health, nutrition, education, production, and interpersonal relations. Chapter 9 presents simulation models for population planning; Chapter 10 discusses optimum use of contraceptive methods. Remaining chapters discuss simulation models for health planning, optimization models, integration of population and health planning, nutritional planning, and integrated planning with a simulation model.

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAC-943	
12. DESCRIPTORS	13. PROJECT NUMBER
	14. CONTRACT NUMBER: CSD-3320 211(d)
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

POPULATION HEALTH, NUTRITION AND DEVELOPMENT

Theory and Planning

HECTOR CORREA

Graduate School of Public and International Affairs
January, 1974

POPULATION, HEALTH, NUTRITION AND DEVELOPMENT

Theory and Planning

Hector Correa
Department of Economic and
Social Development
Graduate School of Public and
International Affairs
University of Pittsburgh

and

Department of Family Health
and Population Dynamics
Tulane School of Public Health
and Tropical Medicine

The publication outlines the use of analytical models for understanding the complex relationships between population, health, nutrition and development. The use of models is described in detail in step wise progression from a static model of individual well-being to a simulation model for planning population growth, health, nutrition, education and economic development. Extensive references are provided for each section.

Attachment, a/s

Financial support for the preparation of this book was given by the Agency for International Development Grant AID csd 3320 to Johns Hopkins University for the Analytical Investigation of the Relation between Health and Economic Development, and by the Department of Family Health and Population Dynamics of the Tulane School of Public Health and Tropical Medicine.

Copyright--Not for publication without written permission of author.

ACKNOWLEDGEMENTS

The author wishes to thank especially four perons for their contribution to this book.

Professor Mark Perlman, who suggested the work and advised in the initial steps of its preparation;

Dr. Joseph Davis without whose interest it would not have been completed;

Mrs. Virginia Correa who translated it from my illegible Spanglish manuscript to a first typed draft in English, and gave understanding moral support durings its preparation; and,

Mrs. Roberta Steyer who supervised and typed the final version.

TABLE OF CONTENTS

		Page
CHAPTER I	A FRAMEWORK FOR THE STUDY OF DEVELOPMENT	1
I-1	Introduction	1
I-2	A Static Model of Individual Well-Being	1
I-2-1	The Model	1
I-2-2	Problems in the Empirical Analysis of the Static Model of Individual Well-Being	7
I-3	The Aggregation and Integration of Individual Levels of Well-Being	10
I-3-1	Problems of Aggregating and Integrating Individual Levels of Well-Being	11
I-3-2	The Integration of Individual Preference into Social Goals	11
I-4	Content of this Book	14
CHAPTER II	POPULATION, HEALTH, NUTRITION AND SOCIAL WELL-BEING	17
II-1	Content of this Chapter	17
II-2	A Method for Estimating the Well-Being of a Typical Individual in a Society	17
II-3	Data and Results of a Practical Application of the Method in II-2	21
II-4	A Simplified Method and Some Additional Results	24
CHAPTER III	INTERACTIONS AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION AND MENTAL CAPACITIES	29
III-1	Introduction	29
III-2	Population Size and Growth and Physical and Mental Capacities	29
III-2-1	The Size of the Population and of the Labor Force	29
III-2-2	Population Growth, Age Structure and Labor Force Participation	30
III-2-3	Population Growth and Participation of Women in the Labor Force	30
III-2-4	Population Size and Growth and Mental Abilities	43
III-3	Health and Physical and Mental Abilities	46

		Page
III-3-1	Introduction	46
III-3-2	Life Expectancy and Working Capacity	47
III-3-3	Morbidity and Working Capacity	53
III-3-4	Health and Mental Abilities	61
III-4	Nutrition and Physical and Mental Capacities	62
III-4-1	Integenerational Effects of Nutrition on Mental Capacities	62
III-4-2	Nutrition, Morbidity and Mortality in Early Childhood	67
III-4-3	Early Childhood Malnutrition and Its Relationship to Mental Abilities	69
III-4-4	Current Nutritional Conditions and Mental Abilities	80
III-4-5	Nutrition and the Working Capacity of Healthy Persons	83
CHAPTER IV	INTERACTION AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION AND EDUCATION	99
IV-1	Population and Education	99
IV-1-1	The Age Structure of the Population and the Burden of Education	99
IV-1-2	The Impact of Population Growth on Increased Enrollment and the Costs of Education	102
IV-2	Health and Education	106
IV-2-1	Introduction	106
IV-2-2	Pregnancy Conditions and Reading Achievement in Childhood	106
IV-2-3	Physical Health Conditions of Children Attending School and Their Relationship to Achievement	107
IV-2-4	Mental Health Conditions of Children Attending School and Their Achievement	109
IV-3	The Influence of Nutrition on Educational Achievement	111
IV-3-1	Impact of Prenatal and Early Childhood Malnutrition on Educational Achievement	111
IV-3-2	Concurrent Malnutrition and Educational Achievement	117

		Page
CHAPTER V	INTERACTION AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION AND EMPLOYMENT	123
V-1	Introduction	123
V-2	The Model	123
V-3	The Impact of Better Health and Nutrition on Employment and Wages	127
CHAPTER VI	INTERACTION AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION, EDUCATION AND EMPLOYMENT	130
VI-1	Introduction	130
VI-2	Health and Production	130
VI-2-1	Introduction	130
VI-2-2	The Impact on Production of One or Several, But Not All, Diseases	132
VI-2-3	Estimates of the Impact of All Diseases, Obtained by Aggregating Detailed Data	132
VI-2-4	Estimates of the Economic Impact of All Health Conditions, Obtained Using Aggregated Health Indices	134
VI-2-5	Percentage of National Income Attributable to Reduced Mortality	134
VI-2-6	Capital Formation Through Health	137
VI-3	Nutrition and Production	137
VI-3-1	Statistical Studies of the Relationship Between Nutrition and Production	138
VI-3-2	Nutrition, Mental Ability and Production	140
VI-3-3	Nutrition, Mental Ability, Education and Productivity	142
VI-4	Simultaneous Influence of Population, Health, Nutrition and Education on Total Production	145
VI-4-1	Statistical Studies of the Simultaneous Influences of Population, Health, Nutrition and Education on Production	149
VI-4-2	Estimates Based on the Decomposition of Technological Change	151
VI-5	Simultaneous Influence of Population, Health, Nutrition, and Education on Per Capita Production	166

		Page
CHAPTER VII	INTERACTION AMONG DETERMINANTS OF WELL-BEING: POPULATION AND ECONOMIC GROWTH	178
VII-1	Introduction	178
VII-2	The Neo-Classic Model of Economic Growth With Endogenous Capital and Exogenous Population	178
VII-2-1	The Neo-Classic Model of Economic Growth With Savings Dependent Only on the Size of Income	178
VII-2-2	The Neo-Classic Model of Economic Growth With Savings Dependent on Income and Population	183
VII-3	The Neo-Classic Model of Economic Growth With Endogenous Population	189
VII-3-1	Introduction	189
VII-3-2	The Neo-Classic Model With Endogenous Population and Savings Dependent Only on Per Capita Income	189
VII-3-3	The Neo-Classic Model With Endogenous Population and Savings Dependent on Income Per Capita and Rate of Population Growth	197
CHAPTER VIII	INTERRELATIONS AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION, EDUCATION, PRODUCTION, AND INTERPERSONAL RELATIONS	201
VIII-1	Indices of Interpersonal Relations to be Used	201
VIII-2	Population Size and Growth and Crime	201
VIII-2-1	Experimental Studies in Animals	201
VIII-2-2	Family Size and Crime Rates	202
VIII-2-3	Population Density and Crime Rate	202
VIII-3	Health and Crime	207
VIII-3-1	Hereditary and Genetic Determinants of Crime	207
VIII-3-2	Health Conditions in Infancy and Childhood and Their Relationship to Crime	208
VIII-3-3	Physical Health and Delinquency	210
VIII-3-4	Mental Health and Crime	211
VIII-4	Nutritional Conditions and Crime	211
VIII-5	Education and Crime	211
VIII-5-1	Introduction	211

		Page
VIII-5-2	Formal Education and Crime	213
VIII-6	Economic Conditions and Crime	216
VIII-6-1	An Economic Model of Rational Choice Between Criminal and Non-Criminal Activities	216
VIII-6-2	Economic Conditions and Crime: Empirical Evidence	224
VIII-7	Health and Group Violence	227
CHAPTER IX	SIMULATION MODELS FOR POPULATION PLANNING	235
IX-1	Introduction	235
IX-2	A Model for Forecasting Total Population and Its Use in Population Planning	235
IX-3	A Model for Forecasting Population by Sex, With Constant Rates--Its Use in Population Planning	239
IX-4	A Model for Forecasting Population by Sex and Age With Constant Rates--Its Uses in Population Planning	240a
IX-5	Forecasting Population by Sex and Age With Changing Rates	248
IX-6	Limitations of the Models in Sections IX-2 and IX-3 as Planning Models	249
CHAPTER X	POPULATION PLANNING: OPTIMUM DETERMINATION OF A TARGET POPULATION	250
X-1	Introduction	250
X-2	Choice of Target Population When Only Differences in Fertility Due to Age are Considered	252
X-2-1	Minimization of Births with Costs of Prenatal and Delivery Care Excluded	252
X-2-2	Minimization of Births With Costs of Prenatal and Delivery Care Included	259
X-3	Choice of a Target Population When Withdrawal From the Program Is Not Controlled By the Planner	260
X-4	Choice of a Target Population When the Planners Can Influence the Proportion of Women Withdrawing From the Program	267
X-5	Extension of the Planning Period so that Births Avoided Influence the Number of Women in the Population	269

		Page
CHAPTER XI	POPULATION PLANNING: OPTIMUM USE OF CONTRACEPTIVE METHODS	271
XI-1	Introduction	271
XI-2	Choosing a Contraceptive Method When Only Total Cost is Considered	274
XI-2-1	Minimization of Pregnancies	274
XI-2-2	Minimization of Births	278
XI-3	Choosing a Contraceptive Method When the Costs of "Side Effects" Are Considered	282
XI-4	Choosing a Contraceptive Method When a Detailed Breakdown of Costs is Considered	283
XI-5	Choosing a Target Population and a Contraceptive Method	285
XI-6	Choosing a Method to Achieve Optimum Family Size	288
XI-6-1	Optimum Family Size: Minimization of Number of Excess Children	288
XI-6-2	Optimum Family Size Considering Disutility of Excess and Defect in the Number of Children Within a One Year Planning Horizon	290
XI-6-3	Optimum Family Size Considering Disutility of Excess and Defect in Number of Children With a Planning Horizon of Several Years	292
CHAPTER XII	HEALTH PLANNING: SIMULATION MODELS	295
XII-1	Introduction	295
XII-2	A Model for Forecasting Population Growth in Which the Influence of Morbidity is Considered	295
XII-2-1	The Population to be Used as a Term of Reference	295
XII-2-2	Number of Cases by Disease, Age and Sex	298
XII-2-3	Number of Deaths by Cause, Age and Sex	302
XII-2-4	A Model for Forecasting Population by Age and Sex	302
XII-3	Demand for Medical Services	303
XII-3-1	Demand for Doctor Services and Number of Doctors Demanded	304
XII-3-2	Demand for Curative Services	304

		Page
XII-3-3	Demand for Preventive Services	305
XII-3-4	Total Demand for Doctors' Services and Number of Doctors Needed	305
XII-4	Demand for Hospital Services	306
XII-4-1	Number of Hospital Discharged by Sex, Condition and Age	306
XII-4-2	Number of Hospital Days Demanded Per Year	307
XII-4-3	Number of Hospital Rooms Demanded	307
XII-5	Influence on Population Growth of Changes in Socio-Economic Conditions in General and in Health Conditions in Particular	308
CHAPTER XIII	HEALTH PLANNING: OPTIMIZATION MODELS	309
XIII-1	Introduction	309
XIII-2	The Objective Function for Health Planning	309
XIII-3	Prevention Versus Cure For One Disease, One Period Model	311
XIII-3-1	Content of this Section	311
XIII-3-2	The Basic Model	311
XIII-3-3	A More Realistic Approach -- Model and Numerical Example	313
XIII-3-4	Minimization of the Number of Deaths When Several Diseases are Considered	318
XIII-3-5	Further Refinements of the Linear Model	329
XIII-3-6	A Non-Linear Model	329
XIII-4	An Integrated Model of Health Planning and Population Growth	330
CHAPTER XIV	INTEGRATION OF POPULATION AND HEALTH PLANNING	337
XIV-1	Introduction	337
XIV-2	Minimization of Infant Deaths	338
XIV-3	Minimization of Mothers' and Infants' Deaths	340
XIV-4	Analysis of the Influence of Number of Children Surviving on Acceptance of Contraception	341
XIV-5	Extensions	342

		Page
CHAPTER XV	AN OPTIMIZATION MODEL FOR NUTRITIONAL PLANNING	344
XV-1	Review of Existing Studies	344
XV-1-1	Mathematical Models in Diet and Menu Planning	344
XV-1-2	Conceptual Models in Nutritional Planning	345
XV-1-3	Simulation Models in Nutritional Planning	346
XV-2	A Mathematical Model for Nutritional Planning	346
XV-2-1	The Model	346
XV-2-2	Computational Aspects of the Model	351
XV-2-3	Extensions of the Model	352
CHAPTER XVI	THE INTEGRATION OF POPULATION AND EDUCATIONAL PLANNING	356
XVI-1	Simulation Models	356
XVI-2	Optimization Models	356
XVI-2-1	Optimum Choice Between Educational and Birth Control Expenditures to Minimize Number of Children Without Education	356
XVI-2-2	Minimum Investment Requires in Order to Open Schools for all the School-Age Population	358
XVI-2-3	Integration of the Models in Sections XVI-2-1 and XVI-2-2	366
CHAPTER XVII	INTEGRATED PLANNING OF POPULATION GROWTH, HEALTH, NUTRITION, EDUCATION AND ECONOMIC DEVELOPMENT	368
XVII-1	Introduction	368
XVII-2	A Simulation Model for Planning Population Growth, Health, Nutrition, Education and Economic Development	368
XVII-2-1	General Statement of the Model	368
XVII-2-2	Part of the Model Dealing with Population, Education and Labor Force	370
XVII-2-3	Parts of the Model Dealing with Economic Aspects	375
XVII-2-4	Application of the Model	380
XVII-3	Optimum Population Control Programs	383
XVII-3-1	Introduction	383

		Page
XVII-3-2	The Cost Function of a Population Control Program	387
XVII-3-3	Maximization of the Rate of Growth of Per Capita Income	391
XVII-3-4	Maximization of Per Capita Income Over an Infinite Time Horizon	394
XVII-3-5	Maximization of Well-Being Over an Infinite Time Horizon	396
XVII-3-6	Maximization of Well-Being When Both Levels of Consumption and of Expenditures on Population Control are Control Variables	397
XVII-3-7	Conclusions	398

LIST OF TABLES

TABLE		PAGE
II-1	ESTIMATED PARAMETERS α OF UTILITY FUNCTION	22
II-2	RANKING OF GOODS AND SERVICES CONSIDERED ACCORDING TO THE VALUES OF COEFFICIENTS α	23
II-3	COMPARISON OF THE RESULTS OBTAINED WITH THE METHOD IN SECTION II-2 AND THE METHOD IN THIS SECTION FOR LINEAR FUNCTIONS	26
II-4	RESULTS OBTAINED WITH FORMULA II-9 FOR EACH COUNTRY	27
III-2-1	TSLS ESTIMATES OF MODEL III-1-10 AND III-1-11	40
III-2-2	TSLS ESTIMATES OF THE PARAMETERS OF MODEL II	42
III-2-3	IQ AND BIRTH RATES FOR SEVERAL SOCIAL GROUPS	45
III-3-1	LIFE EXPECTANCY AND WORKING CAPACITY	49
III-3-2	INCREMENT OF U.S.A. LABOR FORCE ATTRIBUTABLE TO REDUCED MORTALITY	52
III-3-3	EGYPT: SOCIO-ECONOMIC CONDITIONS OF RESEARCH AND CONTROL VILLAGES	54
III-3-4	EGYPT: DISABILITY DAYS AND WORK-LOSS DAYS PER MONTH IN RESEARCH AND CONTROL VILLAGES	55
III-3-5	U.S.A.: NUMBER OF SCHOOL-LOSS DAYS PER YEAR PER 100 CHILDREN AGE 6-16 AND NUMBER OF WORK-LOSS DAYS PER YEAR PER 100 USUALLY WORKING PERSONS, ASSOCIATED WITH ACUTE CONDITIONS	57
III-3-6	ESTIMATED NUMBER OF SCHOOL-LOSS DAYS PER YEAR PER CHILD AGE 6-16, AND OF NUMBER OF WORK-LOSS DAYS PER YEAR FOR USUALLY WORKING PERSONS, ASSOCIATED WITH ACUTE CONDITIONS	59
III-3-7	CORRELATIONS BETWEEN PREMATURITY AND DEVELOPMENT AT 13 1/2 MONTHS	63
III-3-8	CORRELATIONS BETWEEN COMPLICATIONS DURING FIRST WEEK OF LIVE AND DEVELOPMENT OF 13 1/2 MONTHS	64
III-4-1	MEAN IQ SCORES AND BIRTH WEIGHTS FOR 27 SETS OF IDENTICAL TWINS	66
III-4-2	STATISTICAL ANALYSIS OF INDIRECT DETERMINANTS OF INFANTS AND CHILDREN DEATHS	68
III-4-3	COMPARISON OF NUTRITIONAL CONDITIONS AND MORBIDITY IN OBSERVED GUATEMALAN VILLAGES	70

TABLE		PAGE
III-4-4	RATES OF DEATH PER 1,000 IN OBSERVED GUATEMALAN VILLAGES FOR CHILDREN 0-4 YEARS OF AGE	71
III-4-5	SCORES IN INTELLIGENCE TESTS AND NUTRITIONAL STATUS	72
III-4-6	STATISTICAL ANALYSIS OF THE RELATIONSHIP BETWEEN SCORES IN INTELLIGENCE TEST AND INDICES OF NUTRITIONAL STATUS AND SOCIO-ECONOMIC CONDITIONS	74
III-4-7	THE NUTRITIONAL STATUS OF CHILDREN IN DIFFERENT COUNTRIES	77
III-4-8	ESTIMATES OF IQ AS DETERMINED BY NUTRITIONAL CONDITIONS	81
III-4-9	PERFORMANCE OF FOUR GROUPS OF CHILDREN WITH DIFFERENT THIAMIN SUPPLEMENTS	84
III-4-10	CALORIE INTAKE AND WORKING CAPACITY BY TYPE OF WORK	86
III-4-11	TEMPERATURE, PER CAPITA INCOME, CALORIE INTAKE AND WORKING CAPACITY FOR SEVERAL COUNTRIES	87
IV-1-1	AGE STRUCTURE OF THE POPULATION AND THE COST OF EDUCATION	100
IV-1-2	COMPARISON OF DIFFERENT FERTILITY RATES, RATES OF GROWTH OF SCHOOL ENROLLMENT, AND OF NUMBER OF TEACHERS REQUIRED, OBTAINED WITH SIMULATION MODEL	104
IV-1-3	BRAZIL: RATES OF GROWTH OF ENROLLMENT, NUMBER OF TEACHERS AND CLASSROOMS, UNDER SEVERAL ASSUMPTIONS OF POPULATION GROWTH	105
IV-2-1	PREGNANCY CONDITIONS AND READING ABILITY FOR CHILDREN WITH READING DISORDERS AND NORMAL CHILDREN	108
IV-2-2	CORRELATIONS BETWEEN HEALTH CONDITIONS AND SCHOLASTIC ACHIEVEMENT	110
IV-3-1	NUMBER OF PERSONS OF DIFFERENT INTELLIGENCE LEVELS IN A GROUP OF 1,000,000 FINISHING ELEMENTARY SCHOOL WHO REACH DIFFERENT EDUCATIONAL LEVELS (U.S.A. 1949)	112
IV-3-2	COMPUTATION OF EDUCATIONAL ACHIEVEMENT: THE CASE OF ECUADOR	114
IV-3-3	COMPARISON OF THE ACTUAL AVERAGE NUMBER OF YEARS OF EDUCATION AND THE AVERAGE ESTIMATED FROM INFORMATION ON NUTRITION AND INTELLIGENCE	115
IV-3-4	EDUCATIONAL ACHIEVEMENT OF FOUR GROUPS OF CHILDREN WITH DIFFERENT THIAMIN SUPPLEMENTS	119
VI-2-1	USA ECONOMIC COST OF DISEASE IN 1963	133
VI-2-2	GROWTH OF U.S.A. NATIONAL INCOME, 1900-1960, CONTRIBUTABLE TO REDUCED MORTALITY	135

TABLE		PAGE
VI-2-3	PRESENT VALUE AT AN 8% DISCOUNT RATE OF EARNINGS THAT WORKERS ADDED TO THE LABOR FORCE DUE TO REDUCTIONS IN MORTALITY WOULD EARN AFTER 1960	136
VI-3-1	REGRESSIONS OF PER CAPITA INCOME ON PER CAPITA PROTEIN SUPPLY, LAGGED 10 YEARS	139
VI-3-2	REGRESSIONS OF EARNINGS ON IQ CHILEAN DATA	141
VI-3-3	RELATIONSHIP BETWEEN NUTRITIONALLY DETERMINED CHANGE IN IQ AND PRESENT VALUE OF LIFETIME EARNINGS	143
VI-3-4	CHILE: COMPARISON OF THE INTERNAL RATES OF RETURN OF SEVERAL TYPES OF INVESTMENT	144
VI-3-5	INCOME PER CAPITA PER YEAR BY LEVEL OF EDUCATION U.S. 1961	146
VI-3-6	COMPARISON OF ACTUAL PER CAPITA INCOME AND THAT ESTIMATED FROM INFORMATION ON NUTRITION, INTELLIGENCE AND EDUCATION	147
VI-4-1	REGRESSION STUDIES OF THE RELATIONSHIP BETWEEN AGRICULTURAL PRODUCTION AND CAPITAL, LABOR, HEALTH AND EDUCATION	150
VI-4-2	INDICES OF INCOME BY LEVEL OF EDUCATION	157
VI-4-3	DISAGGREGATION OF TECHNOLOGICAL CHANGES IN AN AGGREGATE PRODUCTION FUNCTION FOR 18 COUNTRIES	158
VI-4-4	CORRELATION COEFFICIENTS OF THE CONTRIBUTION OF VARIOUS SOURCES OF ECONOMIC GROWTH WITH INCOME PER CAPITA AND RATE OF ECONOMIC GROWTH	161
VI-4-5	STATISTICAL ANALYSIS OF TECHNOLOGICAL CHANGE IN AN AGGREGATE PRODUCTION FUNCTION	165
VI-5-1	COMPARISON OF THE POSITIVE CONTRIBUTION OF THE BETTER LABOR QUALITY TO INCREASES IN PER CAPITA INCOME, WITH THE NEGATIVE CONTRIBUTION OF POPULATION GROWTH	167
VII-2-1	SAVINGS FUNCTION WITH INDICES OF POPULATION GROWTH CONSIDERED EXOGENOUS	184
VIII-2-1	AVERAGE FAMILY SIZE OF DELINQUENTS AND CONTROLS	203
VIII-2-2	CANADA: INDICES OF CRIME AND POPULATION DENSITY	205
VIII-3-1	HEALTH CONDITIONS IN INFANCY OF DELINQUENTS AND NON-DELINQUENTS	209
VIII-5-1	OFFENSE RATES AMONG BOYS IN AND OUT OF SCHOOL	214
VIII-5-2	PERCENTAGE OF DELINQUENTS AND CONTROLS WITH BELOW NORMAL EDUCATIONAL ACHIEVEMENT	215

TABLE		PAGE
VIII-7-1	CORRELATIONS BETWEEN HEALTH AND NUTRITION INDICATORS AND INDEX OF GROUP VIOLENCE	228
IX-4-1	EQUATIONS RELATING POPULATION BY SEX AND AGE IN YEAR t TO POPULATION IN YEAR t+1	242
IX-4-2	TRANSITION MATRIX FOR FORECASTING POPULATION WITH WOMEN PARTICIPATING IN POPULATION CONTROL PROGRAM	246
X-2-1	POPULATION OF WOMEN FROM WHICH THE TARGET POPULATION FOR A DEMOGRAPHIC PLAN SHOULD BE SELECTED	256
X-2-2	FERTILITY RATES FOR 5-YEAR PERIODS WITH AND WITHOUT CONTRACEPTIVES	257
X-2-3	NUMBER OF WOMEN THAT SHOULD PARTICIPATE IN THE PROGRAM TO MINIMIZE THE NUMBER OF BIRTHS ACCORDING TO THE MODEL IN SECTION XVI-2-1	258
X-3-1	SURVIVAL RATES AND PROBABILITY THAT WOMEN REMAIN IN THE PROGRAM	264
X-3-2	NUMBER OF WOMEN BY AGE AND YEAR OF ENTRANCE THAT SHOULD ENTER IN THE POPULATION CONTROL PROGRAM TO MINIMIZE THE NUMBER OF BIRTHS	265
X-3-3	NUMBER OF WOMEN THAT SHOULD PARTICIPATE IN THE PROGRAM TO MINIMIZE THE NUMBER OF BIRTHS, ACCORDING TO THE MODEL IN SECTION VII-3.	266
XI-2-1	INFORMATION REQUIRED TO APPLY THE MODEL IN SECTIONS II-1 AND II-3	279
XI-2-2	DETERMINATION OF THE MOST EFFECTIVE CONTRACEPTIVE METHOD	280
XIII-3-1	BASIC DATA NEEDED TO APPLY THE MODEL IN THIS SECTION, REFERRING TO WHOOPING COUGH IN NORTHERN SANTIAGO, CHILE, 1963	317
XIII-3-2	DATA USED TO DETERMINE THE ALLOCATION OF RESOURCES THAT MINIMIZE INFANTS AND CHILDREN DEATHS	325
XIII-3-3	NUMBER OF CHILDREN THAT SHOULD RECEIVE PREVENTIVE MEASURES AND NUMBER OF PATIENTS THAT SHOULD BE TREATED TO MINIMIZE CHILDREN DEATH	327
XIII-4-1	HYPOTHETICAL DATA USED FOR NUMERICAL EXAMPLE OF MODEL IN SECTION XIII-4, I=2, T=2	333
XIII-4-2	OBJECTIVE AND CONSTRAINTS OF MODEL IN SECTION XIII-4 EXPRESSED IN TERMS OF M_{hit} and N_{hit}	334
XIII-4-3	NUMBER OF PERSONS THAT SHOULD PARTICIPATE IN THE PROGRAM TO MINIMIZE THE NUMBER OF DEATHS	335

TABLE		PAGE
XVI-2-1	DATA FOR THE NUMERICAL EXAMPLE	362
XVI-2-2	ENROLLMENT AND INVESTMENT UNDER OPTIMUM CONDITIONS AND WHEN THE BACKLOG PROBLEM IS SOLVED IN YEAR 1	365
XVII-2-1	TRANSITION MATRIX [α]	372
XVII-2-2	RESULTS FOR YEAR 20 OBTAINED WITH SIMULATION MODEL WHEN PAST TRENDS ARE FORECASTED	384
XVII-2-3	GNP/POP AND TOTAL POPULATION FOR YEAR 20 ESTIMATED WITH SIMULATION MODEL ASSUMING THAT GOVERNMENTS EXPENDITURES ARE RELOCATED	385
XVII-2-4	GNP/POP AND TOTAL POPULATION FOR YEAR 20 ESTIMATED WITH SIMULATION MODEL ASSUMING THAT GOVERNMENT EXPENDITURES IN POPULATION CONTROL ARE INCREASED, AND THAT PROGRAM ARE VERY EFFECTIVE	386

LIST OF FIGURES

FIGURE		PAGE
VII-2-1	EQUILIBRIUM IN THE NEO-CLASSIC MODEL OF ECONOMIC GROWTH WITH EXOGENOUS POPULATION	182
VII-3-1	RATE OF GROWTH OF THE POPULATION AS A FUNCTION OF PER CAPITA INCOME	192
VII-3-2	EQUILIBRIUM IN THE NEO-CLASSIC MODEL OF ECONOMIC GROWTH WITH ENDOGENOUS POPULATION AND SAVINGS DEPENDENT ONLY ON PER CAPITA INCOME	193
VII-3-3	SAVINGS RATIO AS A FUNCTION OF THE RATE OF GROWTH OF POPULATION	194
VII-3-4	EQUILIBRIUM IN THE NEO-CLASSIC MODEL WITH ENDOGENOUS POPULATION AND SAVINGS DEPENDENT ON PER CAPITA INCOME AND POPULATION GROWTH	195
VIII-6-1	FEASIBILITY SETS DETERMINANT BY THE CONSTRAINTS (3) TO (5)	219
XIII-3-1	MINIMUM NUMBER OF DEATHS AS FUNCTION OF EXPENDITURES	328
XVII-3-1	COMPARISON OF $\alpha(k)$ AND $\hat{\beta}(k)$ vs k	393

CHAPTER I

A FRAMEWORK FOR THE STUDY OF DEVELOPMENT

I-1 INTRODUCTION

The only reasonable approach to the study of the interaction between population, health, nutrition, and development is a general model of the process of development. To construct such a model, several successive approximations are needed, beginning with intuitively accepted concepts and the relationships among them, and proceeding towards the precise definition and measurement of the concepts and relationships involved. In this chapter only the first step will be taken, i.e., only intuitive ideas will be used, with no attempt being made to define them precisely or to determine the indices that should be used for their measurement. The framework obtained through this approach will be general enough so that other, more restricted and precise definitions of the ideas used may be considered, and different indices used.

Development will be defined here as an increment in the personal well-being of all the members of a community. This variable well-being will be considered equivalent to what economists call "Welfare", or to "Quality of Life", or to "Standard of Living".

From the definition, it follows that as a first step in the study of development, well-being must be analyzed. To do so, a static model of individual well-being will be presented in Section I-2. In Section I-3 the problem of aggregating and integrating individual levels of well being in order to obtain a level of well-being for the society as a whole will be considered.

I-2 A STATIC MODEL OF INDIVIDUAL WELL-BEING

I-2-1 The Model

The following determinants of personal well-being will be considered: (a) individual determinants, such as age, level of nutrition, health, shelter,

and education, size of family, personal security, amount of time for leisure available, etc.; (b) social determinants, such as the well-being of other members of the society, the characteristics of interpersonal relations, the characteristics of the government of the society, etc.; and (c) ecological conditions, such as the characteristics of the air, natural surroundings, etc. This description of the determinants of personal well-being can be summarized in the following formula:

$$W_{r,t} = f(X_{r,t}, W_{r,t}, Y_{r,t}, G_{r,t}, Z_{r,t}) \qquad \text{I-1}$$

where

$W_{r,t}$ = well-being of person r at date t

X = a vector of the individual determinants of well-being, including, among others, the following components:

x_1 age

x_2 level of nutrition

x_3 level of health

x_4 level of shelter

x_5 level of education

x_6 family size

x_7 level of economic security

x_8 leisure time available

W = a vector that includes as components the levels w_y of well-being of other persons in the social group.

Y = a vector that has as components indices Y_v of the characteristics of relations between person r and the other persons in the social group

G = a vector that has as components indices of the characteristics of the government, such as indices of the actions the government can perform to obtain co-operation in the goals of the society. For instance, one component of this vector could be an index of the limitation that a government imposes on freedom of speech.

Z = a vector that has as components indices of the ecological conditions, such as

z_1 characteristic of air

z_2 characteristic of surroundings, etc.

The subscript r of the vector arguments of function I-1 indicates that they refer to person r on date t. The components of these vectors, such as x_i, Z_y, have the same subscripts, but they have been omitted in order to simplify typing.

No attempt has been made to include explicitly among components of the arguments of function I-1 all the determinants of an individual's level of well-being. A complete list would be so long as to be impracticable. In the same way, it can be argued that some of the components included in the argument of function I-1 do not belong there. For instance, the interaction between the levels of well-being of persons in two distant countries might be negligible. However, from an operational point of view it is better to assume that, for certain persons, some of the components of the arguments of function I-1 do not have any influence, or to put it differently, that

$$\frac{\delta w_{r,t}}{\delta s} = 0$$

than to assume that different functions should be considered for different persons.

Income and/or wealth are not included among the arguments of function I-1. It is assumed that financial resources as such do not contribute to

personal well-being. They will appear further on in the model as one of the factors influencing the arguments of function I-1, because they constrain the acquisition of the goods and services that do contribute to well-being, and they are one of the determinants of economic security.

An attempt has been made to make function I-1 as general as possible, in the sense of being valid for every human being. Although it is impossible to determine whether this objective has been achieved without empirical verification, it will be assumed here that such is the case. On the other hand, further characterizations of the relationship between the arguments of function I-1 and well-being are likely to be possible only if the number of human beings for which this function is valid is restricted. For example, if nutrition is measured by the intake of nutrients, it is clear that, beyond certain levels, the intake of nutrients reduces the well-being of a person, and that these levels vary from person to person. It should be observed that these changes do not depend only upon physical characteristics, such as sex, age, weight, etc., but also upon the person's values. In other areas such as the influence of the well-being of other persons the impact of values is much more important.

Perhaps the most important characteristic of the arguments of the function of well-being in I-1 is that they are interrelated. These interrelations can be described by the following example. A person's level of health is directly associated with the following arguments of function I-1: his age, his level of nutrition, the characteristics of his shelter, his interpersonal relations, the levels of health of the other persons in the society, ecological conditions, etc. In addition, level of health depends upon the health services that he acquires. These purchases depend upon his income, the prices of the services, and his level of education. This description can be summarized in the following expressions:

$$x_3 = f(X_3, W, Y, Z, S_3)$$

$$S_3 = f(i, p, x_5) \qquad \text{I-2}$$

where

X_3 denotes a vector obtained from X eliminating the component x_3

S_3 denotes health services purchased

i income

p prices

The meanings of the other symbols have been explained. The subscripts needed to show that the variables of the function in I-2 refer to a specific person on a specific date should be added.

It should be emphasized that functions similar to I-2 should be specified for each component of the arguments of function I-1 as part of the specification of the model of individual well-being. It is likely that each of the functions of the interrelations among the components of the argument in I-1 has special characteristics. However, no attempt will be made to describe them in detail. The following observation with respect to the level of economic security (x_7) is useful to avoid confusion. First, it should be observed that the level of personal security evaluated, for example, by the probability of not being criminally attacked appears under interpersonal relations. Next, dealing specifically with an interrelation function of the type in I-2 it will be assumed that x_7 depends mainly upon job security and savings. The first of these two arguments, i.e., job security, is related to general economic conditions and also to interpersonal relations. This means that some of the variables directly related to individual well-being are indices of the condition of the society as a whole. It is not possible to construct a purely micro model. On the other hand, savings is related mainly to individual income.

An additional form of interdependence of the arguments of the well-being function in I-1 appears at this stage. The sum of expenditures on health, nutrition, education, etc. is affected by a constraint on financial resources. The relationship between this financial constraint and the income received by

the person is difficult to specify at any given date. The resources a person can use depend upon his income, plus credit that he receives, minus debts that he pays. However, over his lifetime, his accumulated income minus his legacy is a close approximation of the resources he used.

To complete the static model of well-being, the determinants of income should be considered. It will be assumed here that these determinants are a person's wealth and the returns from his work. Finally, his working capacity depends upon his age, the state of his health, nutrition, education, etc. These relationships can be summarized as follows:

$$i = f(k,m)$$
$$m = f(X) \qquad \text{I-3}$$

where

i = income

k = person's wealth

m = person's work

The statements above have an important implication for decision-making in socio-economic planning. The object of socio-economic planning is to increase or maximize the well-being of the members of the society being planned. For this purpose, the components of the argument in the function I-1 should be modified. It should be observed again that the arguments of the function in I-1 are interrelated, and also that they depend upon purchases. This means that to increase - say - the level of health, the levels of nutrition, education, etc., all have to be increased, along with the purchase of health services. This points to one of the problems of increasing well-being: it is impossible to improve only one of the arguments of function I-1. Improvements are necessarily across the board. The study of functions I-1 and I-2 also shows that an increment in the well-being of one person in a society is very unlikely, because of the interrelation of the well-being of all the persons in the society.

The only argument of the functions I-2 that does not appear in function I-1 is expenditures on purchases. This suggests that one approach to increasing the levels of all the arguments of function I-1 is to increase expenditures. It follows that, as a consequence of the income constraint, income should be increased. This conclusion partly justifies the identification made (mainly but not solely) by economists of increments in well-being with per capita income growth. The reason why the justification is only partial is that the allocation of income among different expenditures (when dealing with one person) and the distribution of income among different members of the society (when dealing with the society as a whole) might be as important as increments in per capita income. In any case, increments in income and its allocation appear as the most important determinants of improvement in well-being as detailed here.

According to equation I-3, income increases are subject to increases in a person's wealth and the amount of work he does, this second variable being again dependent on the arguments of function I-1. As a consequence, the level and increments of wealth appear as one of the most important variables in development. This observation should be considered together with the previous ones with respect to the importance of the distribution of income among members of the society and on expenditures.

I-2-2 Problems in the Empirical Analysis of the Static Model of Individual Well-Being

Several conceptual limitations of the model presented in Section I-2-1 must be removed before it it possible to use it for further analysis.

Problems associated with the well-being function

The first problem encountered in dealing with personal well-being is the fact that it may not be the same from one moment to the next. In order to deal with the variables in functions I-1 to I-3 in a meaningful way, an average over a period of, say, six months should be considered. The observations in

Section I-1 should be interpreted as referring to an average of well-being over a period of time.

A more important limitation of the functions in I-1 to I-3 is that no attempt has been made to define precise indices of well-being or of the components of the arguments used in them. The first problem with well-being is that it cannot be observed except by the person experiencing it. As a consequence, person A can construct an index of well-being for person B only by basing it on person B's behavior. An approach to the construction of indices of well being will be described in Section I-3-3.

Problems connected with construction of indices of the arguments in the well-being function

The observations just made transform the problem of constructing an index of personal well-being into one of constructing indices of each of the individual determinants of well-being, i.e., each of the arguments of function I-1. This problem will be discussed here, using as examples nutrition and health.

The starting point for the construction of an index of a variable is its definition. In principle, any definition is correct as long as it is used consistently. The only way to choose from among possible definitions of a variable is according to its usefulness for one or several specific purposes.

One approach to the solution of the problem of defining the arguments in I-1 is to characterize them by the impact or effect they produce on a person.

A first problem in an attempt to delimit the concept of any of the arguments in function I-1 is that all of the arguments are closely interrelated. These interactions are recognized in functions I-2. As a consequence of this, it is possible to give to any one of the variables a definition that would make it equivalent to well-being. A typical example of this approach is the definition of health given by WHO. This approach cannot be used when attempting to construct an overall model of well-being because it is not meaningful to

define all the arguments of I-1 as equivalent to well-being.

An operational guideline can be given for the process of reducing the scope of the definition of a variable. It should be observed that the object of defining a variable is to use the definition as a basis for deciding which instrument should be used to change the variables, and for estimating the influence of that variable on the others. In the case of health, a definition is needed so that it can be used as a basis for deciding the levels of medical care, nutrition, education, etc. needed to improve health, and also to study the impact of health on productivity, educational achievements, etc. Similar observations can be made with respect to all the other variables. The construction of a definition for a variable should include not only its impact on output, but also its inputs.

A final element that should be taken into consideration is the accepted consensus on the scope of a term.

On the basis of these elements, the variables health and nutrition will be identified here with presence of life, physical and mental capacity, and absence of disease.

A first advantage of this limitation is that it restricts health and nutrition to phenomena that can, in general, be observed. This is clearly the case for the process of life. Height and weight can be used as overall indices of physical abilities, and scores in IQ or similar tests as indices of mental capacity. As much subject to cultural biases and errors of observations as the previous indices is any that could be constructed of absence of disease, but again within bounds this variable is observable. The delimitation above of health and nutrition is still too broad in the sense that it overlaps certain other concepts. Specifically, the aspects mentioned as characteristics of nutrition and health are also associated with genetic conditions, education and ecological factors. Despite this, indices of the presence of life and of absence of disease have been used as indices of health, while height and

weight are used as indices of nutrition.

Applying this approach, it is possible to determine indices for the other components of the arguments of function I-1. For example, as an index of education, number of years of school attended can be used; as an index of housing, rooms per person; for interpersonal relations, percentage of the population who are victims of crime, etc. Similar ad hoc indices are frequently used in planning.

An alternate approach does exist to the specification of an index of health and nutrition, still considering only the impact they produce on a person. Such an index would be the common component - as defined by factor analysis - of the presence of life, height, weight, IQ, and absence of disease. It would better reflect our intuition with respect to health and nutrition, but its usefulness for practical studies would still need to be verified.

Finally, it should be mentioned that the inputs of health and nutrition, such as the ratios doctors/population, hospital beds/population, or calories per day per person, grams of protein per day per person, etc. are frequently used as indices of health and nutrition. These indices are also frequently used in planning.

I-3 THE AGGREGATION AND INTEGRATION OF INDIVIDUAL LEVELS OF WELL-BEING

The model presented in Section I-2 deals with the level of well-being of one member of a society. It is obvious that such a model would not be particularly useful for the study of social development or for social planning. In this Section two questions will be considered. First, in Section I-3-1, problems associated with the construction of a model of social well-being will be considered. In particular, the problems of defining an index of social well-being will be studied. In Section I-3-2 it is observed that an implicit or explicit index of social well-being is needed in order to specify social goals. These goals have been considered as one of the elements that bring

cohesion to a society; i.e., those goals are necessary to the existence of a society. Finally, some observations are made in the same section on the process through which societies specify social goals. These goals - as observed - specify implicitly an index of social well-being. In Chapter II a statistical method of evaluating the parameters of these implicit well-being functions is presented and applied to data from several countries.

I-3-1 Problems of Aggregating and Integrating Individual Levels of Well-Being

Two related characteristics of well-being make it difficult to define and evaluate an index of social well-being. The first is that the level of well-being of an individual cannot be observed except by that person himself. This would not be a major problem if it were possible for a person to communicate to others the level of well-being he feels. However, communication of the levels of well being would only be possible if one person - say A - could at least say to another person - say B - that "I (A) am feeling better or worse than you (B)". This is obviously impossible, and no method to compare levels of well being of different persons has been found.

As a consequence of the characteristics of individual well-being just described, it is difficult for a scientific observer to evaluate indices of social well-being.

I-3-2 The Integration of Individual Preference into Social Goals

While there are problems for the evaluation of indices of social well-being, the fact exists that social goals aggregating and integrating individual goals are needed for the existence of a society. A society could not exist if it did not contribute to the well-being of the persons forming it, at least to the extent that the loss of well-being produced by separation from the society is greater than that of accepting social goals and cooperating towards their achievement.

Thus the question arises of how a society perceives or detects the goals of the individuals forming it, how social goals are formed, and how the resources

of a society are oriented towards their satisfaction.

As a first step it should be observed that in reference (2) it is shown that it is not possible to determine a social goal with a set of assumptions that includes, among others, the assumption that the preferences of each member of a society are just as important as those of every other member. The method to be described below summarizes the methods presented in references (1) and (3) in which the unequal distribution of power in a society is taken into consideration.

The mechanism that aggregates and integrates the preferences and power of the members of a society into social goals and that generates a government with the authority to allocate resources and bring about the cooperation needed to achieve these goals is characterized by the formation of coalitions and delegation of power. This process can be described as follows: Each member of the society has some specific preferences, and some power. This power is basically the capacity of each member to achieve the social state he alone prefers. Coalitions - such as professional groups, unions, political parties, etc. - are formed by several individuals in order to increase the likelihood that a goal common to all of them will be achieved. A coalition yields the power of all the individuals forming it. However, the common social goal of a coalition is likely to differ from the individual goals of each of its individual members This means that the achievement of the goals of the coalition will not bring as much satisfaction to each of its members as would the achievement of their own individual goals. However, since a coalition has the power of all of its members, its goals are more likely to be achieved. The process of exchange between the social state desired by an individual and the additional power yielded by a coalition ends when a winning coalition is formed, i.e., one that is able to force the cooperation of the members of the society who are not members of the coalition. The winning coalition is the one that controls the national government.

Several observations will be made with respect to the process of coalition and goal formation just described. The analysis does not include a description of the process through which individuals with similar preferences identify themselves or the initial steps to the formation of a coalition, nor of the ways through which the preferences of individuals or subgroups are manifested so that they become known by other individuals or subgroups. Unfortunately, very little can be added beyond recognizing this vacuum. The process of formation of coalitions and specification of social goals does not require that any individual express explicitly his level of well-being, or that the level of well-being of any one person be compared with that of any other. The levels of well-being of all the members of a society remain known only to themselves. Finally, from the characteristics of the process it follows that the members of a coalition will keep it open only up to the moment when it becomes a winning coalition. When this point is reached, no further exchange of utility for power is required. New members could be admitted to a winning coalition only by modifying its goals, and as a consequence, reducing the satisfaction that the existing members would derive from their achievement. However, a winning coalition would have no further need for any power that could be added by new members.

A question that should be considered is whether the achievement of social goals set by the process described above maximizes the well-being of all the members of a society. A definitive answer to this question does not seem possible at the present time. It is clear that, with the process described above, the preferences of the members of a society who have more power will weigh more in the determination of the goals of any coalition, including the winning coaliton, if such exists. In other words, the goals of a society, if achieved, will mainly benefit its more powerful members. The less powerful ones will remain in the society while the advantages of doing so overcome the disadvantages of moving to another society. It should be observed that when

one or several individuals prefer to abandon a society rather than to accepts its goals, no winning coalition exists. However, it might happen that a winning coalition exists in the society that remains. In any case, it is not possible to specify at the present whether the fact that all members of a society remain in it means that the well-being of each one of them is being maximized under the constraints imposed by the existing power structure.

It appears that in actual practice the advantages of remaining in a society are really large, if the reluctance of individuals to leave specific societies is any indication. On the other hand, the destruction of metropoli-colony relationships, and the American Civil War are examples of cases where a winning coalition did not exist. In the second example it is also clear that, when the rules of the game were changed in order to permit imposition by force, a winning coalition was established.

In the preceding analysis, the existence of a winning coalition has not been linked with any specific type of government, say, a democracy or a dictatorship. The reason for this is that all the different types of government are based on the same process of coalition formation. All of them are the result of some equilibrium of power achieved through the integration and aggregation of the power and preferences of the members of the society. Perhaps the main difference among the different types of government is the degree in which the instruments they can use are explicitly stated in some public document such as a constitution and the degree in which the winning coalition is in effect restricted to those instruments by the power of the members who do not form part of the winning coalition.

I-4 CONTENT OF THIS BOOK

A systematic study of development should include:

(a) The evaluation of the parameters of the aggregate well-being function in equation I-1. This point will be considered in Chapter II.

(b) Evaluation of the interaction among the determinants of well-being. An example of these interactions is given in formula I-2. In this book, attention will be given to the interaction functions in which physical and mental abilities, interpersonal relations and education appear as explained or dependent variables, and population, nutrition and health appear as the explanatory variables. This means that the contribution of population, nutrition and health to physical and mental abilities and to education will be evaluated. On the other hand, less attention will be given here to the study of the determinants of population, nutrition and health, i.e., functions I-2, in which these variables are explained.

(c) The model in equation I-3 will be studied. This means that the contributions of population, health and nutrition to development will be analyzed.

(d) Once the parameters in functions I-1, I-2 and I-3 are specified, the contribution to well-being of the arguments of function I-1 is known, as well as the resources used, as determined by functions I-2 and I-3. Under these conditions it would be possible to study the question of allocation of resources, mainly economic ones, to optimize well-being, i.e., to study the central problem of social planning.

This general problem will not be analyzed in this study. Many statistical and computational problems remain to be solved before it becomes operationally feasible to deal with it. Instead of the general problem, several separate aspects of it will be considered here. The list of these aspects is found in the titles of Chapters IX to XVII.

REFERENCES

Section I-3-2

(1) Almond, G.A. and J. Coleman
The Politics of Developing Areas
Princeton University Press, 1960

(2) Arrow, J.K.
Social Choice and Individual Values
2nd Edition
John Wiley, 1963

(3) Riker, W.H.
The Theory of Political Coalitions
Yale University Press, 1962

CHAPTER II

POPULATION, HEALTH, NUTRITION AND SOCIAL WELL-BEING*

II-1 CONTENT OF THIS CHAPTER

The object of this chapter is to present a method that can be used to estimate social welfare functions, i.e., functions relating inputs of population size and density, the conditions of health, nutrition, education, etc., to the level of well-being of a society.

The method is based on the assumption that the resources available to a society are allocated among different uses in such a way as to maximize the well-being of each of its members. Since the data used correspond to actual allocations of resources made through the process of coalition, goal and government formation described in I-3-2, the assumption above is equivalent to assuming that such a process allocates resources so as to actually maximize well-being.

Finally, in order to avoid the problem of aggregating the levels of well-being of all the members of a society, that of a typical person will be studied. It should be emphasized once more that it is acceptable to speak of the level of well-being of one individual, despite that the level corresponding to all the members of a society is not defined.

II-2 A METHOD FOR ESTIMATING THE WELL-BEING OF A TYPICAL INDIVIDUAL IN A SOCIETY

It will be assumed that the typical individual has a well-being or utility function of the type described in formula I-1 of Chapter I. Below, to simplify the notation, this function will be written as:

$$W = f(X,\alpha) \qquad \text{II-1}$$

---

*The collection of data and the computations needed for this chapter were performed by Mr. S.B. Kim, under the direction of the author.

where

W = index of well-being of the typical individual

X = vector of dimensions (m,1) of quantities of goods consumed

α = vector of parameters of the well-being function

Following standard practices, it will be assumed that the function in II-1 is specified up to a monotonic transformation, i.e., if W is an index of well-being, and F is a monotonic transformation, then F(W) is also an index of well-being of the same typical individual.

A consequence of this property of function II-1 is that its parameters are indeterminate. To remove this indetermination, one function $f(X,\alpha)$ from the class F(W) has to be selected. To do so, it will be assumed below that

$$\alpha'\alpha = 1 \qquad \text{II-2}$$

Let W_0 and W_1 be maximum value of the function II-1 corresponding to allocations of resources X_0 and X_1. Then,

$$d = W_1 - W_0 \qquad \text{II-3}$$

is a maximum.

Since the specification of which point is X_0 and which one is X_1 is entirely arbitrary, the maximization in II-3 can be replaced by the maximization of the absolute value of the difference between W_1 and W_0.

This observation means that the parameters α of the well-being function $f(X,\alpha)$ have the property that

$$|d| = |f(X_1,\alpha) - f(X_0, \alpha)| \qquad \text{II-4}$$

is a maximum.

In other words, estimators of the parameters α can be derived from the maximization of $|d|$ in II-4 respect to the α, subject to the constraint in II-2.

In the following applications of the observation just made it will be assumed that a sample of vectors X_i^* $i=1,\ldots,n$ is available.

First, these vectors will be transformed into

$$X_i = X_i^* - \overline{X}_i$$

where

X_i = vector of the deviations of the X_i^* from their mean $\overline{X}_i$.

As the reference point X_0 in formula II-4, the vector with zero components will be used, i.e., X_0 is the vector of means of X_i.

In this case, it will be assumed that the utility function is linear, i.e.,

$$W = \alpha' X \qquad \text{II-5}$$

With the assumption above,

$$W_i = d_i = \alpha' X_i$$

and the mean of W_i is zero.

The method of estimating the α would be in this case to maximize

$$\sum_{i=1}^{n} |W_i|$$

subject to the constraint II-2. However, to use a standard statistical technique, the method will be to maximize instead

$$\sum_{i=1}^{n} W_i^2$$

i.e., the variance of W subject to II-2. This, in the present case, is equivalent to maximizing the variance of the linear function in II-5. It is useful to observe that, if observations of W were available, the usual regression methods would be used to estimate the parameters α. However, these methods are also based on the idea of the maximization of the variance of the linear function in II-5.

As a second possibility, it will be assumed that

$$x_i = x_i^* - \overline{x}$$

where

x_i^* is the vector that has as components the logarithms of the components of the vector x_i

The other symbols change meaning accordingly.

In this case, the utility function to be estimated will have the form

$$w = \alpha' x$$

The rest of the analysis remains unchanged.

With these assumptions, the problem of estimating the parameters α has been reduced to one of principal component analysis. Specifically, in references (1) and (3) it is shown that an estimator of α is obtained as follows: compute the vectors λ of characteristic roots of the sample covariance matrix of X, i.e., compute

$$| S - \lambda I | = 0 \qquad \text{II-6}$$

where

S = sample covariance matrix of X

I = identity matrix.

An estimator of α is obtained from the equation

$$S\hat{\alpha} = \lambda_1 \hat{\alpha} \qquad \text{II-7}$$

where λ_1 is the largest component of the vector λ estimated with II-6.

Methods for testing several characteristics of $\hat{\alpha}$ are available. The one in reference (3) for testing the equality of the components of α will be used below.

Due to the emphasis placed on rankings of goods and services according to preferences, it is useful to observe that, according to reference (2), the ranking of goods and services according to the size of the components $\hat{\alpha}$ will closely approximate the following one. For each vector X_i, rank the components X_{ij} $j=1,\ldots,m$ according to magnitude. Next, add the ranking corresponding to each component X_{ij} for all the observations i so as to obtain a score for each component. The ordering according to this score will give a ranking of the goods

and services. This ranking is closely correlated with that obtained according to the magnitude of the α's, i.e., according to the estimated contribution of the goods and services to utility.

The procedure just described has a very strong intuitive appeal.

II-3 DATA AND RESULTS OF A PRACTICAL APPLICATION OF THE METHOD IN II-2

Cross-section data would be the most appropriate for the application of the method described in Section II-2. With data of this type the assumption that prices are constant is less objectionable. However, since cross-section data of public and private expenditures for one country do not seem to be available, time series of the vectors X_i from as many countries as possible - those mentioned in Table II-1 - will be used here.

The sixteen components listed in Table II-1 are included in the observed vectors. Their total is equal to per capita GNP. This means that the 16 components include all public and private expenditures, as well as savings. All the components are measured in dollars in per capita values at constant 1963 prices. The price index refers only to each of the countries studied. No attempt was made to correct for international price differences.

The results of the statistical analysis appear in Table II-1. The interpretation of the coefficients in Table II-1 is handicapped by the lack of terms of comparison and of previous experience.

Some useful insights can be obtained as follows: The coefficients α_j in the linear form give the average contribution of good or service x_j (the j component of the vector X) to well being. On the other hand, the coefficients α_j in the logarithmic form give the contribution of the rate of growth of X_j to the rate of growth of W. From this it follows that the value of α_j will tend to decrease when passing from the linear to the logarithmic form for goods and services that satisfy basic needs, and, as a consequence, have a high priority even for low levels of income. Table II-2 shows the ranking of the 16 goods and services according to the α_j for the linear and the logarithmic equations. This

TABLE II-1 ESTIMATED PARAMETERS α OF UTILITY FUNCTION

Items	Linear form		Logarithmic form	
	All countries	Intermediate & developed countries	All countries	Intermediate & developed countries
Food	.4616	.4037	.1522	.1285
Beverage	.1202	.1169	.2520	.1651
Tobacco	.0626	.0624	.1912	.1889
Clothing	.2445	.2422	.2352	.2143
Rent	.2744	.2857	.2449	.2215
Fuel	.0751	.0709	.2249	.2330
Housing	.2212	.2248	.2600	.2055
Health	.2001	.2033	.2563	.2187
Transportation	.3447	.3687	.3098	.2765
Recreation	.1139	.0959	.2484	.1551
Education	.1372	.1316	.2273	.1088
Public Admin.	.0548	.0355	.2125	.2094
Welfare	.0195	.0154	.2653	.2375
Defense	.2273	.2609	.3112	.4747
Savings	.4946	.4729	.2800	.2999
Miscellaneous	.2979	.3558	.2784	.3916
Percentage of variance explanation	87.61	82.07	89.88	85.18
Level of significance for inequality among estimated α's	.01	.01	.01	.01

Countries in the Sample:

Australia*, Finland*, Italy*, Korea, Malaysia, Panama *, Philippines, Sweden*, United States*

* indicates intermediate and developed countries (70 observations)

Total number of observations: 92

Source of Data: UN Yearbook of National Acct Statistics, Several Years

TABLE II-2

RANKING OF GOODS AND SERVICES CONSIDERED
ACCORDING TO THE VALUES OF THE COEFFICIENTS

	Linear		Logarithmic	
	All	Dev	All	Dev
Food	2	2	16	15
Beverage	11	11	8	10
Tobacco	14	14	15	14
Clothing	6	7	11	12
Rent	5	5	10	7
Fuel	13	13	13	6
Housing	8	8	6	9
Health	9	9	7	8
Transport tion	3	3	2	2
Recreation	12	12	9	11
Education	10	10	12	16
Public Administration	15	15	14	13
Welfare	16	16	5	5
Defense	7	6	1	1
Savings	1	1	3	4
Misc.	4	4	4	3

ranking shows that the most important improvements in rank correspond to welfare and defense expenditures, and the largest reductions in rank to food, clothing and rent.

Attempts to compare the results for all the countries with those for intermediate and developed ones were not successful, despite some interesting characteristics which appeared. This lack of success could have been expected, however, due to the type of data used in the computations.

II-4 A SIMPLIFIED METHOD AND SOME ADDITIONAL RESULTS

In columns (2) and (4) of Table II-3, the percentages obtained with the following formula are presented:

$$100\alpha_j / \sum_{j=1}^{m} \alpha_j \qquad j=1,\ldots,m \qquad \text{II-8}$$

where α_j denote the component j of the vector α. The percentages obtained with the formula

$$100 \sum_{i=1}^{n} X_{ij}^{*} / \sum_{j=1}^{m} \sum_{i=1}^{n} X_{ij} \qquad j=1,\ldots,m \qquad \text{II-9}$$

appear in columns (3) and (5) of the same Table. A study of the results obtained with these two formulas shows that for each j the values obtained with formula II-8 are "close" to those obtained with formula II-9. The main difference seems to be that the values in columns (3) and (5) spread over a larger range than those in columns (2) and (4).

Results like those presented can be expected from the fact that the ranking procedure described in Section II-2 produces a ranking quite similar to that obtained by ranking the α_j. In addition it is intuitively acceptable that the percentage of total resources spend on goods or services j is an index of the satisfaction that good j provides.

On the basis presented above, and due to the lack of data needed to apply the method described in II-2 to each of the countries in the sample, formula II-9 was applied to each one of them. The results obtained are presented in

Table II-4. They show that the percentage of resources spent on food decreases, while those for transportation and health increases. Resources saved present an inverted U shape when moving from underdeveloped to developed countries.

These results can be interpreted in the following way: Food is the need that has the highest priority. Once this need is satisfied, transport and communication, on the one hand, and health, on the other, receive attention. Despite the high priority attached to health, it is surprising to find that it comes second to transport and communication.

TABLE II-3

COMPARISON OF THE RESULTS OBTAINED WITH THE METHOD IN SECTION II-2 AND THE METHOD IN THIS SECTION FOR LINEAR FUNCTIONS

	ALL COUNTRIES		INTERM & DEVELOP.	
	% Table II-1	% Method in II-4	% Table II-1	% Method in II-4
Food	13.78	18.84	12.06	18.24
Beverage	3.59	3.50	3.49	3.53
Tobacco	1.87	2.02	1.86	1.98
Clothing	7.30	7.21	7.24	7.24
Rent	8.19	7.60	8.54	7.64
Fuel	2.21	2.43	2.12	2.43
Housing	6.60	6.23	6.72	6.29
Health	5.97	5.64	6.07	5.69
Transportation	10.29	8.67	11.01	8.81
Recreation	3.40	4.03	2.87	4.06
Education	4.10	4.38	3.93	4.37
Public Administration	1.64	2.49	1.06	2.48
Welfare	.58	.78	.46	.76
Defense	6.79	5.22	7.80	5.30
Savings	14.76	14.72	14.13	14.87
Miscellaneous	8.89	6.26	10:63	6.31
TOTAL	100.00	100.00	100.00	100.00

TABLE II-4

RESULTS OBTAINED WITH FORMULA II-9 FOR EACH COUNTRY

Country	Philippines	Korea	Malaysia	Panama	Italy	Finland	Australia	Sweden	USA
No. of Observations	9	6	7	6	15	15	12	8	14
Per Capita Income 1963 (Dollars)	94	145	275	472	988	1408	1811	2230	3166
Food	44.74	44.08	32.40	31.26	26.58	21.55	17.02	16.85	14.77
Beverage	1.43	3.07	2.48	5.15	4.00	3.16	4.71	3.82	2.26
Tobacco	3.06	2.31	3.95	1.76	2.44	2.05	2.43	1.95	1.42
Clothing	6.03	8.49	4.90	6.19	7.26	7.61	8.07	7.05	6.44
Rent	6.80	5.86	5.21	8.42	6.66	6.76	6.79	5.91	9.85
Fuel	3.08	3.19	1.47	1.60	2.12	3.23	1.91	2.54	2.61
Housing	3.52	2.94	5.41	9.72	5.09	5.24	5.61	5.76	7.79
Health	3.39	3.50	4.59	6.71	5.25	4.83	5.14	6.17	6.47
Transportation	1.87	3.46	5.90	7.34	5.53	7.11	9.28	9.14	10.23
Recreation	1.44	3.26	5.17	6.14	5.28	4.14	3.11	5.59	3.70
Education	4.81	3.44	4.75	4.94	3.83	5.31	3.01	4.94	5.05
Public Administration	1.27	2.90	4.87	3.70	4.44	3.43	1.72	2.74	1.89
Welfare	2.18	.21	.10	.24	.82	1.16	.54	1.61	.42
Defense	1.05	4.94	3.31	.27	2.65	1.66	3.27	4.66	10.39
Savings	9.94	6.01	10.29	4.83	15.82	19.04	17.61	17.01	9.80
Miscellaneous	5.35	2.32	5.18	1.72	2.24	3.70	9.77	4.27	6.89

REFERENCES

(1) Anderson, T.W.
An Introduction to Multivariate Statistical Analysis
Chapter II
John Wiley, 1958

(2) Kendall, M.G.
A Course in Multivariat Analysis
p. 35
Charles Griffin, London, 1965

(3) Morrison, D.F.
Multivariat Statistical Methods
Chapter 7
McGraw-Hill, 1967

CHAPTER III

INTERACTIONS AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION AND PHYSICAL AND MENTAL CAPACITIES

III-1 INTRODUCTION

The object of this Chapter is to study the influence of population size and growth, health and nutritional conditions on physical and mental capacities.

No attempt will be made here to define precisely the physical and mental capacities of a person or of a population. Indices of physical capacities such as number of persons in a population or in a labor force, their life expectancies, and the number of disease-free days that they enjoy, etc., and of mental capacities such as IQ scores will be used below.

Clearly, these indices do not include every aspect of the intuitive idea of physical and mental capacities. However, any attempt to extend them will succeed only in reopening the discussion on the relationships between health and well-being presented in Section I-2.

III-2 POPULATION SIZE AND GROWTH AND PHYSICAL AND MENTAL CAPACITIES

The direct influence of population size and growth on physical capacities is quite obvious, and only brief remarks on this point will be presented below. Special attention will be given to the study of the interaction between population growth, family size, and participation of women in the labor force. This relationship is not only more important from the numerical point of view, but might also have important policy implications.

The influence of population size and growth and mental capacity will be studied in Section III-2-4.

III-2-1 The Size of the Population and of the Labor Force

It is clear that if the age and sex structures of a population are held constant, then the larger the population, the larger the number of persons who can participate in the labor force. The relationship between rate of participation in the labor force (i.e., number of persons in the labor force divided by number

of persons in the population) and age structure is somewhat more complex. It can be described by an inverted "U" curve. Extremely young populations have a low rate of participation in the labor force. This rate tends to increase with the average age up to a certain point, and then it decreases again.

III-2-2 Population Growth, Age Structure and Labor Force Participation

Since the faster the rate of growth of a population, the lower its average age, the observation made in Section III-2-1 leads to the conclusion that the faster the rate of growth of the population, the smaller its labor force will tend to be. However, the magnitude of this effect is likely to be small.

III-2-3 Population Growth and Participation of Women in the Labor Force

This Section presents a detailed study of whether the number of women in the labor force and the rate of population growth are interdependent. The analysis of this hypothesis is particularly interesting. If a high birth rate brings about a low level of participation in the labor force, then it might substantially reduce the size of the labor force, i.e., the actual physical capacity of the population. On the other hand, if the participation of women in the labor force brings about low birth rates, participation could be used as an instrument of population policy, if it is possible for planners or administrators to influence it.

Statistical data indicate that decreases in family size, birth rate, number of births, and rate of population growth occur together with increases in the proportion of women who work, or with certain changes in their occupational status. The U.S.A., (12), (13), (22), Germany, (4), Sweden (6), Hungary, (9), and Peru (18) can be mentioned as examples.

Population growth and participation of women in the labor force have been studied by demographers, sociologists and economists. Examples of analyses having population growth as the only endogenous variable appear in references (1), (2), (3), (5), (15), (16), (17), (20) and (21). Studies having participation of women in the labor force as the endogenous variable appear in (11), (12) and (19).

In these models, participation of women in the labor force is frequently included among the exogenous variables when population growth is the endogenous variable, and vice versa. Other exogenous variables that appear in these models are income, education, urbanization, etc. Demographers and sociologists have also included indices of the preferences and expectations of women. (13), (18).

One limitation of the studies described above is that they do not take explicitly into consideration the fact that decisions about family size and participation of women in the labor force are interdependent. This means that, from a conceptual and statistical point of view, observed family size cannot appear as an explanatory variable only, explaining participation in the labor force and vice versa. This is a problem of two interdependent variables and should be studied by means of a system of equations. Actual data should be analyzed using econometric methods, rather than purely statistical techniques. Below, an attempt will be made to avoid the limitations of previous studies. For this, the methods of economic theory will be used to specify a model of preferences of women with respect to family size and employment. Next, a model in which these desires are translated into actual behavior will be considered. Finally, an econometric test of these two models will be presented.

Model of Preference with Respect to Family Size and Labor Force Participation

The model to be presented is a formalization of the analyses in references (2), (10) and (11).

Following the standard practice in economic theory, it will be assumed that women behave so as to maximize utility u. Utility will be considered as a function only of number of children in the woman's family (n), and family income net of expenditures on children (y), i.e.,

$$u = u(n,y) \qquad \text{III-2-1}$$

with

$$u_n, u_y, u_{ny} > 0 \text{ and } u_{nn}, u_{yy} < 0 \qquad \text{III-2-2}$$

where the subscripts denote derivatives.

As a definition of "family income net of expenditures on children", the following equation will be used:

$$y = y_0 + b_1 w - b_2 n \qquad \text{III-2-3}$$

where y_0 is an exogenous component that includes all income except that obtained from a woman's employment; $b_1 w$ is the income derived from her work, where w is time devoted to employment; and $b_2 n$ is the cost of n children, i.e., b_2 is the cost per child. It should be observed that in equation III-2-3 $b_i > 0$ for $i=1,2$.

The fact that the total amount of time that a woman has at her disposal is limited should also be taken into account. This means that a constraint of the following form restricts women's activities:

$$t = an + w \qquad \text{III-2-4}$$

where

t total time available

$a > 0$ time needed per child

From the first order conditions of the maximization of u with respect to n, the following equation is obtained:

$$u_n = (ab_1 + b_2)u_y \qquad \text{III-2-5}$$

It can easily be verified that the assumptions made in III-2-2 and regarding the signs of a's and b's imply that the second order conditions for maximization are also satisfied.

The expression in III-2-5 is basically the usual condition for maximization of equality between marginal utilities. The marginal utility of net family income is weighted by the marginal change in income (net of expenditures on children) caused by one additional child. This marginal change has two components, one direct (b_2) and the other indirect through the reduction of the amount of time available for work (ab_1).

Equation III-2-5 gives the value of n -- to be denoted with $\hat{n}$ -- that maximizes u as an implicit function of the parameters in III-2-3 and III-2-4. The characteristics of this function will be studied below.

From

$$\hat{n}_{y_0} = -u_{y_0 n}/u_{nn}$$

with $u_{nn} < 0$ from the second order conditions of maximization, and

$$u_{y_0 n} = u_{yn} - (ab_1 + b_2)n_{yy} > 0 \qquad \text{III-2-6}$$

it follows that $\hat{n}$ increases with y_0.

Similarly, it can be shown if

$$u_{b_1 n} = wu_{yn} - (ab_1 + b_2)wu_{vy} - au_y > 0 \qquad \text{III-2-7}$$

then $\hat{n}$ increases with b_1, otherwise it decreases. The inequality in III-2-7 is satisfied if the negative quantity $-au_y$ is "small". For this to occur, it is necessary that either the time needed to care for a child be small, or that the marginal utility of income be small, or both.

Similar results are valid for the change in $\hat{n}$ when a or b_2 change. They will not be presented in detail.

To complete the analysis of the model it should be observed that the optimum value of w -- i.e., $\hat{w}$ -- is obtained by using $\hat{n}$ in equation III-2-4.

For the statistical analysis it will be assumed that the utility function has the form

$$u = c_1 n^2 + c_2 y^2 + c_3 ny + c_4 n + c_5 y + c_6 \qquad \text{III-2-8}$$

with

$$c_1, c_2 < 0 \quad ; \quad c_3 > 0$$

and unspecified values for the other parameters.

With the utility function in III-2-8 and the constraints in III-2-3 and III-2-4, the reduced equations for $\hat{n}$ and $\hat{w}$ take the forms

$$\hat{n} = h_{11} + h_{12} y_0 \qquad \text{III-2-9}$$

and

$$\hat{w} = h_{21} + h_{22}y_0$$

where the h_{ij} are non-linear functions of the parameter in (3), (4) and (8) It can be shown that $h_{i2} > 0$ for i=1,2.

For the statistical analysis, equations III-2-9 are modified and extended in several ways. These changes will be explained below, together with the operational meaning given to the variables used. This operational meaning is the same as that used in the survey made to collect data for testing the model. A more complete description of this survey will be presented later.

To obtain an index of the $\hat{n}$, the question "What number of children do you think best for people like yourself?" was asked.

Two modifications of equations III-2-9 were imposed by the characteristics of the data and preliminary analysis. First, the attempts to collect data on each of the components of y in III-2-3 did not give satisfactory results. As a consequence, data on $v = y_0 + b_1w$ measured in dollars per person per year will be used below. This is a serious limitation, because the three components of y might have different effects on $\hat{n}$ and $\hat{w}$. Second, preliminary trials showed that attempts to explain the opinions of women with regard to participation in the labor force did not produce satisfactory results. For this reason, instead of $\hat{w}$, actual current employment conditions of women are used below as one of the interdependent variables. This variable will be denoted with LFP and assigned the values +1 for currently employed and -1 for unemployed. Women's opinion about working (OWK_1) will be used as an exogenous variable.

Another type of limitation of equation III-2-9 is that is does not include explicitly the interdependence between $\hat{n}$ and LFP. The characteristics of this interdependence are particularly important if employment of women is to be used as an instrument for population control. In order to consider this interdependence, structural equations relating $\hat{n}$ directly to LFP and vice versa will be used below.

Finally, modifications of equations III-2-9 and the corresponding structural forms are needed to take into consideration determinants of $\hat{n}$ and LFP not included in them.

A first set of variables to be included deals with the woman's personal, employment and marital history. These aspects will be shown by variables representing her age (AGE), her employment situation during the first year of marriage (LFF), and years of married life, regardless of whether the union was with the same husband (YRM).

Another set of variables deals with the present husband's preferences. The number of children desired by the present husband (DFS) and his opinion with respect to his wife's employment (OWK_2) will be included among the exogenous variables as indices of those preferences.

Another variable that could influence $\hat{n}$ and LFP is a woman's educational level (EDC). It influences both here employability and the income that she is likely to obtain if working. These observations, together with the conclusion that follows from III-2-6 and III-2-7, show that the influence of a woman's educational level on the $\hat{n}$ and LFP cannot be specified. In addition, her education is likely to influence $\hat{n}$ and $\hat{w}$ by directly reducing the utility of additional children, because it is likely to increase her appreciation of non-child-related uses of her time, even if she is not employed.

Finally, race will be included as a general socio-economic index that might include aspects not covered by the other variables. Race was also introduced with a dummy variable equal to +1 for white and -1 for black.

The following structural equations were derived for the statistical analysis from the observations above:

$$\hat{n} = \alpha_0 + \alpha_1 DFS + \alpha_2 v + \alpha_3 LFP + \alpha_4 LFF + \alpha_5 AGE + \alpha_6 YRM + \alpha_7 EDC + \alpha_8 RC \qquad \text{III-2-10}$$

and

$$LFP = \beta_0 + \beta_1 OWK_1 + \beta_2 OWK_2 + \beta_3 v + \beta_4 \hat{n} + \beta_5 EDC + \beta_6 LFF + \beta_7 RC. \qquad \text{III-2-11}$$

Model of Actual Behavior With Respect to Family Size and Employment

The previous analysis deals only with the desires of women with respect to family size and employment. For policy purposes, it is interesting to determine whether these desires are actually implemented. To study this aspect, the total number of children that a woman had had, and who were alive at the time that the data were obtained, whether or not they lived in her home, was used as one of the endogenous variables. This variable will be denoted here with S.

The variables assumed to explain S can be classified in three sets. The first includes desired family size, the second, the variables assumed to explain $\hat{n}$, and finally, variables describing the ability of a woman to control the size of her family. The reasons for including $\hat{n}$ among the explanatory variables of S is quite clear and will not be elaborated on here. The main reason why the explanatory variables in III-2-10 should also be included among those explaining S is that there is some doubt whether stated values of $\hat{n}$ really represent well-thought-out opinions, rather than off-the-cuff replies to the questions of an interviewer. In the second case, S will represent desired family size better than the value attached to $\hat{n}$, and the inclusion of the explanatory variables of III-2-10 as explanatory variables of S will help to discover how desires regarding family size are determined. Finally, the ability to control the number of children is assumed here to depend, first, upon the woman's level of education, which determines her capacity to learn about contraceptive methods and to use them properly, and second, upon her actual knowledge of these methods and their use.

In summary, the equation for studying actual number of children will have the following form:

$$S = \gamma_0 + \gamma_1 \hat{n} + \gamma_2 DFS + \gamma_3 v + \gamma_4 LFP + \gamma_5 LFF + \gamma_6 AGE + \gamma_7 YRM + \gamma_8 EDC + \gamma_9 RC + \gamma_{10} RNC + \gamma_{11} KPM + \gamma_{12} UCM \qquad \text{III-2-12}$$

where

RNC Right to decide on the number of children

KPM Knowledge about contraceptive methods; and

UCM Use of contraceptive methods.

These last three variables were represented with +1, -1 indices.

The only modification of equation III-2-11 in this second model is the use of S instead of $\hat{n}$. This modified equation will not be presented here. It will be referred to below as equation III-2-13.

Data to be Used to Analyze the Models*

The data used to test the models presented were collected in a sample of women participating in the Lincoln Parish Family Planning Program.

Lincoln Parish is a semi-rural parish (county) in Northern Louisiana, 300 miles northwest of New Orleans. Its total population is about 30,000 persons, 60% of whom were classified as urban and 58% white in the 1960 population census. According to the same census, the median years of school completed by adults 20 years of age and older was 10.7. In 1959, 36% of the families in the parish had incomes of less than $3,000.00 per year.

The universe from which the sample was drawn included all women who declared Lincoln Parish as their place of residence and who had delivered a live or stillbirth during the five-year period from January, 1960 through December, 1964. A 10% random sample was selected from this universe. The women who did not reside in Lincoln Parish during the interview or who were not married were excluded (13), (14). This study is confined to the 101 couples from whom complete data were obtained.

It is clear that the universe from which the sample was selected and the

---

*Grant PH-40 from the Children's Bureau, Dept. of Health, Education and Welfare to the Tulane Center for Population and Family Studies provided support for the survey in which the data were collected.

method used make it inadvisable to attempt to generalize the results obtained to larger populations. On the other hand, the sample is likely to give very reliable information about the relationship between the interdependent and predetermined variables considered. This is true because most of the families in the sample would have a child of five years of age or less, and as a consequence, their preferences about family size and work are more likely to reflect actual feelings and attitudes than those expressed by families without any immediate experience.

Method to be Used to Analyze the Models

Several particular characteristics of the models in III-2-10, III-2-11, III-2-12, III-2-13 must be considered in order to decide what approach should be used for their statistical analysis.

First, in the models in those equations, both endogenous and exogenous variables appear as explanatory variables. In other words, the endogenous variables of these systems are interdependent. It is well known (7) that this is the cause of two problems. The first is the identification problem, and the second is that Ordinary Least Squares estimators of the parameters are generally biased.

The first problem can be loosely stated as follows: if an equation in a system is not identifiable, then the values of its parameters cannot be estimated from statistical data. The use of a direct sample survey, like the one described, designed to obtain data for the study of the models in equations III-2-10 to III-2-13, might suggest that the question of identifiability of the equations in the model could be disregarded. However, this is not the case. It is true that an experiment could be designed in such a way as to eliminate the interdependence of the variables, and in this case the problem of identifiability would not appear. However, a sample survey only records the actual interdependence of the variables, and as a consequence, steps should be taken to insure that the statistical analysis is feasible in spite of that interdependence. With the use of standard techniques (7) it is easy to show that the equations in both models are over-identified.

To specify the method of estimation to be used, in addition to the limitations already mentioned of Ordinary Least Squares estimators, the following points must be considered. In equations III-2-11 and III-2-13 the explained variable is only a classification. The value 1 was assigned to women employed in the labor force and -1 to those who were not employed. In reference (7) it is shown that, as a consequence, the residuals of these equations are heterocedastic.

Finally, multicollinearity of the predetermined variables is another problem in the estimation of the parameters.

From among the different methods of estimation available for the case of interdependent variables in a system of equations, Two Stage Least Squares seems to be less sensitive to multicollinearity, than the others. To gain additional insight into the effects of multicollinearity, a step wise regression program was also used in each of the two stages.

In the case of TSLS, an approach to handling the problem of heterocedasticity mentioned above could be to use Aitken's Generalized Least Squares in each step of the TSLS. However, there is no information about the advantages of such a procedure. In addition, this procedure would require systematic changes in both the explained and explanatory variables in the equations, and this is likely to increase multicollinearity. For this reason, the approach was not used.

Analysis of the Model in Equations III-2-10 and III-2-11

The TSLS estimators of equations III-2-10 and III-2-11 appear in Table III-2-1.

To interpret the results for equation III-2-10, it should be observed that they are in part the consequence of multicollinearity. The first variables to enter the regression were, by order of entrance, number of years the wife has been married, race, and husband's desires with respect to family size. These three variables enter with highly significant coefficients, and with the same sign that appears in the final equation. This suggests that these three variables are the most important in determining what size family the wife will desire. A somewhat surprising result in this equation is that desired family size does not seem to be influenced by the wife's employment at present or during the first

Table III-2-1

TSLS Estimates of Model III-1-10 and III-1-11

Equation III-2-10

$$\hat{n} = 2.0874 + \underset{(.15500)}{.26014}\ DFS - \underset{(.00018)}{.00018}\ v$$

$$+ \underset{(.73494)}{.40179}\ LFP - \underset{(.27620)}{.17628}\ LFF - \underset{(.07072)}{.00318}\ AGE$$

$$+ \underset{(.08885)}{.12058}\ YRM - \underset{(.08204)}{.03220}\ EDC - \underset{(.29068)}{.31022}\ RC$$

$$R = .5921 \qquad F_{(8,93)} = 6.275$$

Equation III-2-11

$$LFP = -.49384 + \underset{(.11256)}{.04230}\ OWK_1 + \underset{(.11250)}{.31376}^{*}OWK_2$$

$$+ \underset{(.00009)}{.00003}\ v + \underset{(.09166)}{.10202}\ \hat{n} + \underset{(.04042)}{.00138}\ EDC$$

$$+ \underset{(.10026)}{.16733}\ LFF + \underset{(.09856)}{.20341}^{*}RC$$

$$R = .4287 \qquad F_{(7,94)} = 3.023$$

In parenthesis under the coefficients: their standard errors.

*Significant at least at a 95% confidence level.

year of marriage, or by her level of education.

A result in Table III-2-1 that needs careful analysis is that showing that family income influences neither desired family size nor labor force participation. From the theoretical analysis it can be concluded that desired family size should be positively correlated, and labor force participation should be negatively correlated, only with the husband's income. No specific sign for the correlation with the wife's income could be specified. Since the data used in the estimations reported in Table III-2-1 deal with total family income, it is possible that two opposite effects of husband's and wife's incomes cancel each other out.

In equation III-2-11 the only significant variables influencing participation of women in the labor force appear to be the husbands' opinion about wives' working, and race. A favorable opinion on the part of the husbands tends to increase labor force participation. The negative coefficient for race indicates that black women are more likely to work than white women. The lack of influence of income and education is acceptable if the population strata being studied is considered. The variance of these two variables simply is not large enough to influence wives' employment. Finally, the lack of a relationship between employment of women and family size already observed in equation III-2-10 also appears in equation III-2-11. From the values of the R and F coefficients, it follows that the variables chosen do not explain a large percentage of the variation in the employment of women. However, at least part of this might be due to the use of a dummy variable as the dependent variable in equation III-2-11.

Analysis of the Model in Equations III-2-12 and III-2-13

The results obtained from the analysis of the models in III-2-12 and III-2-13 appear in Table III-2-2. According to this table, the principle positive influence on family size is the wife's idea of how large the family should be. The coefficient of this variable is highly significant and shows that a desired increment

Table III-2-2

TSLS Estimates of the Parameters of Model II

Equation III-2-12

$$S = 2.36693 + \underset{(.09982)}{.47159^{*}n} + \underset{(.14198)}{.13150\ DFS} - \underset{(.00011)}{.00016\ v}$$

$$+ \underset{(.55786)}{.45211\ LFP} - \underset{(.26894)}{.12936\ LFF} + \underset{(.07514)}{.02520\ AGE} + \underset{(.09127)}{.14778\ YRM}$$

$$- \underset{(.07629)}{.23056^{*}EDC} - \underset{(.40174)}{.46709\ RC} + \underset{(.44243)}{.29056\ RNC} + \underset{(.13908)}{.10454\ KPM}$$

$$- \underset{(.36906)}{.16424\ UCM}$$

$$R = .8583 \qquad F_{(12,86)} = 20.046$$

Equation III-2-13

$$LFP = -.24359 + \underset{(.11107)}{.01785\ OWK_1} + \underset{(.11497)}{.33845^{*}OWK_2} + \underset{(.00005)}{.00001\ v}$$

$$+ \underset{(.04952)}{.05261\ S} + \underset{(.04536)}{.00255\ EDC} + \underset{(.10389)}{.17874\ LFF} - \underset{(.09956)}{.24756^{*}RC}$$

$$R = .4431 \qquad F_{(7,91)} = 3.177$$

In parenthesis under coefficients: their standard error.

* Significant at least at a 95% level.

is fulfilled about 50% of the time. The only other significant variable is level of education, which appears with a negative coefficient. The size of the coefficients suggests that more education is a strong deterrent to having a large family. To interpret this result it should be observed that, on the theoretical side, it was not possible to determine the sign of the derivative of family size with respect to income. On the other hand, the results in Table III-2-1 for equation III-2-10 show that education does not influence desired family size, those in equation III-2-11 and III-2-13 show that it does not influence the employment status of women. Finally, the influence of education does not seem to be through its impact on attitudes about contraceptives, knowledge about contraceptive methods, and their use, because these variables do not have significant coefficients in equation III-2-12. In conclusion, it can be said that education seems to influence family size because it increases womens' preference for non-work activities.

It is useful to observe that in reference (2), with somewhat less specific data, it is concluded that education reduces fertility because it contributes to the knowledge of contraceptive methods and their use.

Conclusions

The principal conclusion to be drawn from this analysis is that the observed relationship between reduction in family size and employment of women does not seem to be the result of a direct causal link. The reduction in family size appears to be a consequence of the education of women. The policy implications of this result are quite evident.

Another point that should be emphasized is that the use of simple equation models and the statistical methods used to analyze them might not be appropriate for the study of the problems of employment of women and family size.

III-2-4 Population Size and Growth and Mental Abilities

An hypothesis that relates population size and growth to mental abilities can be stated as follows: The larger the size of a population or the greater its

rate of growth, "other things" held constant, the higher the probability of persons with high and very high mental abilities being born. It is also stated that, apart from genetic factors, one of the determinants of intelligence is frequency of interpersonal contacts. Since population density increases with the size of the population, this is another reason why the greater the rate of population growth, the higher the probability of persons with high and very high mental abilities.

On the other hand, it has also been argued that increments in the rate of growth of a population have a negative effect on the average intelligence of that population. In Table III-2-3 the IQs of children from several social groups and the reproduction rate in those groups are presented. The data on IQ support the hypothesis that it is correlated with social class. The hypothesis that psychological traits are largely determined by heredity can be accepted. As a consequence of this, two observations may be made. First, a high rate of growth of the population brought about by a high reproduction rate for the social classes with lower mental capacities might increase the probability of persons with low and very low IQs, rather than the other way around. Second, if population growth tends to increase the proportion of population in low socio-economic classes, it will also tend to increase, from one generation to the next, the likelihood of birth of persons with low mental abilities. In summary, the previous observation can only lead to the conclusion that the average level of mental abilities in any population should be declining, and that this decline will be faster in those populations having a growth rate that brings about increases in the proportion of persons in low socio-economic classes.

Although the evidence in Table III-2-3 and in similar studies seems to confirm the hypothesis, in reference (2) it is stated that there is no direct evidence that the average intelligence of the population is declining.

Table III-2-3

IQ and birth rates for several social groups

Occupational class	Median IQ of children (1)	Percent of total births (2)	Reproduction rate (3)
Professional	116	3	.76
Business - clerical	107	18	.85
Skilled	98	15	1.06
Semi-skilled	95	14	1.03
Farmer	91	31	1.32
Unskilled	88	19	1.17

Mean IQ , weighted by column (2) = 95.7

Mean IQ, weighted by product of columns (2) and (3) = 94.6

Source: Reference (2) as quoted in Reference (1) page 50

The main points of the argument are:

1. Experts do not agree on their interpretation of the data available.
2. There is also a lack of agreement on what influence parents' social level has on their children's intelligence.
3. An argument similar to that utilized in stating that the intelligence of the population tends to decline can be used to affirm that length of life and stature of the population tend to decline, when in reality they are increasing.
4. The few direct investigations made indicate that in place of a decline in the level of average intelligence, there has been a rise.

It should be observed that the two hypotheses discussed above do not contradict each other. It is possible to increase the number of persons of very high intelligence and at the same time reduce the average intelligence of the population. For this it is enough that the number of persons with below average intelligence increase more than the number of those with above average intelligence. The consequences of this increasing gap, if it exists, have not been studied.

III-3 HEALTH AND PHYSICAL AND MENTAL ABILITIES

III-3-1 Introduction

The influence of health on the physical and mental capacities of a person is the final result of three sets of influences: genetic factors, prenatal and delivery conditions, and personal history. To make a complete analysis of the influence of health conditions on physical and mental capacities, it is necessary first to classify the elements in the sets mentioned above. Next, data on the characteristics of physical and mental conditions associated with each combination of the classes defined in the first step would have to be obtained and studied.

At present, no study of this type exists. At best, the information available associates limitations in physical and mental capacities with the most recent disease suffered. This is also true in the case of data on death rates or lost

days by cause. General data on mortality are used as an index of health conditions. Since it is all that is available, the information will be used below to study the impact of health on physical capacities. Statistical association between health conditions and scores in intelligence tests will be used to study the impact of health on mental abilities.

III-3-2 Life Expectancy and Working Capacity

Several approaches have been used to estimate the impact of mortality on working capacity. Perhaps the most direct of these appears in reference (5). There it is stated that "approximately 1.8 million persons died from all causes in 1963. Assuming that these deaths occurred evenly during the year, approximately 900,000 man-years were lost in 1963. After adjustment for labor force participation and employment rates, the losses in output resulting from these deaths are equivalent to more than 600,000 man-years". Clearly these figures underestimate the losses in working capacity caused by death, because they do not include the capacity lost in subsequent years. Attempts to correct this limitation are based on the use of life tables.

To present a more specific description it is necessary to remember, first, that a life table gives the probabilities that a person of a specific age will live one year more. In other words, a life table gives the percentage of a group of persons of a specific age and alive at date t that will be alive at date t +1 (reference 3). These probabilities or percentages are estimated to bring into consideration the conditions of mortality and morbidity prevalent at a specific time and place.

The life expectancy of a group of persons can be computed from a life table. There is one life expectancy for each age group. The life expectancy at birth of a group of persons is equal to the average number of years lived by that group of persons.

One approach to the study of the impact on mortality of one or several diseases is based on the estimation of the number of persons who would be alive

at a fixed date - say t - if these diseases had not occurred. For this, the populations beginning in, say, (t - 100) and continuing up to t are considered. The mortality in these populations is recorded in the ordinary life table. To evaluate the impact of eliminating certain diseases, the life tables are modified. They are computed assuming that the mortality caused by the diseases under consideration is zero. These life tables are used in the populations from (t - 100) to t to estimate the number of persons who would have been alive at date t, excluding the influence of the diseases under consideration. The population so estimated is, of course, higher than the actual population. Several indices can be defined at this point. The difference between population computed as above and actual population shows the number of deaths caused by the diseases considered. This index is used in reference (6) to estimate the impact of cancer and cardiovascular diseases on physical capacities. The actual population divided by the computed population shows the proportion of potential physical capacities actually used. Similar indices can be obtained using life expectancy. The difference between the computed and the actual life expectancies gives the average number of years of life lost by each person in the society. The actual life expectancy divided by the computed gives the proportion of potential life actually realized. Although this method can be used for the study of one or several diseases, it cannot be used for all of them. The reason for this is that the assumption that all mortality is reduced to zero is not acceptable.

The approach presented above can be adapted to make a comparative analysis of the impact of mortality on the physical capacity of, for example, several populations in different countries. For this purpose the life table of one country is considered as term of reference. A first possibility is to use this life table to estimate the population that would exist in the countries studied if the mortality conditions in the country of reference were prevailing. The comparisons between actual and computed population can be used as indices of the number of man years lost due to differences in health conditions. Another

Table III-3-1

Life Expectancy and Working Capacity

Country (1)	Life expectancy at birth (2)		Active life	
	year	No. years	No. years (3)	As % of USA (4)
Africa				
Bel. Congo	1950-52	38.82	23.82	.48
Fr. W. Africa	1956-58	35.00	20.00	.40
Guinea	1954-55	33.15	18.15	.36
Egypt	1936-38	38.56	33.56	.67
N. America				
Canada	1950-52	68.58	50.00	1.0
Costa Rica	1949-51	55.85	40.85	.82
El Salvador	1949-51	51.17	36.17	.72
Guatemala	1949-51	43.67	28.67	.57
Mexico	1940	38.85	23.85	.48
Panama	1952-54	61.75	46.75	.93
U.S.A.	1957	69.49	50.00	1.0
S. America				
Argentina	1947	59.15	44.15	.88
Brazil	1949-51	52.88	37.88	.76
Chile	1952	51.86	36.86	.74
Asia				
Cambodia	1958-59	43.75	28.75	.58
Ceylon	1954	59.85	44.85	.90
Cyprus	1948-50	66.20	50.00	1.00
India	1941-50	32.05	17.05	.34
Israel	1958	70.99	50.00	1.00

Japan	1958	67.28	50.00	1.00
Philippines	1946-49	51.08	36.08	.72
Thailand	1947-48	50.29	35.29	.71
Europe				
Belgium	1946-49	64.65	49.65	.99
Czechoslavakia	1956	69.14	50.00	1.00
Denmark	1951-55	71.24	50.00	1.00
Finland	1951-55	66.60	50.00	1.00
France	1952-56	68.10	50.00	1.00
Germany, Fed. Rep.	1949-51	66.52	50.00	1.00
Hungary	1955	66.92	50.00	1.00
Ireland	1950-52	65.81	50.00	1.00
Italy	1954-57	67.88	50.00	1.00
Netherlands	1953-55	72.45	50.00	1.00
Norway	1951-55	72.90	50.00	1.00
Poland	1955-56	64.35	49.35	1.00
Portugal	1957-58	62.40	47.40	.95
Spain	1950	61.13	46.13	.92
Sweden	1951-55	71.96	50.00	1.00
Switzerland	1948-53	68.61	50.00	1.00
U.K. (England)	1958	70.82	50.00	1.00
Yugoslavia	1952-54	58.13	43.13	.86
Oceania				
Australia	1953-55	69.95	50.00	1.00

Source: Elaborated from results in References (1) and (2)

possibility is to compare the life expectancy in the different countries. This approach is used in references (1) and (2). The method and results are summarized below.

The life expectancies in the countries mentioned in column (1) of Table III-3-1 appear in column (2) of that same Table. The average years of economically useful life for those countries are shown in column (3). These estimates are based on the assumption that a person's productive life begins at the age of 15 years and continues until death or until the age of retirement, arbitrarily fixed at 65 years.

One index of the differences in working capacity is the quotient obtained by dividing the number of years of active life in a country by the corresponding number for the U.S.A. These figures appear in column (4) of Table III-3-1. According to this index, the working capacity of the population in countries like India is about 1/3 that of the U.S.A.

Another approach used to estimate the impact of mortality on working capacity is, to a large extent, the inverse of the previous one. It is based on the evaluation of the number of persons who would be alive at date t if the conditions of mortality in previous periods had not changed since a reference date, say (t-100). To make this evaluation, the populations from (t-100) to t are considered. The mortality of these populations is evaluated using the life table of (t-100). The estimated population is less than the actual one. The difference is an index of the number of persons alive due to improvement in health conditions between (t-100) and t. A quotient index could also be computed in this case, as well as indices based on life expectation. This method is applied in reference (4) to estimate the growth of the labor force in the U.S.A. attributable to improvements in health conditions between 1900 and 1960. The results are presented in Table III-3-2 columns (2) to (4).

Table III-3-2

Increment of U.S.A. Labor Force Attributable to Reduced Mortality.

Year (1)	Labor Force in 1960 if mortality rates had remained constant since year in column(1) (2)	Additional L.F. attributable to reduced mortality rate (3)	Percentage by which labor force increased $\frac{(3) \times 100}{(2)}$ (4)
1960	66.7	--	--
1950	66.4	.3	.5
1940	65.3	1.4	2.0
1930	63.2	3.5	5.6
1920	60.7	6.0	9.9
1910	56.2	10.5	18.8
1900	53.5	13.2	24.7

Source Reference (4).

III-3-3 Morbidity and Working Capacity

The methods suggested to estimate the impact of reduced mortality on the physical capacity of a population do not show the total effect of better health conditions, because they do not take into consideration the effect of reductions in bed disability days and improvements in the working capacity of persons who keep working in spite of illness. The most reasonable approach would be to modify the methods in Section III-3-2 to consider as far as possible the impact of morbidity. Although this approach is used in reference (4), it will not be presented here, because the results are used only to estimate the impact of better health conditions on economic growth. This analysis will be described later.

Below, attention will be paid only to the attempts to estimate the impact of different health conditions on absenteeism from work. No information seems to be available at present on the reduction of working capacity of sick persons who continue to work.

Health Services and Work Days Lost:

A study made in two Egyptian villages is reported in references (5) and (6). In village A (Kom-Eshfim) a health unit was established in 1967. Village B (Kharkania) was retained without a health unit, as a control. The socio-economic characteristics of these two villages in 1967 appear in Table III-3-3.

Absenteeism from work due to illness was tabulated in 1971. The results appear in Table III-3-4. They show that the average number of illnesses per person in village A was 20% lower than that of village B.

Morbidity, School Days Lost and Work Days Lost:

The methods used and results obtained in references (1) to (4) are summarized below.

The number of school-loss days per student and of work-loss days per member of the labour force in a cross-section of countries will be estimated as an index of the influence of health conditions on physical capacity. These

Table III-3-3

Egypt: Socio-economic conditions of research and control villages

	Research village	Control village
Population	6536	5284
Population growth rate	2.1%	2%
Family size	5.2	5.2
rooms/family	2.7	2.5
Illiteracy	54.9%	47.1%
Employment among family heads	98.2%	98.1%
Family monthly income	11.8	12.8
Working persons per family	2.0	2.2
Monthly income per working peroson	5.9	£. 5.9

Source: Reference (6)

Table III-3-4

Egypt: disability days and work-loss days per month in research and control villages

	Research	Control
Disability days	4	5
Work-loss days	2.5	3.5

Source: Reference (6)

employed is the following:

The number of school-loss and work-loss days caused by groups of diseases such as infectious and parasitic ailments, circulatory disease, etc. are presented in Table III-3-5 for the U.S.A. Data on death rates, by causes, for various countries are contained in the Demographic Yearbooks of the United Nations. The classifications used in Table III-3-5 and those used in the Demographic Yearbooks are comparable. The estimation of the number of days lost in different countries is based on the assumption that the proportion of school-loss and work-loss days in a given country to that in the U.S. is equal to the proportion of the death rate in the country under consideration to that of the U.S. That is, for school-loss days, if

q_{0i} = death rate in the U.S. due to cause i

q_{1i} = death rate in other country, cause i

d_{0i} = school loss days in U.S., cause i

d_{1i} = school-loss days in other country, cause i

then

$$d_{1i} = \frac{q_{1i}}{q_{0i}} d_{0i} \qquad \text{III-3-1}$$

A similar formula is used for work-loss days. The results obtained appear in Table III-3-6.

The assumption on which these estimates are based has several limitations. There is no reason to believe that the relationships between school-loss days, work-loss days, illness and mortality rates are the same in two different countries. Differences in education and attitude of adults, availability of medical care, income, labor legislation, etc., tend to result in differences in these relationships (9). However, the errors introduced with the use of this assumption are likely to result in an underestimation of number of days lost. One possibility is that higher income and social legislation may tend to increase the number of school-loss and work-loss days. A less protected student or worker will

Table III-3-5

U.S.A.: Number of school-loss days per year per 100 children age 6-16 and number of work-loss days per year per 100 usually working persons, associated with acute conditions.

July, 1957 - 1958

Condition group	school-loss days	work-loss days
Total conditions	788.2	598.6
Infectious & Parasitic	124.4	33.0
Respiratory	565.2	367.1
Digestive	23.9	22.9
Injuries	37.3	113.4
All other conditions	37.4	62.2

Source: Reference (12)

attend school or work even when sick. This suggests that if the results obtained with equation III-3-1 had only the defect just mentioned, they would overestimate the number of days lost, but would not overestimate the working capacity of persons who continue working while sick.

Another bias in the results obtained with equation III-3-1 is a consequence of the fact that a better-educated population would be likely to receive medical attention more promptly. The medical attention would also be of better quality where the standard of living is higher. This observation suggests that the same disease results in a lower number of days lost in developed than in underdeveloped countries.

Still another bias is introduced by deficiencies in the data on mortality. A 40% under-registration of deaths is not extraordinary in developing countries (10), (11). Also, the diseases occuring with the greatest frequency, and as a consequence, those which produce the largest number of school-loss and work-loss days, might not be those causing the highest proportions of deaths. This is the case, for instance, with parasitic diseases. Again, the result of these biases will be an underestimation of the work-loss and school-loss days in developing countries.

The criticisms above reduce the value of the estimates obtained with respect to school-loss and work-loss days. In order to test the validity of the results presented in Table III-3-6, they were compared with statistical data for Egypt (6) England and Wales (8) and Holland (7). The differences between estimates and statistics were of no importance according to an intuitive judgment. On this basis, the results that appear in Table III-3-6 give some idea of what really occurs.

The capacity to attend school and to work, as far as it is dependent upon health, is presented as a percentage of total capacity in Table III-3-6. This is based on the assumptions that the number of school days is 200 and that the number of working days is 240 per year.

Table III-3-6

Estimated Number of School-loss Days Per Year Per Child Age 6-16, and of Number of Work-loss Days Per Year For Usually Working Persons, Associated With Acute Conditions (Data Around 1958)

	School-loss days		Work-loss days	
	No.	% of school days	No.	% of working days
Africa				
Egypt	49	24	37	15
America, North				
Canada	8	4	6	2
Guatamala	52	26	39	16
Mexico	37	18	28	12
USA	8	4	6	2
America, South				
Argentina	9	4	7	3
Brazil	28	14	21	8
Chile	50	25	37	15
Colombia	49	24	37	15
Ecuador	92	41	69	29
Peru	20	10	15	6
Venezuela	65	32	49	20
Uruguay	9	4	7	3
Asia				
Burma	38	19	28	12
Japan	10	5	8	3
Europe				
Austria	13	6	10	4
Belgium	13	6	10	4
Czechoslovakia	11	5		
Denmark	9	4	7	3
Finland	8	4	6	2

France	14	7	11	3
Germany (West)	19	9	14	6
Greece	9	4	6	2
Italy	18	9	13	5
Netherlands	9	4	7	3
Norway	9	4	7	3
Portugal	20	10	15	6
Spain	17	8	13	5
Sweden	10	5	7	3
Switzerland	9	4	7	3
U. Kingdom	22	11	16	7
Oceania				
Australia	9	4	6	2
New Zealand	11	5	8	3

Source: Reference (1) and (3).

In judging the results in Table III-3-6, one should bear in mind that they might be undervalued for underdeveloped countries. In spite of this, they show that for several developing countries, the number of school-loss and work-loss days is more than five times that of the USA and European countries.

III-3-4 Health and Mental Abilities

The possibility that acute or chronic diseases affect the mental capacities of a person both at the time that the disease occurs and afterwards has not been studied.

In reference (1) information is presented on the relationships among:

(a) social-environmental variables such as mother's education and index of socio-economic status;

(b) maternal complications such as anemia during pregnancy, toxemia, and labor and delivery problems;

(c) prematurity estimated by weight at birth;

(d) complications during the first weeks of life such as hyperbilirubinemia, hypoxia, weight loss as an index of dehydration and infection, and

(e) motor and mental development evaluated with the development quotients obtained from the Gesell Gross Motor Development schedule and the Cattell Infant Intelligence Scale administered at about 13½ months of age.

This information was collected from a sample of 351 black premature births and 50 black full-term births. Analysis of covariance is the technique best suited for the analysis of the information collected. However, it was not used in the study mentioned. Only first-order and partial correlations between variables in each of the four groups enumerated above and those in group e are presented in reference (1). The results obtained can be summarized as follows:

(a) No significant correlations were obtained between development quotients (DQ) and the indices of socio-environmental variables. This might be due to the fact that all the observations were made in subjects from low socio-economic classes.

(b) No significant correlations were obtained between DQ and most of the indices of maternal complications. Also, the authors consider that the significant correlations obtained might be due to sampling errors.

(c) The results obtained with respect to prematurity appear in Table III-3-7. The correlation coefficients in this table show a relationship between weight at birth and the development quotient measured at 13 1/2 months of age.

(d) In Table III-3-8 it can be observed that the indices of several of the health conditions during the first weeks of life are significantly correlated with development quotients at 13 1/2 months of age.

III-4 NUTRITION AND PHYSICAL AND MENTAL CAPACITIES

The influence of nutrition, like that of health, is a total of genetic factors, prenatal conditions, and personal history. Again in the case of nutrition, no systematic analysis covering all these aspects seems to be available. Only fragmentary information dealing with specific questions at specific stages exists. The information that seems to be most relevant will be presented below.

III-4-1 Integenerational Effects of Nutrition on Mental Capacities

Nutritionists single out two periods in human life during which the effect of nutrition on mental capacity is believed to be especially important. The first is during the period of gestation. Here, the nutrition of the mother is the important element. The second period (to be considered in the following section) is the first two years in the life of a child.

An especially critical time when nutritional deficiency can spell mental inadequacy is during the eighth through the twelfth weeks of pregnancy. Beginning at the eighth week following conception, the fetal cerebral cortex begins to form. Mal-

Table III-3-7

Correlations between prematurity and Development

at 13½ months.

	Gross Motor Development		Cognitive Development	
	First Order	*Partial*	First Order	*Partial*
Males				
Sample size	84	84	103	103
Correlations	32**	.25**	..26**	n.a.
Females				
Sample size	122	122	145	145
Correlations	.31**	.15**	.14**	n.a.

* First order correlations and Partial Correlations excluding the effect of significant complications during first weeks of life see table III-3-8

** Significant at least at a .05 confidence level in a two - tailed test.

n.a. not available

Source; Reference (1).

Table III-3-8

Correlations between complications during first week of live and development of 13½ months

COMPLICATIONS	Gross Motor Development		Cognitive Development	
	First order*	Partial*	First Order*	Partial*
Males				
Sample size	84	84	103	103
Hyperbilirubinemia	- .30**	-.28**	-.13	-.16
Hypoxia	- .22**	-.12	-.11	-.02
Weight loss	- .06	.08	.07	.10
Infection	- .07	.00	.04	.01
Females				
Sample size	126	122	145	145
Hyperbilirubinemia	-.06	.02	-.03	.06
Hypoxia	-.25**	-.10	-.01	.08
Weight loss	-.31**	-.19	-.18	-.13
Infection	-.37**	-.30	-.09	-.05

* First order corralations and partial correlation excluding the influence of prematurity measured by weight at birth.

** Significant at least at a .05 level of confidence in a two-tailed test.

Source: Reference (1)

brain formation due to lack of the basic protein building blocks (the single most important process in brain formation). (2)

Reference (4) reports studies in which babies born during the winter months are associated with the following characteristics:

1. Lower IQ's than babies born in the spring-summer months;
2. Lighter body build;
3. Shorter height;
4. Abnormally high incidence of mental deficiency

The underlying cause for shorter, mentally deficient babies born during the winter months is malnutrition. During the warm summer months a pregnant woman's appetite decreases. Thus she eats less, and may endanger a developing fetus in the critical 8-12 week period.

Reference (5) compares sets of identical twins. It is observed that the twin with the lower birth weight usually has the lower IQ (by about 5 percent, on the average) at school age. These results are summarized in Table III-4-1. They are interpreted to indicate that nutrient supplies are sometimes inadequate for proper body and brain development in twin pregnancies, and that unequal sharing of nutrients and space stunted one twin more than its mate.

In reference (3) the intelligence of two groups of children is compared. One group was born of undernourished mothers who received vitamin and mineral supplements during pregnancy. The other mothers received placebos. The children born of the mothers with supplemented diets had IQ's at the age of four which were 4-8 percent higher than those of the other children.

Table III-4-1

Mean IQ Scores and Birth Weights for 27 Sets of Identical Twins

	Heavier	Lighter
Mean birth weight (kg)	2.49	2.22
Mean verbal IQ*	88.80	84.40
Mean performance IQ*	94.40	89.10

*Wechsler Scale for children

Source : Reference (5)

Some support for the previous observations is provided by the investigation reported in (1) showing that: (a) malnutrition of the mother increases the probability of premature births, and (b) premature children--frequently underweight--are more likely to suffer physical, mental and emotional handicaps than normal children.

III-4-2 Nutrition, Morbidity and Mortality in Early Childhood

Statistical studies of the relationship between nutritional conditions and mortality appear in references (2), (4) and (6). References (3) considers the influence on death rates for children 0-1, 1-4 and 0-4 years of age of lack of medical services, sufficient food, and adequate housing. Data from as many countries as possible are used. The results of their regression analyses appear in Table III-4-2.

According to these results, the only significant reason for the high infant mortality rate is deficient nutritional conditions. This result is consistently maintained both when height of children of 4 years of age is used as an index of nutritional status, and when grams of proteins per person per day are used for the same purpose. Percentage of houses with piped water inside or outside the house has coefficients with appropriate negative signs, but they are not significant in any of the regressions. Number of persons per doctor has a positive and significant coefficient in only one case, but in two of the regressions it has a negative coefficients. Such values--if significant--would mean that the larger the number of persons per doctor, the lower the mortality rate, a result that I hope is meaningless.

Reports on what is likely to be the most complete study of the influence of nutrition on morbidity and mortality appear in references (1) and (5). For these studies, three rural villages in Guatemala were investigated over a period of five years. One village served as a control. The children in the second village (feeding village) received a dietary supplement, and comprehensive medical services were available in the third village (treatment village). The

Table III-4-2

Statistical Analysis of Indirect Determinants of Infants and Children Deaths

Explained Variables			Explanatory Variables						
Death Rate 0-1 (1)	Death Rate 1-4 (2)	Death Rate 0-4 (3)	Population per Doctor (4)	Proteins per Person per day (5)	Height Children 4 (6)	Weight Children 4 (7)	%Houses with piped water (8)	Constant (9)	R^2 (10)
Y (32)			-.00222 (-1.44)		-7.24* (-4.48)	-.09 (-.21)		772.14	.49* (8.9
	Y (32)		-.00084 (-2.69)		-1.846* (-5.66)	.021 (.25)		188.77	.56* (12.0
Y (48)			-.00201 (1.46)	1.160* (-3.57)				114.77	.35* (12.5
	Y (48)		-.00084 (2.68)	-.236* (-3.16)				23.62	.42* (16.0
Y (32)			.01185 (2.26)				-.477 (-2.20)	67.26	.37* (8.3
	Y (32)		.0033* (3.00)				-.083 (-1.48)	6.60	.41* (10.1
		Y (42)	.00039 (.32)	-.431* (-3.12)				49.18	.32* (9.3

Y denotes dependent variable in regression

Figures in Parenthesis mean:
(a) Under Y sample size
(b) Under coefficients in columns (4) to (8) value of t statistics
(c) Under R^2 in column (10) value of F statistics for regression

*Significant of a 99% confidence level

results obtained are summarized in Table III-4-3 and III-4-4 for the years in which complete information is available.

A clear pattern appears in these two Tables. The illnesses per child were 20% lower in the feeding village than in the control village. Comparisons between the incidence of disease in these two villages and the treatment village are meaningless, because this last village was subject to an unusually high number of epidemics. The data in Table III-4-4 show the impact of better nutrition and medical care on mortality. Two separate results can be observed. First, despite the unusually high number of disease cases brought about by epidemics in the treatment village, its mortality rate is the lowest. On the other hand, the rate of decrease of mortality rate is 3.63% in the treatment village, while it is 3.93% in the feeding village, suggesting that better nutrition reduces mortality faster than improved medical care. This means that an initial mortality rate of 76.5% in the treatment village would have been reduced to 46.44% through better nutrition. It should be emphasized that these results must be interpreted with great care, because the morbidity conditions differed in the two villages compared.

III-4-3 Early Childhood Malnutrition and Its Relationship to Mental Abilities

The effects of nutrition during early childhood on mental capacity have been investigated often and in various ways (2), (4), (5), (6), (7), (8), (10), (12), (13), (14), (17), (18), (19), (20), (21), (24) and (25).

A summary of the data used for the studies in references (18) and (19) is presented in Table III-4-5. According to these studies, malnourished children had IQs from 20 to 25 percent lower than those of well-nourished children. This is true despite the fact that there was no significant difference in measured intelligence or in level of education of the parents of experimental and control groups in the two studies. This finding is particularly important because of the possibility that much of the variance in IQ may be explained by the influence of genetic factors on the intelligence of the children, as reflected in the IQ

Table III-4-3

Comparison of Nutritional Conditions and Morbidity in Observed Guatemalan Villages

	Treatment Village				Feeding Village				Control Village			
Dates (1)	Calories (2)	Protein Gr. (3)	Annual day of Illness per Child (4)	Illness per Child per year (5)	Calories (6)	Protein Gr. (7)	Annual days of Illness per Child (8)	Illnesses per Child per year (9)	Calories (10)	Protein Gr. (11)	Annual Days of Illness per Child (12)	Illness per Child per year (13)
1959	908	25.0	n.a.	n.a.	678	19	n.a.	n.a.	836	21.8	n.a.	n.a.
1960	852	22.9	71.1	3.4	1048	33	10.0	1.3	798	20.1	13.3	1.9
1961	1046	29.0	59.8	4.7	1025	31	11.4	1.3	948	24.5	12.0	1.5
1962	775	22.1	57.7	5.0	1083	33	9.6	1.4	812	21.9	12.9	1.7
Average 60-62	891	24.7	62.9	4.4	1052	32.3	10.3	1.3	852.7	22.2	12.7	1.7

Source: Elaborated from data in Reference (5).

Table III-4-4

Rates of death per 1,000 in observed
Guatamalan villages for children 0 - 4 years of age

Dates	Treatment village	Feeding village	Control village
Before feeding program, 50-58	76.5	93.4	115.8
During feeding program, 59-64	48.7	56.7	92.8

Source: Elaborated from data in Reference (5)

Table III-4-5

Scores in Intelligence Tests and Nutritional Status

	South Africa (Cape)		Chile (Santiago)	
	Malnourished	Well-nourished	Malnourished	Well-nourished
Sample size	20	20	28	35
Scores on intelligence test	61.15*	76.70*	72.8(11.4)**	97.1(9.9)**
Score as % of normal group	79.73	100.0	74.97	100.0
Weight				
W_1 (%)	n.a.	n.a.	73.9(10.5)	102.2(11.0)
W_2 (%)	n.a.	n.a.	65.0(6.8)	102.6(13.2)
W_3 (%)	n.a.	n.a.	72.6(7.3)	103.9(13.5)
W_4 kg	23.38	29.45	n.a.	n.a.
Height (cm.)	125.73	133.68	n.a.	n.a.
Race	Black	Black	White	White
Parents' raw score in intelligence test	19.59	21.05	n.a.	n.a.
Mothers' IQ	n.a.	n.a.	70.9(14.7)	70.7(13.4)
Parents' years of education	3.3	4.4	n.a.	n.a.
Mothers' years of education	n.a.	n.a.	3.7	3.8

* Wechsler test given to 11-year old children

** Terman-Merril Children Test given to children between 3 and 5 1/2k years of age

W_1 average monthly weight third semester expressed as percentage of standard in reference (9)

W_2 average monthly weight first 18 months expressed as percentage of standard in reference (9)

W_3 average monthly weight first 30 months expressed as percentage of standard in reference (9)

W_4 weight in kilograms at 11 years of age

In parenthesis standard deviations

SOURCE: South Africa, Reference (19) and Chile, Reference (18).

of the parents, or by environmental conditions associated with the parents' education. (12)

In order to further analyze these data, it is assumed that IQ is linearly related to the indices of level of nutrition and--when available--to mothers' scores on intelligence tests, mothers' level of education, and to indices of socio-economic conditions reflecting the following characteristics: types of housing; toilet, bathing and cooking facilities; ownership or rental arrangement of the dwelling; sewage facilities, water source and lighting; and per capita income.

To estimate the parameters of these linear functions, Wald's method of fitting a straight line when both variables are subject to error (11) was used in the case of the data for South Africa, and usual regression in the case of Chile (18). The results appear in Table III-4-6. They show a positive relationship between the indices of nutritional conditions and scores on intelligence tests that continue to hold true when (a) different races are considered, (b) different indices of level of nutrition are used, (c) data for either malnourished only or for both well and malnourished children are considered, and (d) when an index of socio-economic status is also used as an explanatory variable. The coefficients for the mothers' score on intelligence tests and the mothers' levels of education were not statistically significant, and these variables were excluded from the regressions presented in Table III-4-6.

The fact that in the analysis of the children's data the mothers' score in an intelligence test and their education, as well as an index of socio-economic status, have been explicitly considered, overcomes in part the criticisms of similar analyses made in reference (7). The other criticism, i.e., that it is not proved that malnutrition causes permanent mental retardation and that this might not be the case, is not relevant to the study of the impact of nutrition on mental characteristics and through them, on development. This is true because in many countries, deficient nutritional conditions cannot be improved without specific programs for doing so. Since such programs are not available, the physical and mental deficiencies brought about by malnutrition will be

Table III-4-6

Statistical Analysis of the relationship between scores in intelligence test and indices of nutritional status and socio-economic conditions

Independent variable	Sample	
	Malnourished children	Malnourished and well nourished children
1. Intdrcept	35.18 (2.18)	23.83 (2.44)
W_1	.50 (2.26)	.67 (5.50)
	R^2 = .16 F = 5.08	R^2 = .47 F = 30.22
2. Intdrcept	42.13 (1.92)	36.53 (4.47)
W_2	.56 (1.33)	.55 (5.03)
	R^2 = .08 F = 1.78	R^2 = .43 F = 25.35
3. Intercept	32.98 (1.43)	25.94 (2.47)
W_3	.54 (1.69)	.65 (4.90)
	R^2 = .10 F = 2.87	R^2 = .42 F = 24.0
4. Intercept		13.62
W_4		3.067
5. Intercept		-184.65
Height		1.955
6. Intercept	9.33 (.45)	
W_1	.49(2.32)	
SI	.46 (1.94)	
	R^2 = .47 F = 4.69	

(contd.)

7. Intercept	1.03 (.03)
W_2	.59 (1.83)
SI	.56 (2.24)
	R^2 = .22
	F = 3.53
8. Intercept	-6.13 (-.22)
W_3	.64 (2.14)
SI	.56(2.27)
	R^2 = .25
	F = 4.24

W_i i = 1,4 see Table III-4-5

SI index of socio-economic condition
In parenthesis t ratio of the coefficient
Sources: Fits 1,2,3, 6,7,8 Ref. (18)

Fits 4,5 elaborated from data in Ref. (19)

permanent.

In reference (3), attempts are made to study the implications of the relationship between mental abilities and nutritional status, using the parameters presented in Table III-4-6 and the following procedure:

Data on average height and weight for 4-year-old children in different countries, taken from reference (15), are used as a starting point. They show that at this age, children from developing countries show a deficiency of up to 20% in height and up to 40% in weight as compared with children from developed countries. These substantial deficits should be evaluated, keeping in mind that in (20) it is mentioned that in all groups for which data exist, the average growth rates of wholly breast-fed babies are very satisfactory, and may even exceed those which are regarded as optimal in Britain and the United States. In Table III-4-7 these data are compared with information on percentage of calories and protein requirements satisfied in each country.

In the next step, the information in Tables III-4-5 to III-4-7 is combined to estimate the impact of malnutrition on the average mental capacity of the population of different countries. The procedure used with respect to the South African data is the following:

(a1) As indicated, the South African data refer to 11-year-old-children. As a first step, the height and weight data were modified to make them equivalent to data for 4-year old children. This is done by multiplying the height and weight in Table III-4-5 by .74 and .49, respectively. These coefficients were obtained from reference (23).

(b1) Again it was assumed that a straight line equation describes the relationship between IQ and height in the one case and IQ and weight in the other. The data used for IQ are the original ones for South Africa, and for height and weight, those obtained from step (a1) are used. Wald's method (11) was used to fit the equation.

(c1) The intercepts of the straight lines obtained in (b1) were modified so that an IQ of 100 would correspond to normal heights and weights.

The Nutritional Status of Children in Different Countries

Countries (1)	Percentage of calorie requirement satisfied (2)	Percentage of protein requirement satisfied (3)	Height children 4 years old cm. (4)	Height as % of tallest (5)	Weight children 4 years old kg. (6)	Weight as % of heaviest (7)
Africa						
Congo	n.a.	n.a.	85.8	82.9	11.3	66.9
Ethiopia	n.a.	n.a.	90.3	87.2	12.2	72.2
Gambia	n.a.	n.a.	92.5	89.4	13.1	77.5
Kenya	n.a.	n.a.	92.0	88.9	13.6	80.5
Nigeria	n.a.	n.a.	92.6	89.5	13.2	78.1
Sudan	n.a.	n.a.	98.1	94.8	13.3	78.7
America, North						
Canada	116.4	135.8	95.9	92.7	15.0	88.8
Guatemala	n.a.	n.a.	92.6	89.5	13.4	79.3
Jamaica	n.a.	n.a.	97.7	94.4	14.5	85.8
Mexico	98.4	46.5	92.2	89.1	14.0	82.8
U.S.A.	120.9	142.9	102.9	99.4	16.7	98.8
America, South						
Bolivia	n.a.	n.a.	90.9	87.8	14.0	82.8
Chile	95.8	56.7	100.0	96.6	16.4	97.0
Colombia	87.6	52.2	90.4	87.3	13.1	77.5
Ecuador	91.3	42.5	90.1	87.1	13.4	79.3
Peru	80.8	27.3	93.6	90.4	12.2	72.2
Uruguay	116.1	n.a.	98.8	95.5	15.9	94.1
Venezuela	87.9	59.5	95.6	92.4	14.3	84.6
Asia						
Burma	n.a.	n.a.	91.4	88.3	12.3	72.8
India	78.9	14.8	86.8	83.9	11.9	70.4
Indonesia	n.a.	n.a.	90.9	87.8	12.5	74.0
Israel	109.9	74.2	99.4	96.0	16.4	97.0
Japan	88.4	41.0	96.1	92.9	14.8	87.6
Jordan	n.a.	n.a.	90.2	87.1	14.0	82.8
Lebanon	n.a.	n.a.	96.3	93.0	15.7	92.9
Malaysia	n.a.	n.a.	94.2	91.0	12.8	75.7
Pakistan	88.4	17.7	88.3	85.3	11.1	65.7
Philippines	84.1	36.2	94.2	91.0	12.5	74.0
Taiwan	97.5	34.8	98.5	95.2	14.7	87.0
Thailand	n.a.	n.a.	90.9	87.8	12.3	72.8
Vietnam, North	n.a.	n.a.	86.4	83.5	11.2	66.3

Table III-4-7

Countries (1)	Percentage of calorie requirement satisfied (2)	Percentage of protein requirement satisfied (3)	Height children 4 years old cm. (4)	Height as % of tallest (5)	Weight children 4 years old kg. (6)	Weight as % of heaviest (7)
Europe						
Austria	108.8	98.1	102.2	98.7	16.5	97.6
Belgium	112.1	99.9	101.5	98.1	16.4	97.0
Czechoslovakia	n.a.	n.a.	102.5	99.0	16.8	99.4
East Germany	n.a.	n.a.	101.0	97.6	16.3	96.4
Finland	111.9	109.3	100.5	97.1	16.0	94.7
France	113.8	112.5	99.6	96.2	15.7	92.9
Hungary	n.a.	n.a.	100.8	97.4	15.7	92.9
Italy	104.6	60.2	99.9	96.5	15.9	94.1
Netherlands	112.1	96.0	103.5	100.0	16.9	100.0
Norway	109.9	102.4	102.6	99.1	16.7	98.8
Poland	n.a.	n.a.	100.0	96.6	16.0	94.7
Switzerland	116.1	109.1	102.9	99.4	16.3	96.4
U.K.	121.7	110.4	101.1	97.7	16.2	95.9
U.S.S.R.	n.a.	n.a.	100.2	96.8	16.2	95.9
West Germany	112.1	101.1	102.3	98.8	16.2	95.9
Oceania						
Australia	122.7	133.6	101.2	97.8	16.5	97.6

Sources: Column (2) Reference (22)

Column (3) Reference (22) elaborated as follows:

The approach used to compute the required intake of proteins for the U.S.A. is described in reference (16) pp. 18, 19. This approach is adapted in the following way:

a) First the basal calorie requirement was estimated, using the formula

$$BCR_i = CR_i * \frac{BCR_u}{CR_u}$$

where

BCR_i basal calorie requirement country i

CR_i total calorie requirement country i obtained from reference (22)

when i = u the values are those of the U.S.A. taken from (16)

Table III-4-7 (cont'd)

(b) The ideal amount of Protein is 20 mg. per basal calorie requirement, i.e. the ideal protein requirement in country i is given by

$$BCR_1 * .002$$

(c) Again, according to (22), a correction of 30% is made to take into consideration individual variability in the ideal protein requirement.

(d) In reference (22) only 70 percent of the protein intake is considered to be utilized in the U.S.A. The reason for this is that some of the protein provided by certain foods is not used. This is particularly true of protein provided by non-animal foods. In the computations made here it was assumed that 85 percent of the protein provided by animal foods is used, while only 37 percent of that provided by non-animal food is used. The data on total protein and on that of animal origin are from (22)

(e) The results of step (d) were compared with the information on total protein intake in the countries studied in order to obtain the percentage of protein requirements that are satisfied.

Columns 4 and 6 Reference (15)

(d1) The equations obtained using steps (b1) and (c1), together with the data for height and weight presented in columns (4) and (6) of Table III-4-7, are used to estimate the average IQ of children 4 years of age in different countries. The average of these two results appears in Table III-4-8, column 2.

The procedure used in the case of the Chilean data is the following:

(a2) The intercepts of results 1, 2 and 3 in Table III-4-6 were modified so that IQ would be 100 for a 100% weight.

(b2) The percentages in column 7 of Table III-4-8 were used in the equation obtained in (a2) to obtain three estimates of the average IQ in different countries. The average of these three estimates appears in column 3 of Table III-4-8.

Despite the fact that South African and Chilean data used as a starting point for obtaining the results in Table III-4-8 are completely independent of each other, and despite substantial differences in the methods used to arrive at the values in columns 2 and 3, the results are identical from a practical point of view. This high degree of consistency leads to the conclusion that differences in nutritional conditions might produce substantial differences in the average mental abilities of the populations of different countries. Although it should already be obvious, it is worthwhile to emphasize that the results in Table III-4-8 are extremely provisional, if not in the general trend they suggest, at least in their specific magnitudes.

III-4-4 Current Nutritional Conditions and Mental Abilities

References (1) and (2) report the effects of adding Thiamin to the diets of children. For the second experiment, which lasted two years, 120 children of about 11 years of age, living in an orphanage and having a diet that provided an average of 1 milligram of thiamin per day, were divided into four homogeneous groups: The first group received a tablet of 2.0 milligrams of thiamin per day during the two years, the second group received the same tablet during the first year only and during the second year a placebo; the third group received a placebo during the first year and thiamin during the second, and the fourth received placebos during the entire two years.

Table III-4-8

Estimates of IQ as determined by nutritional conditions

Countries (1)	Estimates of IQ, with data	
	S. Africa (2)	Chile (3)
Africa		
Congo	73.3	79.4
Ethiopia	82.0	82.3
Gambia	87.7	86.0
Kenya	88.6	87.8
Nigeria	88.1	86.4
Sudan	95.8	86.7
N. America		
Canada	98.0	93.0
Guatemala	88.7	87.1
Jamaica	98.9	91.1
Mexico	90.0	89.3
U.S.A.	100.0	99.3
S/ America		
Bolivia	88.3	89.3
Chile	100.0	98.1
Colombia	84.9	86.0
Ecuador	85.4	87.1
Peru	86.4	82.7
Uruguay	100.0	96.3
Venezuela	95.5	90.4
Asia		
Burma	83.8	83.1
India	76.5	81.6
Indonesia	83.7	83.8

Israel	100.0	98.1
Japan	97.7	92.3
Jordan	87.4	89.3
Lebanon	100.0	95.6
Malaysia	89.0	84.9
Pakistan	76.0	78.6
Philippines	88.1	83.8
Taiwan	100.0	91.9
Thailand	83.1	83.1
Vietnam, N.	73.8	79.0
Europe		
Austria	100.0	98.5
Belgium	100.0	98.1
Czechoslovakia	100.0	99.6
Germany	100.0	97.8
Finaland	100.0	96.7
France	100.0	95.6
Hungary	100.0	95.6
Italy	100.0	96.3
Netherlands	100.0	100.0
Norway	100.0	99.3
Poland	100.0	96.7
Switzerland	100.0	97.7
U.K.	100.0	97.4
U.S.S.R.	100.0	97.4
W. Germany	100.0	97.4
Oceania		
Australia	100.0	98.3

Source: explained in text

The results obtained appear in Table III-4-9. Their interpretation--contrary to what their author claims--is not entirely clear. The two-year experimental group gained more than the corresponding control in the intelligence test score. However, the magnitude of the gains, and the characteristics of the gains of the one year reversed groups, makes it difficult to establish a clear link between those gains and the thiamin supplement. The results for retention of word-number pairs and memorization show a better defined cause-effect relationship.

III-4-5 Nutrition and the Working Capacity of Healthy Persons

In this section, the influence of different levels of nutrition on the working capacity of the populations of different countries, first investigated in reference (9), will be estimated using references (3), (4), (5) and (6).

Although an oversimplification, it can be said that nutritional requirements are related to body weight, sex, age, environmental temperature and type of occupation, and that the principal nutritional elements that need to be considered are calories, vitamins and proteins (7).

Some non-experimental evidence of the relationship between nutrition and working capacity is presented in reference (2). Experimental results are presented in reference (7). A challenge to this information appears in reference (1). This reference presents a report of physical work tests making use of bicycle ergometry and dynamometry performed on six groups of Ethiopian children and adults, classified by nutritional status. The conclusion reached is that "it was not possible to demonstrate any definite correlation between the results of the physical work tests and the nutritional status of the subjects or the quality of the diet as measured by a 24 hour recall". This conclusion--well based on experimental data--is not relevant to the analysis below. It only shows that nutritional status has little influence on the physical capacity required for very short periods of competitive effort. The laws of physics with respect to work and energy imply that the intake of nutrients determines an upper limit to a person's long-term working capacity. On this basis, the results in reference (7) presented in Table III-4-10 and referring only to calories

Table III-4-9

Performance of Four Groups of Children with Different Thiamin Supplements

Activities	Group	Index of Performance		
		Initial	End 1st year	End 2nd year
Intelligence, power-type test	1	100.0	103.0	104.3
	2	100.0	102.0	104.4
	3	100.0	100.8	102.6
	4	100.0	102.0	102.9
Intelligence test, timed	1	100.0	108.2	124.7
	2	100.0	109.5	118.1
	3	100.0	108.6	117.2
	4	100.0	104.0	117.3
Retention: Morse alphabet	1	n.a.	n.a.	n.a.
	2	100.0	30.8	n.a.
	3	100.0	13.2	n.a.
	4	n.a.	n.a.	n.a.
Retention: word-number pairs	1	n.a.	n.a.	n.a.
	2	100.0	35.6	7.5
	3	100.0	20.6	13.7
	4	n.a.	n.a.	n.a.
Retention: Face-name pairs	1	n.a.	n.a.	n.a.
	2	n.a.	100.0	15.3
	3	n.a.	100.0	23.7
	4	n.a.	n.a.	n.a.
Memorization	1	n.a.	n.a.	n.a.
	2	100.0	104.8	97.6
	3	100.0	89.4	106.5
	4	n.a.	n.a.	n.a.

Source: Reference (2)

and to men between 20 and 30 years of age, working in an average temperature of about 50°F, and of unspecified body weight, will be used below.

In order to use the results in Table III-4-10 to estimate the influence of nutrition on working capacity, the calorie intake of workers was estimated, using as a basis the data in (10) on daily average intake of the population, presented in column 3 of Table III-4-11. Next, the intake of male adults was estimated. For this it was assumed that the distribution of actual intake among the age and sex groups is equal to the theoretical distribution of required intake by age and sex published in (7). The intake of workers was assumed to be equal to that of male adults. Women are excluded, in order to obtain figures comparable to those used in Table III-4-10.

Corrections for differences in environmental temperature were then introduced. The averages of the data on temperature are presented in Table III-4-11, column 2.

Data showing that calorie requirements decrease when average temperature increases appear in reference (7). They make it possible to estimate calorie intakes comparable with respect to temperature to those in Table III-4-10. These comparable intakes will be higher than the actual ones for countries with average temperature above the 50°F used as a reference in Table III-4-10. The opposite is true for countries having average temperatures below 50°F.

Lack of information makes it impossible to correct for difference in bodily weight.

Next, differences in occupation were considered. The correspondence in Table III-4-10 between the occupations considered in reference (8) and those in the international classification of industries published by the United Nations (10) was established using the descriptions in (8).

Again, no information exists with regard to the calorie intake of persons having different occupations. To assume that actual intake is proportional to required intake is not reasonable in the case of the developing countries. In these countries, the workers in occupations that require the highest intakes have

Table III-4-10

Calorie Intake and Working Capacity by Type of Work

Type A Commerce, Banking, Insurance, Services		Type B Manufacture, Construction, Electricity, Transport		Type C Agriculture		Type D Mining	
Daily Intake	% Capacity	Daily Intake	% Capacity	Daily Intake	% Capacity	Daily Intake	% Capacity
1450	0	1450	0	1450	0	1450	0
1500	0	2000	27	2500	44	3000	55
1750	0	2250	42	2750	54	3300	64
2000	30	2500	58	3000	66	3600	76
2200	65	2750	76	3300	82	3900	83
2400	100	3000	100	3600	100	4200	100

Source: Reference (8) as quoted in References (3), (4), (5) and (6).

TABLE III-4-11

Temperature, per capita income, calorie intake and working capacity for several countries

Country (1)	Average temperature, degrees F. (2)	Calorie intake per day (3)		Calorie requirements for 100% working capacity (4)	Working capacity as % of full capacity (5)
		date	value		
Africa					
Egypt	73.23	1954-6	2,570	2,520	100.
Madagascar	70.79	1947-8	2,074	2,389	84.
Morrocco	61.22	1952-5	2,350	2,988	83.
Tanganyika	70.40	1947-8	2,163	2,446	92.
U. of S. Af.	62.94	1958	2,780	2,901	96.
N. America					
Canada	33.76	1957-8	3,070	2,838	100.
Cuba	76.29	1948-9	2,730	2,731	100.
El Salvador	72.80	1947-8	1,557	2,944	46.
Honduras	72.80	1954-5	2,260	3,280	64.
Mexico	71.52	1957	2,420	3,066	80.
U.S.A.	53.64	1958	3,100	2,608	100.
S. America					
Argentina	58.91	1957	3,100	2,739	100.
Brazil	75.09	1954-7	2,530	2,881	87.
Chile	54.09	1954-7	2,530	2,824	86.
Ecuador	67.43	1954-6	2,130	2,806	78.
Paraguay	73.65	1956	2,690	2,737	95.
Venezuela	75.0[illegible]	1951	2,280	2,772	86.
Asia					
India	74.43	1957-8	1,800	2,893	51.
Israel	62.62	1957-8	2,750	2,514	100.

Table III-4-11 (cont'd.)

Japan	55.28	1958	2,210	2,763	80.
Philippines	80.74	1957	1,980	2,691	74.
Thailand	83.05	1948-9	2,020	2,710	73.
Turkey	57.15	1954-8	2,790	2,732	100.
Europe					
Austria	48.82	1957-8	2,940	2,737	100.
Czechoslavakia	48.22	1948-9	2,656	2,821	98.
Denmark	45.58	1957-8	3,420	2,701	100
Finland	40.65	1957-8	3,110	2,850	100.
France	54.22	1957-8	2,910	2,682	100.
W. Germany	47.13	1954-9	2,970	2,731	100.
Greece	63.65	1958	2,860	2,900	100.
Italy	59.0	1957-8	2,600	2,850	94.
Netherlands	49.75	1957-9	2,940	2,709	100.
Norway	39.51	1957-9	3,010	2,878	100.
Portugal	60.97	1958	2,410	2,890	83.
Spain	58.97	1954-9	2,530	2,987	86.
Sweden	35.38	1957-9	2,940	2,805	100.
Switzerland	37.76	1957-8	3,100	2,724	100.
U. Kingdom	48.97	1957-8	3,300	2,630	100.
Yugoslavia	53.05	1959	2,970	3,063	100.
Oceania					
Australia	70.67	1957-8	3,210	2,579	100.
New Zealand	55.12	1958	3,430	2,694	100.

Sources: References (3) and (4)

the lowest incomes. As a consequence, the distribution of calories intake might be inversely related to requirements. Therefore, it was assumed that the intake of the workers in different occupations was equal to the average intake for all workers.

The intake estimated for workers and corrected for temperature, and the results in Table III-4-10, were used to estimate the working capacity of workers in each of the four occupational classifications considered in Table III-4-10.

The final step was to compute the average working capacity of the labor force as a whole as a weighted average of the capacities of each of the four occupational classifications. For weights, the United Nations data on labor force classified by industry for years as close as possible to 1950 were used. These weighted averages appear as the working capacity of the labor force as a whole in Table III-4-11, column 5.

REFERENCES

Section III-2-3

(1) Adelman, I.,
"An Econometric Analysis of Population Growth"
The American Economic Review, Vol. 52, 1963
Vol. 52, 1963

(2) Becker, G.,
"An Economic Analysis of Fertility" in National Bureau of Economic Research
Demographic and Economic Change in Developed Countries
Princeton: Princeton University Press, 1960

(3) Drakatos, C.G.,
"The Determinants of Birth Rate in Developing Countris: An Econometric Study of Greece"
Economic Development and Cultural Change
Vol. 17, 1969

(4) Freedman, R., G. Baumert, and M. Bolte
"Expected Family Size and Family Size Values in West Germany"
Population Studies
Vol. 13, 1959

(5) Friedlander, S. and M. Silver
"A Quantitative Study of the Determinants of Fertility Behavior"
Demography
Vol. 4, 1967

(6) Gendell, M.
Swedish Working Wives: A Study of Determinants and Consequences
Ottawa: Bedminister Press, 1963

(7) Goldberger, A.S.
Econometric Theory
New York: John Wiley, 1964

(8) Klein, L.R. and M. Nakamura
"Singularity in the Equations Systems of Econometrics: Some Aspects of the Problems of Multicollinearity,"
International Economic Review
1962

(9) Klinger, A.,
"Trends of Differential Fertility by Social Strata in Hungary" in
International Population Conference
London: UNESCO, 1963.

(10) Leibenstein, H.
Economic Backwardness and Economic Growth
New York: John Wiley and Sons, Inc., 1957

(11) Mincer, J.,
"Labor Force Participation of Married Women: A Study of Labor Supply," in National Bureau of Economic Research
Aspects of Labor Economics
Princeton: Princeton University Press, 1962

(12) Nye, F.I. and L.W. Hoffman
The Employed Mother in America
Chicago: Rand McNally and Co., 1963

(13) Parrish, Vestal W., Jr.
Attitudes Toward Maternal Employment: An Influence on Desired Family Size in a Southern Semi-Rural County.
An Unpublished Doctoral Dissertation.
School of Public Health and Tropical Medicine, Tulane University, New Orleans, LA. 1969

(14) Parrish, Vestal W. Jr., Jill Kaplan, Carl L. Harter and Joseph D. Beasley
"Family Survey of Lincoln Parish: Instruction Manual,"
New Orleans: Center for Population and Family Studies
Tulane School of Public Health and Tropical Medicine, 1965 (mimeo)

(15) Phillips, L., H. Votey and D.E. Maxwell
"A Synthesis of the Economic and Demographic Models of Fertility: An Econometric Test,"
The Review of Economics and Statistics
Vol. 51, 1969

(16) Schultz, T.P.,
"An Economic Model of Family Planning and Fertility"
The Journal of Political Economy
Vol. 77, 1969

(17) Stafford, F.P.
"Student Family Size in Relation to Current and Expected Income"
The Journal of Political Economy
Vol. 77, 1969

(18) Stycos, J.M.,
"Female Employment and Fertility in Lima, Peru"
Milbank Memorial Fund Quarterly
Vol. 43, 1965

(19) United Nations
Demographic Aspects of Manpower, Report 1, Sex and Age Patterns of Participation in Economic Activities
New York: United Nations, 1962

(20) Weintraub, R.
"The Birth Rate and Economic Development: An Empirical Study"
Econometrica
Vol. 40, 1962

(21) Westoff, C.F., R.G. Potter, P.C. Sagi and E.G. Mishler
Family Growth in Metropolitan America
Princeton: Princeton University Press, 1961

(22) Whelpton, P.K., A.A. Campbell and J.E. Patterson
Fertility and Family Planning in the United States
Princeton: Princeton University Press, 1966

Section III-2-4

(1) Correa, H.
The Economics of Human Resources
North Holland Publishing Co.,
2nd Printing, 1967, Amsterdam

(2) Duncan, O.D.
"Is the Intelligence of the General Population Declining?", in
Spengler, J.J., and O.D. Duncan (eds.)
Demographic Analysis: Selected Readings
The Free Press, 1956

Section III-3-2

(1) Correa, Hector
The Economics of Human Resources
North Holland Publishing Co.,
2nd Printing, 1967, Amsterdam

(2) Correa, Hector
"La Planificacion de la Salud y su Integracion con la Planificacion Socio-Economica",
Depto. de asuntos Cientificos, Union Panamericana, 1968

(3) Keyfitz, N.
Introduction to the Mathematics of Population
(Chapter 1)
Addison-Wesley, 1968

(4) Mushkin, S.J.
"Health as an Investment"
The Journal of Political Economy
Vol. 70, No. 5, Part 2 Supplement, October, 1962

(5) Rice, Dorothy P.
Estimating the Cost of Illness
U.S. Department of Health Education and Welfare
Public Health Office, 1966

(6) U.S. Department of Health Education and Welfare
Economic Costs of Cardiovascular Diseases and Cancer, 1962
Health Economics Service, No. 5,
Public Health Service Publication, No. 947-5
U.S. Government Printing Offices, 1965

Section III-3-3

(1) Correa, Hector
The Economics of Human Resources
North Holland Publishing Co.,
Amsterdam, 2nd Printing, 1967

(2) Correa, Hector
"Planificacion de la Salud y su Integracion con la Planificacion Economica",
Departmento de Asuntos Cientificos
Union Panamericana, 1968

(3) Correa, Hector
"Nutrition, Health and Education"
Department of Economics and Center for Family Health and Population Dynamics
Tulane University (mimeo)

(4) Correa, Hector
"Sources of Economic Growth in Latin America,"
The Southern Economic Journal
Vol. 37, No. 1, July, 1970

(5) Gomaa, R.A.
"A Field Research in Health Economics for the Cost-Benefit Analysis of the Rural Health Unit"
Third Statistical Conference, Ministry of Health, Cairo, 1967

(6) Gomaa, R.A.
"Resume of Field Research on Impact of Health on Economic State"
Ministry of Health, Cairo, 1971 (mimeo)

(7) Netherlands Productivity Center (1955)
The Influence of Sickness Absenteeism on Labor Producitivity in the Netherlands

(8) Stocks, P.
Sickness in the Population of England/Wales in 1944-47
London, 1949

(9) Silver, M.
"An Economic Analysis of Variations in Medical Expenses and Work-Loss Rates", in
Klarman, H.E. (ed.)
Empirical Studies in Health Economics
The Johns Hopkins Press, 1970

(10) United Nations Economic Commission for Latin America (ECLA)
"Proyeccion de la Problacion Urbana, Poblacion Urbana, Poblacion Rural y Fuerza Trabajadora de Colombia," (mimeo, 1966)

(11) United Nations Economic Commission for Latin America (ECLA)
"Proyeccion de la Poblacion Urbana y Rural de Cuba"
(mimeo, 1960)

(12) U.S. Department of Health Education and Welfare
Public Health Service Statistics of the U.S. National Health Survey: Disability Days
Series B No. 6

Section III-3-4

(1) Braine, M.D.S., C.B. Heimer, H. Worlis and A.M. Freedman
Factors Associated with Impairment of the Early Development of Prematures
Monographs of the Society for Research in Child Development
Serial No. 106, Vol. 31, No. 4, 1966.

Section III-4-1

(1) Birch, H.G. and J.D. Gussov
Disadvantaged Children, Health, Nutrition and School Failure
Harcourt, Brace and World, New York, 1970.

(2) Carvioto, J.
"Malnutrition and Behavioral Development in the Pre-School Child"
in National Academy of Sciences - National Research Council, 1966
Pre-School Child Malnutrition: Primary Deterrent to Human Progress

(3) Harrell, R.F., E. Woodyard and A.I. Gates
The Effects of Mothers' Diets on the Intelligence of Offspring
Bureau of Publications of Teachers' College
Columbia University, 1955

(4) Knoblock, H., and B. Pasamanick
"Seasonal Variations in the Births of the Mentally Deficient"
American Journal of Public Health
Vol. 48, September, 1958, 1201:8

(5) Willerman, L. and J.A. Churchill
"Intelligence and Birth Weight in Identical Twins"
Child Development
38:623, 1967

Section III-4-2

(1) Ascoli, W., M.A. Guzman, N.S. Scrimshaw and J.E. Gordon
"Nutrition and Infection in Field Study in Guatemalan Villages, 1959-64"
IV Deaths of Infants and Preschool Children
Archives of Environmental Health
Vol. 15, October, 1967, pp. 439-449.

(2) Bengoa, J.M., D.B. Jelliffe and C. Perez
Algunos Indices para la Evaluacion General en Grupos de Poblacion, de la Magnitud de la Desnutricion Proteico-Calorica en Ninos Pequenos
Publicaciones Cientificas de Org. Panamericana de Salud
No. 136

(3) Correa, Hector and W.A. Hassouna
Planning for Health of Infants and Children in Egypt
UNICEF Report, Cairo 1972 (mimeo)

(4) Enderica, R.V.
"Cuociente de Defunciones de 1-4 anos entre 1-11 meses vs. mortalidad proporcional, como indicadores del problema nutricional"
Archivos Latino Americanos Nutr.
Vol. 21:57-67 (1971)

(5) Scrimshaw, N.S., M.A. Guzman, M. Flores and J.E. Gordon
"Nutrition and Infection in Field Study in Guatemalan Villages, 1959-64: V Disease Incidence Among Preschool Children Under Natural Village Conditions, with Improved Diets and with Medical and Public Health Services"
Archives of Environmental Health
Vol. 16, February, 1968, pp. 223-234

(6) Wills, V.G. and Waterlow
"The Death Rate in the Age Group 1-4 Years as an Index of Malnutrition"
Journal of Tropical Pediatry
Vol. 13, 1958, pp. 167-170

Section III-4-3

(1) Belli, P.
"The Economic Implications of Malnutrition: The Dismal Science Revisted"
Economic Development and Cultural Change
Vol. 20, No. 1, October, 1971, pp. 1-23

(2) Cabak, V., and R. Najdanvic
"Effect of Undernutrition in Early Life on Physical and Mental Development"
Archives of Disease in Childhood
Vol. 40, October, 1965, pp. 53-54

(3) Correa, H.
"Nutrition, Health and Education"
Department of Economics and Center for Family Health and Population Dynamics
Tulane University (mimeo)

(4) Cravioto, J., and B. Robles
"The Influence of Protein Calorie Malnutrition on Psychological Test Behavior", in
Blix, G. (ed.)
Mild-Moderate Forms of Protein Calorie Malnutrition
Almquist and Wiksells, 1963

(5) Cravioto, J.,
"Malnutrition and Behavioral Development in the Preschool Child"
Proceedings of the International Conference on the Prevention of Malnutrition in the Preschool Child, Washington, D.C., 1964

(6) Cravioto, J.,
"Malnutrition and Behavioral Development in the Preschool Child",
in National Academy of Sciences - National Research Council
Preschool Child Malnutrition: Primary Deterrent to Human Progress
Washington, D.C., 1966

(7) Frish, R.E.,
"Present Status of the Supposition that Malnutrition Causes Permanent Mental Retardation"
The American Journal of Clinical Nutrition
Vol. 23, No. 2, February, 1970, pp. 189-195

(8) Guzman, H.A.,
"Impaired Physical Growth and Maturation in Malnourished Populations," in
Scrimshaw, N.S. and J.E. Gordon
Malnutrition, Learning and Behavior
Cambridge: M.I.T. Press, 1968

(9) Jackson, R. and H. Kelly,
"Growth Charts for Use In Pediatric Practice,"
Journal of Pediatrics
1945, pp. 27-215

(10) Jeliffe, D.B.,
"Effect of Malnutrition on Behavioral and Social Development,"
Proceedings of Western Hemisphere Nutrition Congress.
Chicago, 1965

(11) Johnston, J.,
Econometric Methods
McGraw-Hill Book Co., Inter., 1963

(12) Jensen, A.R.,
"How Much Can We Boost IQ and Scholastic Achievement?"
Harvard Educational Review
Vol. 39, 1969, p. 1

(13) Kugelmass, N.I., L.E. Poull and E.L. Samuel,
"Nutritional Improvement of Child Mentality",
American Journal of the Medical Services
Vol. 208, November, 1944, pp. 631-632

(14) Lauw, Tjin Giok, C. Rose and P. Gyorgy,
"The Influence of Early Malnutrition on Some Aspects of the Health of School Age Children,"
American Journal of Clinical Nutrition
Vol. 20:1280, 1967

(15) Meredith, H.V.,
"Body Size of Contemporary Groups of Preschool Children Studied in Different Parts of the World,"
Child Development
June, 1968, Vol. 39, No. 2, pp. 336-337

(16) National Academy of Sciences
Recommended Dietary Allowances
7th Edition, Washington, D.C., N.A.S., 1968

(17) Pek Hiem Liang, Tjook Tiauw Hie, Dey Henk Jan and Lauw Tjin Giok,
"Evaluation of Mental Development in Relation to Early Malnutrition,"
American Journal of CLinical Nutrition
20:1290, 1967

(18) Selowsky, M.,
"An Attempt to Estimate Rates of Return to Investment in Infant Nutrition Programs",
Paper Presented at the International Conference on Nutrition, National Development and Planning
M.I.T., October, 1971

(19) Stoch, M.B., and P.M. Smythe,
"Undernutrition During Infancy, Subsequent Brain Growth and Intellectual Development," in
N.S. Scrimshaw and J.E. Gordon (eds.)
Malnutrition, Learning and Behavior
Cambridge: MIT Press, 1968

(20) Thompson, A.M.,
"Historical Perspectives of Nutrition, Reproduction and Growth,"
in N.S. Scrimshaw and J.E. Gordon (eds.)
Malnutrition, Learning and Behavior
Cambridge: MIT Press, 1968

(21) U.S. Department of Commerce
Statistical Abstract of the U.S.A.
1966

(22) United Nations
Compendium of Social Statistics
New York, 1963

(23) Watson, E.H. and G.H. Lowrey
Growth and Development of Children
Chicago: Yearbook Publishers, 1958

(24) Winick, M.,
"Malnutrition and Brain Development",
Journal of Pediatrics
Vol. 74, May, 1969, pp. 774-778

(25) Winick, M. and P. Rosso,
"Head Circumference and Cellular Growth of the Brain in Normal and Abnormal Children,"
Journal of Pediatrics
Vol. 74, May, 1969

Section III-4-4

(1) Harrell, R.F.,
Effect of Added Thiamin on Learning
Teachers' College, Columbia University, New York, 1943

(2) Harrell, R.F.,
Further Effects of Added Thiamin on Learning and Other Processes
Teachers' College, Columbia University, New York, 1947

Section III-4-5

(1) Areskog, N.H., R. Selinus and B. Vahlquist
"Physical Work Capacity and Nutritional Status in Ethiopian Male Children and Young Adults,"
American Journal Clin. Nutr.
Vol. 22, 1969, pp. 471-479

(2) Berg, Allan D.,
"Malnutrition and National Development,"
Foreign Affairs
October, 1967, pp. 126-136

(3) Correa, Hector
The Economics of Human Resources
North Holland Publishing Co., Amsterdam, 1963

(4) Correa, Hector
"Nutrition, Working Capacity, Productivity and Economic Growth,"
In American Medical Association, Proceedings of Western Hemisphere Nutrition Congress II, 1968

(5) Correa, Hector, and Gaylord Cummins,
"Estimates of the Contribution of Nutrition to Economic Growth,"
American Journal of Clinical Nutrition, May, 1970

(6) Correa, Hector and Gaylord Cummins,
"Some Economics of Malnutrition in the United States,"
Paper presented to symposium on "The Role of Malnutrition in the Pathogenesis of Slums," Sponsored by the University of Alabama School of Medicine and the Council on Foods and Nutrition of the American Medical Association, February, 1970.

(7) Food and Agriculture Organization of the United Nations
Calorie Requirements
Nutritional Study
No. 15, FAO, Rome, 1957

(8) Lehman, G., E. Muller and H. Spitzer
"Der Calorienbedarf bei gewerblicher Arbeit",
Arbeitsphysiologie
June, 1950, pp. 166-235

(9) Leibenstein, Harvey
Economic Backwardness and Economic Growth
New York: John Wiley, 1957

(10) United Nations Statistical Yearbook, several issues

CHAPTER IV

INTERACTION AMONG THE DETERMINANTS OF WELL-BEING - POPULATION, HEALTH, NUTRITION AND EDUCATION

IV-1 POPULATION AND EDUCATION

In studying the influence of population on education, two main questions will be considered below: first, the impact of differences in the age structure of the population on educational costs, and second, that of population growth on the increase in enrollment and thus eventually on the increasing costs of education.

IV-1-1 The Age Structure of the Population and the Burden of Education

In this section the differences in the burden of education between one country and another due to (a) purely demographic factors, namely the varying proportion of school-age population, and (b) differences in per capita income as presented in reference (1) will be summarized.

A comparison of the variations in the cost of providing the same educational level for the populations of various countries having different age structures is presented in Table IV-1-1. The impact of these cost variations on income is studied in the same table.

The results appearing in Table IV-1-1 are based on the assumption that the costs of education are the same in every country. This unrealistic assumption is necessary because of the lack of data.

The contents of Table IV-1-1 can best be explained by an example. Consider two countries, the U.S.A. and Panama. Panama has a population between the ages of 5 and 19 years of 264,443, and between 20 and 69 years, 454,331. That is, 454,331 adults must be responsible for the education of

TABLE IV-1-1

Age Structure of the Population and the Cost of Education

(Population Around 1950, Income Around 1955)

Countries	Population		$p = \frac{P_{5-19}}{P_{20-69}}$	Income per active person(y)	$\frac{p}{p_{U.S.}}$	$\frac{y_{U.S.}}{y}$	(5) x (6)
	P_{5-19}	P_{20-69}					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Africa							
Algeria	3,338,900	4,277,800	0.781	539	1.962	6.477	12.70
Morocco	90,300	216,100	0.418	252	1.050	13.853	14.55
North America							
Canada	3,711,200	8,237,600	0.451	2,833	1.132	1.232	1.40
Costa Rica	294,689	359,012	0.821	558	2.063	6.256	12.91
Honduras	526,415	703,815	0.748	321	1.880	10.875	20.44
Panama	264,443	454,331	0.582	416	1.463	8.392	12.27
United States	37,197,000	93,485,000	0.398	3,491	1.000	1.000	1.00
South America							
Brazil	18,826,409	23,876,603	0.789	327	1.982	10.676	21.16
Asia							
Cyprus	152,065	261,923	0.581	665	1.459	5.250	7.66
Israel	370,338	830,630	0.446	1,410	1.121	2.476	2.77
Japan	26,805,000	42,819,000	0.626	497	1.573	7.024	11.05
Korea (South)	7,626,959	8,526,572	0.895	198	2.248	17.631	39.64
Turkey	7,264,800	10,118,400	0.718	516	1.805	6.766	12.21
Europe							
Belgium	1,734,807	5,645,120	0.307	1,376	0.772	2.537	1.96
Finland	1,032,600	2,358,700	0.438	1,175	1.100	2.971	3.27
France	8,850,000	26,755,400	0.331	1,308	0.831	2.669	2.22
Germany, Fed. Rep.	11,299,050	30,557,000	0.370	1,023	0.929	3.413	3.17
Ireland	783,160	1,655,758	0.473	1,048	1.189	3.331	3.96
Netherlands	2,758,914	6,020,259	0.458	1,239	1.152	2.818	3.25
Norway	684,708	2,067,639	0.331	1,414	0.832	2.469	2.06
Portugal	2,409,335	4,782,724	0.504	358	1.266	9.751	12.35
Sweden	1,459,120	4,525,497	0.322	2,227	0.810	1.568	1.27
Switzerland	1,024,050	3,002,150	0.341	2,036	0.857	1.715	1.47
England, Wales	8,710,600	28,349,400	0.307	1,926	0.772	1.813	1.40
Yugoslavia	4,946,983	9,259,827	0.534	271	1.343	12.882	17.29
Oceania							
Australia	2,003,113	5,292,704	0.379	1,722	0.951	2.027	1.93
New Zealand	422,277	1,081,793	0.390	1,966	0.981	1.776	1.74

P_{5-19} = population in age-interval 5–19

$p_{(U.S.)}$ = part of the cost of education that any adult must bear (in the U.S.)

$y_{(U.S.)}$ = income per adult (in the U.S.)

P_{20-69} = population in age-interval 20–69

Source: Reference (1)

264,443 children. Therefore, each adult must pay a part equal to 264,443/454,331 = 0.582 = p of the cost of education of a child in Panama. Since in the U.S.A. there are 37,197,000 persons between the ages of 5 and 19 and 93,485,000 between 20 and 69, each adult must pay a part equal to 37,197,000/93,485,000 = 0.398 = p_{US} of the cost of the education of one child. If the cost of education is denoted by c, in Panama each adult must pay a cost equal to 0.582c, and in the U.S.A. a cost equal to 0.398c.

If the cost of 0.398c in the U.S.A. is taken as a unit, the cost in Panama will be 0.582/0.398 = 1.463. These results appear in column (5) of Table IV-1-1, and give an idea of the effect of the variations in age structure of the population on the burden of education.

On the other hand, the average income in Panama of a person between the ages of 20 and 69 years is U.S. $416, and in the U.S., $3,491. Therefore, the part of an adult's income which must be spent on educational costs for the 5-19 year old population is in Panama equal to 0.582c/416 and in the U.S.A. to 0.398c/3,491.

Finally, in order to compare the importance of the cost of education in the U.S.A. with its importance in Panama, the proportion of an adult's income which, in U.S.A., must be spent for education (that is the value 0.398c/3,491) is taken as a unit of measurement. The proportion of an adult's income in Panama which must be spent on education is, on the basis of the unit adopted, 12 times as great. This means that the impact on income of the cost of the same level of education is 12 times as great in Panama as in the U.S.A., owing to the different age structures of the population and to differences in income (Table IV-1-1, column 7).

It may be concluded from this analysis that the difference in burden due to differences in the age structures of the populations vary only between

1 and 2. The variations due to differences in income are much greater.

IV-1-2 The Impact of Population Growth on Increased Enrollment and the Costs of Education

Numerous models for forecasting student enrollment, taking into consideration the number of births, are available (1), (4), (5), (7). These models - identical in their basic concepts - describe the computation that should be performed, but do not attempt to determine the implications of the rate of population growth for the rates of growth of enrollment, of number of teachers needed, etc. This question will be briefly explored below.

Under the assumption that enrollment in the educational system is a constant proportion of the number of births from 4 to 8 years before the entrance date, the number of persons entering the educational system tends to grow at the same rate as population. If it is also assumed that the students in any grade and level are a proportion of the students in the previous grades and levels, it follows that the number of students in any grade and level increases at the same rate as the population.

Finally, the total number of students in all grades and levels, under the assumptions mentioned, also grows at the same rate as the population. This can be demonstrated as follows:

Let E_{1t} = enrollment in level 1, date t

E_{2t} = enrollment in level 2, date t

P_t = population, date t

Then $P_t = P_0 e^{\rho t}$

$E_{1t} = \alpha_0 P_{t-1}$

$E_{2t} = \alpha_1 E_{1t-1}$

α_0 = enrollment rate

α_1 = transition rate

It follows that:

$$E_{1t} = [\alpha_0 P_0 e^{-\rho}]\ e^{\rho t}$$

$$E_{2t} = [\alpha_0 \alpha_1 P_0 e^{-2\rho}]\ e^{\rho t}$$

$$E_{1t} + E_{2t} = (\text{const})\ e^{\rho t}$$

Assuming that class sizes are constant, the number of teachers needed will increase at the same rate as the population.

The simple model and conclusions just presented are altered when it is assumed that rates of entrance, transition and class sizes change.

Estimates of the influence of different fertility patterns and rates of growth of enrollment on the number of students and teachers in an hypothetical educational system appear in ref. (8). These results are summarized in Table IV-1-2. In this Table, it can be seen that, as predicted by the theoretical model above, the rate of growth of the number of teachers required is equal to the rate of growth of enrollment.

In Table IV-1-3, estimates of rates of growth of population, enrollment, and of teachers required under different assumptions for enrollment rate and teacher/student ratios are presented, using Brazilian data. Similar results are reported in reference (2) for Ceylon, Colombia, Tunisia and Tanzania.

An important consequence of the relationship between number of births and enrollment appears when the number of births oscillates in time. In this case it is possible that teachers coming from periods with low birth rates will teach generations from periods having high birth rates, and vice versa. This means that the patterns of population growth might tend to produce large supplies of teachers during the periods of lowest demand and vice versa. This fact is part of the reason for periodic oversupplies of teachers, such as is occuring in the U.S.A. at the present time.

Two problems complicate the relationship between population growth and enrollment. The first is that enrollment is also determined by per capita

TABLE IV-1-2

Comparison of different fertility rates, rates of growth of school enrollment, and of number of teachers required, obtained with simulation model

Time horizon years	Fertility rate per 1,000 women		Rate of growth of school age population	Rate of growth of enrollment	Rate of growth of no. of teachers needed
	Begin. period	End period			
40	1254.89	1254.89	2.90	4.70	4.70
	1254.89	941.17	2.38	4.17	4.17
	1254.89	627.44	1.74	3.52	3.52
30	1254.89	1254.09	2.73	5.14	5.14
	1254.89	941.17	2.25	4.63	4.63
20	1254.89	1254.89	not avail.	6.18	6.18

Source: Reference (8)

TABLE IV-1-3

Brazil: Rates of Growth of Enrollment, Number of Teachers and Classrooms, under several assumptions of population growth.

Rates	A	B
Population growth, 1965	30.5	30.5
Population growth, 2000	24.0	14.0
Enrollment		
Elementary	31.5	20.8
Gimnasio	58.1	49.4
Colegio	90.0	82.3
Number of teachers		
Elementary	31.1	20.3
Gimnasio	58.1	48.3
Colegio	90.9	83.1
Number of classrooms		
Elementary	31.4	20.6
Gimnasio	58.1	50.0
Colegio	89.5	83.1

Source: Reference (6)

income. As a consequence, population growth tends to increase enrollment because of the increase in the number of children. but also tends to decrease enrollment because it tends to cause a decrease in per capita income. The final effect might be positive or negative, depending upon the relative magnitude of the two trends.

The second problem is that created by the need to provide education to the backlog of children who are of school age, but who did not enter the educational system at their first opportunity. Because of this, a large number of children approximately 5 through 15 years of age remain outside the system, and any attempt to bring them into it will overtax its facilities. A method for minimizing the investment needed to assimilate this backlog appears in Reference (3).

IV-2 HEALTH AND EDUCATION

IV-2-1 Introduction

In this section the influence of the mother's health conditions before the birth of her child and those of the child attending school on educational achievement will be studied. These analyses do not cover all the possibilities. In the case of the impact of health on education, as in that dealing with the influence of health on physical and mental abilities, studies covering genetic factors, prenatal and delivery conditions, and total personal history are needed. However, again, the necessary investigations do not seem available.

IV-2-2 Pregnancy Conditions and Reading Achievement in Childhood

In this section, the methods used and results obtained in references (1) and (2) will be described. In these references a sample of 372 white boys

with IQ's of 85 or more on the Binet scale, ages 10 to 14, with reading retardation of 2 years or more. were matched with 372 normal readers. The vital statistics and hospital records of their families were studied. Due to lack of data for some cases studied, the sample was reduced to 250 cases and the respective controls. The results obtained and summarized in Table IV-2-1 show that the proportion of pregnancies and deliveries with complications and the average weight at birth are significantly different for the children in the two samples.

IV-2-3 Physical Health Conditions of Children Attending School and their Relationship to Achievement

In this section, the method used in reference (1) for evaluating the relationship between health conditions and scholastic achievement will be described.

A high school on the North side of Pittsburgh, Pa. was investigated. The following samples were used:

1. A random sample of 195 students. A health index was given to them as follows: 1 for students with uncorrectable defects in vision, hearing or speech, 2 for students with correctable but not yet corrected defects, 3 for students with corrected defects, and 4 for students without defects.

2. Forty students with health index 1 were matched in age, sex, race, IQ and grade level with 40 students having health index 4.

3. Forty students with health index 1, plus 40 with health index 2, were matched with 80 students having health index 4.

TABLE IV-2-1

Pregnancy Conditions and Reading Ability for Children with Reading Disorders and Normal Children

Conditions	Children with Reading Disorders	Normal Children
Average Mother's Age (years)	26.68	26.63
Average Father's Age (years)	30.45	30.05
Average No. of Previous Pregnancies	1.32	.93
Percentages of Cases with Pregnancy and Delivery Complications	51.21*	24.39*
Average Hours of Labor for Delivery	12.61	11.95
Average Weight at Birth (grams)	3290.20*	3360.25*

*Significant differences with a confidence level of .05. In the case of average weight at birth the significant difference is actually between percentage with weight under 2500 grams and not between average weight at birth as stated above.

Source: Reference (1)

These samples were studied with correlation analysis. The results appear in Table IV-2-2, and show that indices of health and of achievement are correlated. It should be noted that the application of more sophisticated statistical methods, such as analysis of variance, to these samples could provide additional evidence of the relationship between health and educational achievement.

IV-2-4 Mental Health Conditions of Children Attending School and their Achievement

The question of the influence of mental health on reading and numerical achievement is studied in reference (1) using a sample of 531 students.

The students were classified by sex and grade. The following 13 tests were administered to them: one IQ test, one test of reading and one of numerical achievement, five tests of creativity and five of psychological health.

The statistical analysis of the data is not completely satisfactory. No attempt seems to have been made to determine - say through factor analysis - whether all the tests of psychological health measured the same characteristic of the subjects, and if not, how many basic characteristics could be defined. Only a matrix of correlation coefficients for each sex and grade among the scores obtained in the different tests seems to have been computed. These correlation coefficients do not reflect - as analysis of covariance would - whether a general trend linked poor psychological health measured with all the tests and achievement.

The main conclusion presented is that "the relationship between psychological health and cognition (including achievement) appears to be rather weak although quite variable. The mean of the correlations was .04, and the range was from -.56 to +.56."

TABLE IV-2-2

Correlations between health conditions and scholastic achievement

Sample	Size	Correlation with	
		verbal achievement	mathematical achievement
I	195	.101 *	.137 *
II	40	.207 *	.258 *
III	80	not avail.	.179 *

Significant at a 10% Confidence Level

Source: Reference (1)

Given the limitation of the statistical analysis, it is not possible to put much confidence in the results mentioned above, despite that a superficial inspection of the tables of correlation coefficients gives the impression that the conclusions above are quite justified.

IV-3 THE INFLUENCE OF NUTRITION ON EDUCATIONAL ACHIEVEMENT

The nutritional conditions of children can affect their educational achievement in two ways. First, there is the influence of prenatal and early childhood malnutrition on the mental development of a child, and second, the influence of malnutrition on every day performance and development as the child grows. These two effects are studied below.

IV-3-1 Impact of Prenatal and Early Childhood Malnutrition on Educational Achievement

In reference (2), the information in Table III-3-8, column 2 and in Table IV-3-1 is used to estimate the average number of years of education that the population of a country should have, assuming that all conditions except level of nutrition are the same as those existing in the United States. By using this approach it is possible to study the relationship between mental deficiency of a nutritional origin and educational achievement. The figures in Table IV-3-1, adopted from reference (1), describe the educational achievement of one million children in the U.S., classified by a score on the Army General Classification Test. This score may be considered equivalent to IQ for the purposes of this study.

The case of Ecuador will be used as an example of the computations made to estimate educational achievement. According to the results in Table III-3-8, column 2, the average IQ in that country is 85.4. If this is the case, the

TABLE IV-3-1

Number of Persons of Different Intelligence Levels in a Group of 1,000,000 finishing elementary school who reach different educational levels (U.S.A. 1949)

Score on Army General Classification Test (1)	Total reference group (2)	Number entering high school (3)	Number graduating from high school (4)	Number entering college (5)	Number graduating from college (6)
0-37	889.	41.	0.	0.	0.
38-42	1099.	78.	2.	0.	0.
43-47	2248.	234.	10.	0.	0.
48-52	4373.	643.	41.	0.	0.
53-57	7934.	1582.	151.	0.	0.
58-62	13497.	3561.	488.	16.	0.
63-67	21569.	7250.	1368.	87.	3.
68-72	32330.	13497.	3374.	320.	20.
73-77	45600.	22800.	7296.	935.	83.
78-82	60648.	35249.	14090.	2253.	286.
83-87	75239.	49704.	24031.	4560.	816.
88-92	88007.	64751.	36480.	8162.	1933.
93-97	96671.	77063.	49704.	12768.	3894.
98-102	99863.	84815.	61104.	17601.	6703.
103-107	96671.	86639.	67943.	21797.	10123.
108-112	88007.	81623.	68399.	24213.	12859.
113-117	75239.	71591.	63383.	24441.	15002.
118-122	60648.	58824.	53808.	22526.	15504.
123-127	45600.	44779.	42316.	19015.	14409.
128-132	32330.	32011.	30825.	14820.	12084.
133-137	21569.	21432.	20930.	10716.	9302.
138-142	13497.	13452.	13224.	7205.	6521.
143-147	7934.	7889.	7798.	4510.	4213.
148-152	4373.	4368.	4332.	2640.	2522.
153-157	2248.	2248.	2234.	1427.	1386.
158-162	1099.	1099.	1094.	734.	720.
163-	889.	889.	885.	620.	616.
TOTAL	1,000,000.	787962.	575467.	201550.	119015.

Source: Adapted from reference (1).

normal distribution of the population by level of intelligence will be that appearing in column 2 of Table IV-3-2. This distribution is comparable to that in column 2 of Table IV-3-1. While the distribution in this Table is centered around an IQ of 100, that in Table IV-3-2 is centered around one of 85.

Next, it is assumed that the proportion of persons passing from one educational stage to the next in Table IV-3-1 is also valid for the case in Table IV-3-2. This assumption makes it possible to compute the values in the other columns of Table IV-3-2. The total of each of these columns gives the number of persons reaching the advanced stages of education for a population with a mean IQ of 85. These totals, expressed as percentages of the total in the first column, also appear in Table IV-3-2.

With the total in the last line of Table IV-3-2 and the assumption that, for the first column, the average number of years of education is 3, for the second column, the average is 9, for the next column 15, and for the last, 18, it is possible to compute the average number of years of education for a population with mean IQ 85. This estimated mean in the case of Ecuador is 7.46. This mean can be interpreted to be the average number of years of education that the population of Ecuador should have, according to the IQ of its population as determined by nutritional conditions and assuming that all other conditions in education as those of the U.S. The averages for Ecuador and the other countries studied are presented in Table IV-3-3, column 2. These results are compared in the same Table with the actual educational achievement of those populations.

In Table IV-3-3 it may be observed that the actual averages fall below those computed when only nutritional conditions are considered. The reason

TABLE IV-3-2

Computation of Educational Achievement: The Case of Ecuador

Estimated IQ (1)	Total Reference Group (2)	Number entering high school (3)	Number graduating from high school (4)	Number entering college (5)	Number graduating from college (6)
0-37	889.	40.	0.	0.	0.
38-42	1098.	78.	2.	0.	0.
43-47	2248.	233.	10.	0.	0.
48-52	4373.	642.	41.	0.	0.
53-57	7934.	1582.	151.	0.	0.
58-62	13497.	3561.	48[illegible].	15.	0.
63-67	21568.	7250.	1367.	87.	3.
68-72	32330.	13497.	3374.	320.	19.
73-77	45599.	22799.	7295.	934.	82.
78-82	60647.	35248.	14090.	2252.	286.
83-87	75239.	49703.	24031.	4559.	816.
88-92	60647.	44621.	25138.	5624.	1332.
93-97	45599.	36350.	23445.	6022.	1836.
98-102	32330.	27458.	19781.	5698.	2170.
103-107	21568.	19330.	15159.	4863.	2258.
108-112	13497.	12518.	10490.	3713.	1972.
113-117	7934.	7549.	6684.	2577.	1582.
118-122	4373.	4241.	3879.	1624.	1117.
123-127	2248.	2207.	2086.	937.	710.
128-132	1098.	1088.	1047.	503.	410.
133-137	889.	883.	862.	441.	383.
138-142	0.	0.	0.	0.	0.
143-147	0.	0.	0.	0.	0.
148-152	0.	0.	0.	0.	0.
153-157	0.	0.	0.	0.	0.
158-162	0.	0.	0.	0.	0.
163	0.	0.	0.	0.	0.
Totals as % of total in column 2	100.0	63.8	35.0	8.8	3.3

Source: Reference (2).

TABLE IV-3-3

Comparison of the actual average number of years of education and the average estimated from information on nutrition and intelligence

Country (1)	Average estimated from information on nutrition and IQ (2)	Actual Average (3)	Explained difference (4)
Africa			
Congo	6.2	0.8	35.9
Ethiopia	7.5	n.a.	n.a
Gambia	8.1	n.a	n.a
Kenya	8.1	n.a	n.a
Nigeria	8.1	n.a	n.a
Sudan	8.7	2.2	8.4
America, North			
Canada	9.3	9.0	1.9
Guatemala	8.1	2.6	18.2
Jamaica	9.3	5.9	0.2
Mexico	8.1	3.4	20.7
U.S.A.	9.3	8.6	0.9
America, South			
Bolivia	8.1	0.5	13.8
Chile	9.3	5.7	0.2
Colombia	7.5	4.8	40.9
Ecuador	7.5	3.6	32.2
Peru	7.5	2.0	25.4
Uruguay	9.3	5.1	0.2
Venezuela	8.7	0.8	7.0
Asia			
Burma	7.5	2.6	27.5
India	6.2	3.1	49.4
Indonesia	7.5	2.6	27.7
Israel	9.3	7.2	0.3
Japan	9.3	7.6	0.4
Jordan	8.1	3.1	19.8
Lebanon	9.3		
Malaysia	8.1	3.4	20.6
Pakistan	6.2	0.5	34.6
Philippines	8.1	4.9	27.4
Taiwan	9.3	2.0	0.1
Thailand	7.5	0.2	20.3
Vietnam, North	6.2	3.6	45.3

TABLE IV-3-3 (cont.)

Country (1)	Average estimated from information on nutrition and IQ (2)	Actual Average (3)	Explained difference (4)
Europe			
Austria	9.3	n.a	n.a
Belgium	9.3	n.a	n.a
Czechoslovakia	9.3	4.1	0.1
Germany, E.	9.3		
Finland	9.3	2.8	0.1
France	9.3	6.4	0.2
Hungary	9.3	6.8	0.3
Italy	9.3	4.9	0.1
Netherlands	9.3	7.9	0.5
Norway	9.3	9.7	-1.9
Poland	9.3	3.8	0.1
Switzerland	9.3	4.9	0.1
U.K.	9.3	6.8	0.3
U.S.S.R.	9.3	5.2	0.2
W. Germany	9.3		
Oceania			
Australia	9.3	n.a.	n.a

Source: Reference (2).

for this is not difficult to find. The actual average number of years of education depends not only upon nutritional conditions, but also upon many other factors. The values obtained with the following formula are presented in column 4 of Table IV-3-3.

$$\frac{MAX - VN_i}{MAX - AN_i} * 100$$

where

MAX = 9.3, i.e., the average number of years of education in the U.S.

VN_i = average for country i computed from nutritional data

AN_i = actual average for country i computed from census data.

To understand these values it should be observed that MAX - VN_i can be interpreted as the deficiency in the average educational achievement due to deficiencies in nutrition, while MAX - AN_i is the total educational deficiency; hence the formula above gives the percentage of educational deficiency explained by nutritional factors.

IV-3-2 Concurrent Malnutrition and Educational Achievement

A first approach to the study of the influence of nutritional status on educational achievement could be based upon data in Table III-4-10 used to evaluate the influence of nutrition on working capacity. However, information on the influence of working capacity on educational achievement is not available.

Attempts to relate nutritional conditions directly to educational achievement appear in references (1), (2), (3) and (4). Those in reference (3) will be commented upon below. As mentioned in Section III-4-4, this reference shows the effect of a thiamin supplement on four groups of children. The results

with respect to educational achievement appear in Table IV-3-4. As was the case with the results for intelligence tests, those in Table IV-3-4 do not show any clear relationship between educational achievement and thiamin supplement.

TABLE IV-3-4

Educational Achievement of Four Groups of Children
with Different Thiamin Supplements

	Group	Index of Achievement		
		Initial	End 1st year	End 2nd year
Educational Achievement, total score (Metropolitan test)	1	100.	122.2	151.9
	2	100.	98.3	122.0
	3	100.	96.9	115.6
	4	100.	115.4	138.5

SOURCE: Reference (3).

REFERENCES

Section IV-1-1

(1) Correa, Hector
The Economics of Human Resources
Second printing
North Holland Publishing Co., Amsterdam, 1967

Section IV-1-2

(1) Chau, T. N.
Demographic Aspects of Educational Planning
UNESCO, IIEP, Paris, 1969

(2) Chau, T. N.
"The Effect of Population Growth on the Development and Cost of Education in Developing Countries"
Mimeo
UNESCO, IIEP, Paris, 1971

(3) Correa, Hector
"An Optimum Enrollment Policy for Developing Countries,"
In Richard H. P. Kraft
Education and Economic Growth
Florida State University, 1968

(4) Correa, Hector
Quantitative Methods in Educational Planning
UNESCO International Textbook Co., 1969

(5) Correa, Hector
"Quantitative Methods in Population and Health Planning"
Mimeo, University of Pittsburgh, 1972

(6) Merrick, T. W.
"Population Growth and the Costs of Expanding and Maintaining the Brazilian Education System, 1965-2000"
Mimeo
No date or place of publication

(7) Siddiqui, F. and Zaharchuk, T. M.
"A Simulation Model for Projecting Live Births, Population and Enrollment"
In Macleod (ed.)
Demography and Educational Planning
The Ontario Institute for Educational Planning, Toronto, 1970

(8) Vyas, M. D.
"Planning for Universal Primary Education Under Alternative Assumptions of Fertility Patterns and Target Dates"
Ph.D. Dissertation
Department of Economics, University of Pittsburgh, 1971

Section IV-2-2

(1) Kawi, A. A., and Pasamanick, B.
"Association of Factors of Pregnancy with Reading Disorders in Childdhood"
Journal of the American Medical Association
Vol. 166, No. 12, p. 1420-1423
March, 1958

(2) Kawi, A. A., and Pasamanick, B.
Prenatal and Paranatal Factors in the Development of Childhood Reading Disorders
Monographs of the Society for Research in Child Development
Vol. 24, No. 4, 1959

Section IV-2-3

(1) Hassouna, W. A.
A Decision Model for School Health Services
Ph.D. Dissertation
Graduate School of Public and International Affairs
University of Pittsburgh
Mimeo, 1968

Section IV-2-4

(1) Jackson, P. W., Getzels, J. W., and Xydis, G. A.
"Psychological Health and Cognitive Functioning in Adolescence"
Child Development
Vol. 31, pp. 285-298, 1960

Section IV-3-1

(1) Correa, Hector
The Economics of Human Resources
Second printing
North Holland Publishing Co., Amsterdam, 1967

(2) Correa, Hector
"Nutrition, Health and Education"
Department of Economics and Center for Family Health and Population Dynamics
Tulane University, Mimeo

Section IV-3-2

(1) Boyd, A. M.
"Malnutrition, Endemic Diseases and Education: the Nigerian Case"
Meeting of Experts on Deprivation and Disadvantage in Developing Countries
UNESCO Inst. for Education, Hamburg, 1970

(2) Harrell, R. F.
Effect of Added Thiamin on Learning
Teachers' College
Columbia University, New York, 1943

(3) Harrell, R. F.
Further Effects of Added Thiamin on Learning and Other Processes
Teachers' College
Columbia University, New York, 1947

(4) Smart, K. F.
Malnutrition, Endemic Disease and Education: An Overview
Meeting of Experts on Deprivation and Disadvantage in Developing Countries
UNESCO, Inst. for Education, Hanburg, 1970

CHAPTER V

INTERACTION AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION AND EMPLOYMENT

V-1 INTRODUCTION

In order to study the influence of population size and growth, health and nutrition - through their impact on physical and mental capacities - on the level and rate of economic growth, the questions of participation in the labor force, of employment and of the use made of employed workers must be considered.

In Chapter III some observations were made on labor force participation. In particular, the question of the interdependence of the participation of women in the labor force and the size of their families was studied in III-1-2. These topics will not be considered again in this Chapter.

The next question deals with the relationship between working capacity, employment, and productivity. It will be studied below with the aid of Leibenstein's model. (See references 1 to 5).

A rigorous presentation and analysis of this model is made in Section V-1-1. This analysis indicates that it has some limitations. In Section V-1-2 the model is used to show that under certain fairly general assumptions, government expenditures on health and nutrition of the labor force will increase the demand for labor, and if labor is fully employed, will increase wages.

V-2 THE MODEL

A production function

$$Y = f(E) \qquad \text{V-2-1}$$

where

Y output

E total workers' effort

is assumed. Two characterizations of this function will be considered below.

In both of them it will be assumed that the function in V-2-1 is continuous and has continuous first and second derivatives respect to E, and that

$$\lim_{E \to \infty} f'_E \leq 0$$

For the form A of the function in V-2-1 it will be assumed that

$$\lim_{E \to 0} f'_E = \infty$$

and that

$$f''_E < 0$$

for all E.

Form B of the function in V-2-1 will be characterized as follows:

$$\lim_{E \to 0} f'_E = 0$$

$$f''_E \geq 0 \text{ for } E \leq \hat{E}$$

$$f''_E < 0 \text{ for } E > \hat{E}$$

Form A of the production function has a decreasing marginal productivity of effort, while in form B the marginal productivity increases from 0 up to a maximum for $\hat{E}$ and then decreases again.

The workers' effort is described by the function

$$E = g(w) N \qquad \text{V-2-2}$$

w wages per worker

N number of workers employed.

The function g (w) is an index of working capacity as determined by expenditures in health and nutrition. This function is an abstraction of the results in III-2 and III-3. In addition, it will be assumed that these expenditures are determined by the level of wages. As a consequence, if wages are low, then the health and nutritional conditions of the workers will be low, and as a result their working capacity will be low also. The function g (w) will be characterized as follows:

$$\lim_{w \to o} g(w) = o$$
$$\lim_{w \to \infty} g(w) = 1$$
$$\lim_{w \to o} g'_w > o$$
$$\lim_{w \to \infty} g'_w = o$$

and

$$g''_w < o \text{ for all } w.$$

Two consequences of these characterization will be used below First, applying L'Hospital theorem it follows that

$$\lim_{w \to o} w/g(w) = \begin{cases} >0 \\ <\infty \end{cases}$$

A second property is that the average working capacity generated by wages, i.e., $g(w)/w$ is a decreasing function of w. To prove this, observe that from the application of the mean value theorem of differential calculus to $g(w)$ in the closed interval $(0, w)$ one obtains $g(w)/w = g'_w(w^o)$ where $0<w^o<w$, and since g'_w is a decreasing function of w it follows that $g(w)/w \geq g'_w$ as required.

With the elements presented so far it is possible to specify the demand for labor. To do so, it is assumed that the demand for effort is derived from the conditions of maximization of profits. However, effort as such cannot be obtained. It is always embodied in workers. As a consequence, the number of workers employed is the variable under the control of the entrepreneurs. With the notation above, the problem just described is to maximize profits P with respect to N, i.e.,

$$P = f(E) - wN$$

subject to condition V-2-2.

The first and second order conditions for maximization are:

$$P'_N = f'_E\, g(w) - w = 0 \qquad \text{V-2-3}$$

and

$$P''_N = f''_E\, g^2(w) < o \qquad \text{V-2-4}$$

With conditions V-2-3 and V-2-4 satisfied, condition V-2-3 is an implicit expression of the demand for labor in terms of w. Condition V-2-4 is satisfied

if f'_E is decreasing.

With respect to the supply of labor it will be assumed that a fixed number of workers offers their services whatever the wages paid. This assumption is quite compatible with the conditions in developing countries having either very primitive unemployment insurance, or none at all. It is this fact that creates the puzzle of why an over supply of labor does not reduce salaries to zero. Leibenstein affirms that the model above solves the puzzle. To verify whether this is the case, it is necessary to determine whether the equation $N(w) = N_s$, where $N(w)$ is the demand for labor defined by V-2-3 and N_s is the fixed supply of labor, has a solution $\hat{w}$ such that $\hat{w}>0$.

Under form A of the production function it can be shown that Leibenstein's statement is correct. For this, observe that there is a value of $w>0$ such that

$$f'_N(N_s) - w/g(w) > 0$$

where the notation emphasizes that N has been replaced by N_s. Also from the assumptions it follows that

$$\lim_{w\to\infty} [f'_E(N_s) - w/g(w)] = -\infty$$

and, from the continuity of the function

$$f'_E - w/g(w)$$

the existence of $w > 0$ follows.

However, for form B of the production function it can be shown that there are cases where a $\hat{w}>0$ does not exist. For example, for the production function

$$Y = k_1 E^2 - k_2 E^3 \quad k_1, k_2 > 0$$

and the working capacity function

$$g(w) = w/(1+w)$$

it can be shown that the demand for labor function has the implicit form

$$-1 + (2k_1 N - 3)w + (-3 + 2k_1 N - 3k_2 N^2)w^2 - w^3 = 0$$

and that this equation, for $N = 3/2k_1$ has only one negative and two complex roots. For this observe that the continuous function

$$x = -1 - 27k_2 w^2/4k_1^2 - w^3 \qquad \text{V-2-5}$$

ranges from $(-\infty,\infty)$ to $(\infty,-\infty)$ and has a minimum for $w=-27k_2/6k_1^2$ in which $x<0$. This implies the existence of root $w<0$. The function V-2-5 also has a maximum for $w=0$ with $x=-1$. This implies that the only zero of x is for $w<0$, and that the other two roots of the cubic in V-2-5 are complex.

V-3 THE IMPACT OF BETTER HEALTH AND NUTRITION ON EMPLOYMENT AND WAGES.

The object of this section is to use the model in Section V-2 to determine the effect of exogenous changes in the health and nutrition conditions of the workers and their impact on working capacity on the demand for labor. For this it will be assumed that an exogenous variable h influences the working capacity function. The characterization of working capacity as a function of h is basically the same of a function of w.

From this function it follows that

$$\frac{\delta N}{\delta h} = -(f''_E E + f'_E)\, g'_h / P''_N$$

Since $P''_N < 0$ from condition V-2-4, and $g'_h > 0$ by assumption it follows that N will increase with h if $f''_E E + f'_E > 0$.

This condition might seem unduly restrictive. However, it is easily shown that in an economy with a CES production function, it will always be satisfied if $\sigma > 1 - wN/Y$ where σ is the CES parameter. This means that exogenous expenditures in health and nutrition of the labor force increase the demand for labor when σ is larger than the share of capital in the economy, as is the usual case. It will usually occur for economies with a Cobb-Douglas production function. Only in extreme cases of complementarity between capital and labor will increases in h reduce the demand for labor.

The impact of changes in the conditions of health and nutrition on wages, when demand and supply of labor are equal and fixed, can be studied from the expression

$$\delta w/\delta h = -(f''_E E + f'_E) g'_h / \left[(f''_E E + f'_E) g'_w - 1\right] \qquad \text{V-3-1}$$

This equation shows that wages will increase only if the demand for labor increases, i.e., if the numerator of V-3-1 is positive and the denominator is

negative. However, this will be the case as can be seen as follows: the denominator of V-3-1 can be put in the following form

$$[P''_N N + f'_E g\ (w)]\ \ g'_w - f\ (w) \qquad \text{V-3-2}$$

without affecting the sign of the numerator. With equation V-2-3, equation V-3-2 becomes

$$P''_N N g'_w + w g'_w - g\ (w) \qquad \text{V-3-3}$$

and the first term of V-3-3 is negative since $P''_N < 0$ and Ng'_w is positive. The last two terms of V-3-3 are less than zero, since $g\ (w)/w$ is monotonically decreasing.

REFERENCES

(1) Ezekiel, H.
An Application of Leibenstein's Theory of Underemployment
Journal of Political Economy
Vol. 58, October, 1960, pp. 511-517

(2) Leibenstein, H.
Economic Backwardness and Economic Growth
Chapter 6
New York: John Wiley, 1967

(3) Mazumdar, D.
The Marginal Productivity Theory of Wages and Disguised Unemployment
The Review of Economic Studies
Vol. 26, No. 71, June, 1959, pp. 190-197

(4) Oshima, H.T.
Underemployment in Backward Economies, An Empirical Comment
Journal of Political Economy
Vol. 56, No. 3, June, 1958, pp. 256-264

(5) Yotopoulos, P.A.
The Wage-Productivity Theory of Underemployment: A Refinement
Review of Economic Studies
Vol. 32, 1965, p. 59

CHAPTER VI

INTERACTION AMONG THE DETERMINANTS OF WELL-BEING, POPULATION, HEALTH, NUTRITION, EDUCATION AND PRODUCTION

VI-1 INTRODUCTION

Studies of the influence of population growth, nutrition and health on mental and physical abilities, and thus on education were presented in Chapters III and IV. The nature of these studies made it possible to consider the isolated impacts of each of the determinants considered, to the exclusion of the others. This approach will be used in Sections VI-2 and VI-3 for studying the impact of health and nutrition on the economy. However, in the case of the influence of population, health and nutrition on the economy, the most valuable analyses include a study of the simultaneous influence of these and other determinants. These analyses will be presented in Section VI-4.

VI-2 HEALTH AND PRODUCTION

VI-2-1 Introduction

As observed, in this section attention will be given to the study of the influence of health on the economy, to the explicit exclusion of other determininants of production, such as nutritional conditions of the labor force, their education, etc. In this section the main points of references (1) to (10) will be briefly summarized.

To study the economic consequences of health deficiencies, it is useful to observe that

a) they include, on the one hand, the costs of preventing and curing diseases, and on the other hand, the production lost due to the reduction in the size of the labor force and/or its working capacity;

b) their study can be subdivided according to two criteria: the magnitude of the damage caused by deficient health, and the coverage of the damaging factors. Presence or absence of disease and death will be considered here as the only indices of the magnitude of the damage, despite that a finer gradation is possible at least in the case of disease. The coverage can be partial, i.e., of one or several diseases, or total, i.e., of health conditions in general.

The estimation of the economic resources used to prevent or cure disease does not present any conceptual problems. Basically, such an estimate can be obtained by adding together expenditures for doctors, hospitals, medicines, etc. However, it should be clear that when a large number of persons is considered, the size of the undertaking creates serious operationl problems, even when sampling techniques are used.

A point that needs additional explanation arises from the fact that the production of an industry is by definition equal to salaries, profits and the rents it pays. This is true regardless of whether the industry produces goods, such as foods, or services, such as collection of refuse. As a consequence, a large portion of the expenditures considered to be costs of disease appear in the national accounts as contributions to production made by the health industry. At present, no satisfactory method of avoiding this contradiction seems to exist.

Three methods for estimating the impact of mortality on the working capacity of the labor force were described in Section III-2-2. The first method provides estimates of days lost due to deaths, in the same year in which the deaths occur. With the second method, the difference between the size and the labor force that could be expected with reduced mortality and the actual labor force is computed. With the third method, the difference

between actual labor force and the labor force that could be expected if past mortality had not changed is computed. Clearly, the differences obtained with methods 2 and 3 can be transformed to number of days that could be gained (in the case of method 2) or that actually have been gained (in the case of method 3).

Estimations of the number of days lost due to disease are presented in Section III-2-3.

Several ways that the results described above can be used to estimate the influence of morbidity and mortality on economic production are described below.

VI-2-2 The Impact on Production of One or Several, But Not all, Diseases

Numerous partial studies dealing with the impact on production of one or several, but not all diseases have been made. A list of them, classified by the disease to which they refer, appears among the references of this section. The methods used in these studies are the same as those used in analyzing the impact on production of all diseases. As the specific data and results of the studies have only a topical value, no additional space will be devoted to them here.

VI-2-3 Estimates of the Impact of all Diseases, Obtained by Aggregating Detailed Data

Perhaps the only study that deals with the influence on production of all health conditions, aggregating the influence of each of them, appears in reference (1). Table VI-2-1 was obtained from that reference.

The direct expenditures in Table VI-2-1 are computed by adding expenditures on Personal Services and supplies, and non-personal such as medical research, construction, government public health activities, voluntary agencies, and net cost of insurance.

Table VI-2-1

USA Economic Cost of Disease in 1963

DIAGNOSIS	TOTAL	DIRECT EXPENDITURES	PRODUCTION LOST		
			TOTAL	MONTHLY	MORBIDITY
	Amount (millions of dollars)				
TOTAL	$58,036.1	$34,263	$23,773.1	$2,731.0	$21,042.2
fective and parasitic diseases	1,392.0	501.9	890.1	32.1	858.0
Tuberculosis	645.0	241.4	403.6	18.3	385.2
Other	747.1	260.6	486.5	13.7	472.8
oplasms	2,613.5	1,279.0	1,334.5	483.8	850.7
lergic, endocrine, metabolic, nutritional diseases	1,510.1	902.9	607.2	67.7	539.5
seases of blood and blood-forming organs	204.4	155.9	48.5	7.3	41.3
ntal. psychoneurotic and personality disorders	7,035.7	2,401.7	4,634.0	10.0	4,624.0
seases of nervous system and sense organs	3,241.7	1,416.4	1,825.3	299.8	1,525.5
seases of circulatory system	6,412.9	2,267.3	4,145.6	1,225.9	2,919.7
seases of respiratory system	4,886.8	1,581.1	3,305.7	139.4	3,166.3
seases of digestive system	5,501.7	4,158.1	1,343.6	123.4	1,220.1
seases of genitourinary system	1,756.3	1,210.2	546.1	48.3	497.8
ternity	1,425.4	1,391.1	34.3	2.1	32.2
seases of skin and cellular tissue	379.8	248.1	131.7	3.3	128.4
seases of bones and organs of movement	2,660.6	1,430.0	1,230.6	5.6	1,225.0
ngenital malformations	161.5	113.0	48.5	6.7	41.8
rtain diseases of early infancy	30.3	30.3	------	-----	-------
mptoms, senility and ill-defined conditions	945.9	623.7	322.2	33.7	288.5
juries	3,755.2	1,702.8	2,052.4	241.7	1,810.7
ecial conditions and examinations	977.6	965.8	11.8	-----	11.8
scellaneous	1,411.1	150.1	1,261.0	-----	1,261.0
t distributed	11,733.0	11,733.0			

SOURCE: Reference (1)

The cost of deficient health in production lost is estimated from figures on days lost due to death during the year in which the disease occured, and days lost due to disease. These figures are corrected, taking into consideration labor force participation, employment, etc.

VI-2-4 Estimates of the Economic Impact of All Health Conditions, Obtained Using Aggregated Health Indices

Most studies dealing with the total economic impact of health conditions do not explicitly aggregate the impact of all individual diseases, as is done in Section VI-2-3. Instead, over-all health indices such as total number of days lost, mortality rates, life expectancy, etc. are used. What is lost in detail when these methods are used is gained in flexibility.

This will be seen in the two studies below, which deal only with the effect of reduced mortality. It seems that no attempt has been made to complete them by including direct cost of disease, on the one hand, and information on morbidity, on the other.

VI-2-5 Percentage of National Income Attributable to Reduced Mortality

Section III-2-2 Table III-2-2 presents estimates of the part of the labor force in 1960 attributable to the reduction of mortality rate since 1900. These estimates are reproduced in Table VI-2-2 columns (2) to (4).

Average wages and salaries in 1960 (or equivalent, for the self-employed) are used as a measure of the output attributable to labor. This average must be distinguished from income, which includes returns on property or capital.

Average earnings in 1960 multiplied by the number of working years added as result of reduced mortality yields the dollar estimates in Table VI-2-2, columns (5) to (7).

TABLE VI-2-2

Growth of U.S.A. National Income, 1900-1960, Contributable to Reduced Mortality

Year (1)	Work Force in 1960 if mortality rates had continued unchanged since Year Column (1) (2)	Additional Work Force in 1960 Attributable to Reduced mortality rates (3)	% by which 1960 work force raised (4) $=\frac{(3)x100}{(2)}$	Value of Added Labor Product in 1960 (5)	Percentage by which 1960 National Income Raised	
					Total (6)	Per Annum Equivalent (7)
1960	66.7	--	--	--	--	--
1950	66.4	0.3	0.5	$ 1,390	0.4	.04
1940	65.3	1.4	2.0	6,489	1.5	.07
1930	63.2	3.5	5.6	16,222	4.0	.13
1920	60.7	6.0	9.9	27,810	7.2	.18
1910	56.2	10.5	18.8	48,668	13.7	.26
1900	53.5	13.2	24.7	61,182	18.0	.27

Source Reference (2)

TABLE VI-2-3

Present value at an 8% discount rate of earnings that workers added to the labor force due to reductions in mortality would earn after 1960

Addition due to change in mortality up to 1960 since	Present value 10^9
1960	0
1950	12.0
1940	65.3
1930	194.7
1920	365.9
1910	649.2
1900	820.5

Source: Reference (1)

VI-2-6 Capital Formation Through Health

The method and results in reference (2) are summarized here. Resources used in health, as in other types of investment, produce returns over a period of years. Actually, some investments in health, such as the complete eradication of a disease, yield returns into perpetuity.

In particular, the present value of the future earnings of the workers whose presence in the labor force is attributable to improvements in life expectancy can be another index of the impact of health on the economy.

The present value of the earnings that the workers added to the U.S. labor force up to 1960 (Table VI-2-2, column 3) would obtain after 1960 appears in Table VI-2-3. A discount rate of 8% has been assumed in its computation.

If the discount rate used is assumed to be equal to the "internal rate of return" of the future stream of earnings,* the present value is equal to the capital needed to yield these future earnings. With reference to Table VI-2-3, 820.5 billion dollars is the capital that, at 8% interest, would produce the same amount of income as that produced by the workers added to the U.S. labor force up to 1960 by reductions of the mortality rate since 1900.

VI-3 NUTRITION AND PRODUCTION

Two types of studies have been made of the relationship that exists between nutrition and production when the other factors of production are

*The internal rate of return is the rate of discount which makes the present value of the benefits of an investment exactly equal to the present value of its costs. In a mathematical formula this is expressed as follows:

Let B_t $t=0,\ldots,n$ be the benefit of an investment

C_t its costs.

The internal rate of return is the discount rate δ that satisfies the equation

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+\delta)^t} = 0$$

For additional information see reference (1).

excluded. In the first type, no attempt is made to specify the mechanism through which the level of nutrition affects productivity. The characteristics of the relationship are investigated by means of statistical analysis. A study of this kind is reported in Section VI-3-1.

In the second type of study, an attempt is made to specify the mechanism for the influence of nutrition.

As already observed, it is useful to subdivide the influence of nutrition on working capacity into two parts. One is the influence of nutritional conditions during prenatal and early childhood development. These affect an individual's mental development, and as a consequence, his educational achievement, and finally, his productivity. The second influence is that of contemporary nutritional conditions on the productivity of workers.

Several attempts have been made to estimate the isolated effect of nutrition on productivity through its impact on mental abilities in early childhood. Two of these attempts will be described below. On the other hand, no attempt to estimate the isolated effect of nutrition on productivity through its impact on the current working capacity of the workers seems to be available. The only studies on this point integrate nutrition with several other determinants of the quality of labor. They will be discussed in Section VI-4.

VI-3-1 Statistical Studies of the Relationship Between Nutrition and Production

In reference (1), the relationship between per capita income (Y) at date t and per capita production of proteins ten years previously (i.e., per t-10) is studied. The lag is introduced in an attempt to establish that protein production is a determinant of future per capita income. The results obtained are presented in Table VI-3-1. The regression coefficients show a high interdependence between the two variables. Unfortunately, the method used does not

TABLE VI-3-1

Regressions of Per Capita Income on Per Capita Protein Supply, Lagged 10 Years

Y	X	a	b	R^2	Sample Size
1968	1957-59 per capita supply of proteins	-1277.65	30.21 (4.88)	.52	37
1968	1957-59 per capita supply of animal proteins	- 117.49	32.28 (3.74)	.68	37

SOURCE: Reference (1)

verify that increases in protein consumption bring about increases in per capita income. The reason for this is that the production of proteins in year t-10 might be determined by per capita income in year t-10, and the results in Table VI-3-1 might simply reflect the correlation between income per capita in year t and in year t-10. The fact that per capita income is more closely correlated with consumption of animal proteins than with consumption of total proteins might also explain the increase in R_2 between the first and second regressions in Table VI-3-1.

VI-3-2 Nutrition, Mental Ability and Production

In reference (3) an attempt is made to evaluate the impact on worker productivity of the deficiency in mental capabilities caused by early malnutrition. Two types of information are needed for this analysis. The first is the relationship between nutrition and mental ability discussed in Section III-3-3. The results in Table III-3-6, in particular, are used in this study.

The second type of data needed are those describing the relationship between mental ability and economic performance. Several studies of this question have been performed (1). A summary will be presented below of the study used in reference (3). In Table VI-3-2, the regression analyses of logarithms of monthly earnings on logarithms of scores in the Wechsler-Bellevue Test and on logarithms of age are presented. Regressions not presented in this Table showed that the education of the parents of the workers and of the workers themselves did not affect earnings significantly. The results suggest that a 10% change in Wechsler-Bellevue Test scores is associated with a 6 to 6.5% increase in earnings.

The next step is to combine the information on nutrition, weight and IQ for children up to 30 months of age in Table III-3-6 with that on IQ and

TABLE VI-3-2

Regressions of Earnings on IQ
Chilean data

Sample / Indep. Variables (1)	Construction workers (2)	Unemployed workers (3)	Pooled sample (4)
Intercept	4.12 (4.82)	3.08 (3.55)	2.65 (3.86)
log age	.87 (3.52)	1.06 (4.06)	1.23 (6.03)
	R^2 = .30	R^2 = .22	R^2 = .29
Intercept	3.23 (2.28)	2.82 (2.78)	1.92 (2.16)
log IQ	.87 (2.75)	.87 (3.74)	1.11 (5.49)
	R^2 = .21	R^2 = .19	R^2 = .25
Intercept	1.68 (1.25)	1.36 (1.26)	.34 (.38)
log age	.74 (3.08)	.79 (2.92)	.92 (4.48)
log IQ	.65 (2.26)	.60 (2.52)	.76 (3.83)
	R^2 = .41	R^2 = .30	R^2 = .39
Sample size	31	60	91

Figures in parenthesis are the t ratio of the coefficients.

Source: Reference (3)

earnings of adult workers in Table VI-3-2, to obtain the effect of changes in nutritional conditions during childhood on earnings during adult life. From Table III-3-6 it is estimated that if children increase in percentage weight with respect to the normal from 65-74% to 95-100%, their IQ scores will increase from 73 to 91. The results in Table VI-3-2 make it possible to estimate that this increase in IQ would bring about an increase in the discounted value of life time income of U.S. $340.00 (see Table VI-3-3). In this computation it is assumed that the person begins working at 15 years of age. The discount rate used is 10% and the reference age is 2 years. This age was chosen because the expenditures needed for improved nutrition would have to be made at this time.

Assuming that the increase in weight and IQ are obtained by feeding the children high protein milk, it is possible to estimate the cost of those increases. It reaches a total of U.S. $50.4 per child. This means that the net present value of the nutritional expenditures is U.S. $290. An idea of the importance of this quantity is obtained with the results in Table VI-3-4. This Table shows the internal rate of return (2)* of several types of investment, with that of nutrition being the largest.

VI-3-3 Nutrition, Mental Ability, Education and Productivity

In Section ~~III-3~~ VI-3 the relationship between nutrition, mental ability and education is explored. In particular, in Table III-3-8 estimates are presented of educational achievement in various countries under the assumption that the only limiting factor is deficient nutrition. All the other determinants of educational achievement are assumed to be the same as those existing in the U.S.A.

An extension of this approach is presented in reference (1) and summarized in this Section. The level of income that a group of countries could achieve under the assumption that every socio-economic condition except nutritional level is the same as in the U.S.A. is presented.

TABLE VI-3-3

Relationship Between Nutritionally Determined Change In IQ and Present Value of Lifetime Earnings

(Estimates for Chilean Data)

	INITIAL	FINAL	CHANGE
Weight as % of normal	65 - 74	95 - 104	30
IQ	72.8	90.8	18.0
Present value of increment in lifetime income US$			340

NOTE: Present value of income at age 2 for persons who begin working at age 15, 10 percent discount rate.

SOURCE: Elaborated from reference (3).

TABLE VI-3-4

Chile: Comparison of the Internal Rates of Return of Several Types of Investment

Type of Investment	Rate of Return
Physical capital	15%
Nutrition	19% - 25%
Education:	
Elementary	17%
Secondary	15%

SOURCE: Reference (3).

The starting point in these computations is income by level of education in the U.S.A. These data appear in Table VI-3-5.

Another basis for the computations is the estimate of population by educational level computed--but not presented-- in Section IV-3-1 (see last line in Table IV-3-2) with the nutritional data as a starting point. These two pieces of information are used to estimate the income that would correspond to a given country if all the determinants of per capita income were those in the U.S.A., except educational achievement determined by the mental development allowed by the existing nutritional conditions. In other words, the estimates in Table VI-3-6, column 2 can be interpreted as the level of income that the U.S.A. would have had in 1961 if the level of consumption and corresponding mental development and educational achievement had been those of the countries in column 1.

The percentage of income deficiency explained by the influence of nutritional factors on education and of education on income is also presented in Table VI-3-6, column 4. This percentage is computed with a formula similar to that used in Section IV-3-1.

As might be expected, these percentages are lower than those in Table IV-3-3, column 4. This is because educational achievement is more closely related to mental development than is income.

VI-4 SIMULTANEOUS INFLUENCE OF POPULATION, HEALTH, NUTRITION AND EDUCATION ON TOTAL PRODUCTION

In the previous sections, methods for estimating the impact of one isolated determinant on production have been presented, and their results revised and commented on.

The attempts that have been made to study simultaneously the influence of several factors of production and of several determinants of the quality of labor will be presented below. In these studies, the influence of each factor of determinant of the quality of labor is still evaluated by itself, but the fact that other factors and determinants exist is explicitly recognized.

TABLE VI-3-5

Income per capita per year by level of education U.S.
1961
data for/(in U.S. dollars)

No. of Years of education	Income
3	1009.67
9	2449.52
15	3673.67
18	5238.28

Source : Elaborated from reference (2) (Table 478)

TABLE VI-3-6

Comparison of actual per capita income and that estimated from information on nutrition, intelligence and education

Country (1)	Income estimated from information on nutrition, IQ and education (2)	Actual per capita income 1961 (3)	Explained difference (4)
Africa			
Congo	1789.0	92.0	31.7
Ethiopia	2088.4	55.0	19.3
Cambia	2248.7	n.a.	n.a.
Kenya	2248.7	87.0	13.10
Nigeria	2248.7	78.0	13.10
Sudan	2412.6	63.0	6.5
America, North			
Canada	2577.0	1947.0	0.0
Guatemala	2248.7	189.0	13.7
Jamaica	2577.0	316.0	0.0
Mexico	2248.7	262.0	14.2
U.S.A.	2577.0	2577.0	0.0
America, South			
Bolivia	2248.7	99.0	13.2
Chile	2577.0	379.0	0.0
Colombia	2088.4	263.0	21.1
Ecuador	2088.4	189.0	20.5
Peru	2088.4	179.0	20.4
Uruguay	2577.0	475.0	0.0
Venezuela	2412.6	648.0	8.5
Asia			
Burma	2088.4	57.0	19.4
India	1789.0	73.0	31.5
Indonesia	2088.4	131.0	20.0
Israel	2577.0	726.0	0.0
Japan	2577.0	306.0	0.0
Jordan	2248.7	129.0	13.4
Lebanon	2577.0	362.0	0.0
Malaysia	2248.7	356.0	14.8
Pakistan	1789.0	70.0	31.4
Philippines	2248.7	220.0	13.9
Taiwan	2577.0	161.0	0.0
Thailand	2088.4	96.0	19.7
Vietnam, North	1789.0	55.0	31.2

TABLE VI-3-6 (Cont.)

Country	Income estimated from information on nutrition, IQ and education	Actual per capita income	Explained difference
(1)	(2)	(3)	(4)
Europe			
Austria	2577.0	670.0	0.0
Belgium	2577.0	1196.0	0.0
Czechoslovakia	2577.0	680.0	0.0
E. Germany	2577.0	600.0	0.0
Finland	2577.0	794.0	0.0
France	2577.0	943.0	0.0
Hungary	2577.0	490.0	0.0
Italy	2577.0	516.0	0.0
Netherlands	2577.0	836.0	0.0
Norway	2577.0	1130.0	0.0
Poland	2577.0	475.0	0.0
Switzerland	2577.0	1428.0	0.0
U.K.	2577.0	1189.0	0.0
U.S.S.R.	2577.0	600.0	0.0
W. Germany	2577.0	927.0	0.0
Oceania			
Australia	2577.0	1316.0	0.0

Source: Reference (1).

These studies are based on models in which it is assumed that several independent variables are the cause of variations in the dependent variables. These basic models have many different levels of sophistication. The reasonable thought that the level of nutrition and health of the labor force should influence production is--for the question in study--the initial level. More advanced levels attempt to specify more precisely the indices that should be used to evaluate the variables and the characteristics of the relationship.

Two approaches that have been used to study the relationship of population, nutrition, health and other variables to production will be described below.

In the first, statistical techniques are applied to different indices of production, factors of production and qualities of labor.

The second approach is based on the theory of economic growth, in particular on the technique developed to disaggregate increments of productions due to technological change. This disaggregate can be achieved with or without recourse to the methods of regression analysis. Examples of both cases will be presented below.

VI-4-1 Statistical Studies of the Simultaneous Influences of Population, Health, Nutrition and Education on Production

The pioneering attempt to analyze the contribution of population, health, nutrition and education to economic development appears in reference (4). In this study, correlations among the most relevant indices of economic growth and quality of the population are used to evalute the statement that "as a rule, economic and social factors complement or support each other in the objective process of development". The work begun in reference (4) is completed and extended in references (1), (3) and (5). However, none of these studies attempts--perhaps with good reason--to actually specify the positive or negative contributions of population growth and improvements in health, nutrition and education on economic growth. Only correlation matrices are computed. One of the most systematic attempts to evaluate the influence of health on production, using only multiple regression, is that in reference (2). The five

TABLE VI-4-1

Regression Studies of the Relationship Between Agricultural Production and Capital, Labor, Health and Education

Country (Sample Units) (1)	Number of Observations (2)	Dependent Variable (3)	R (4)	Constant (5)	Cap. Z_1 (6)	Cap. Z_2 (7)	Cap. Z_3 (8)	Labor X_{11} (9)	Health X_{21} (10)	Health X_{22} (11)	Health X_{23} (12)	Health X_{24} (13)	Health X_{25} (14)	Health X_{26} (15)	Education X_{31} (16)	Education X_{32} (17)
Cross Country (Country)	22	Changes in Ag.output	.62	133.	.038 (.73)			.344* (2.2)	-.00095* (3.8)	-.13* (2.7)					-.024 (.25)	
Mexico,1940 (States)	24	Output per Worker	.66	572				-1.5 (.7)	-.0004 (1.1)	-1.1* 2.7)					-2.5 * (2.0)	
Mexico,1960 (States)	29	Output per Worker	.63	5842		44* (2.4)		67 (1.4)	-.9* (2.2)	-6.0 (.3)					-84.0 * (2.7)	
Thailand (Provinces)	50	Output per Worker	.62	-1042		6.8* (7.3)		7.6* (3.1)			31.9 (.76)				8.5 * (3.2)	
India "Blocks"	20	Total Output	.73	-1878	93* (2.3)		5708* (3.0)					100 (.44)	255 (1.7)	.7 (.47)		352 (.14)

Z_1 Use of commercial fertilizer: Mexico pounds per acre; India metric tons supplied per year.

Z_2 Percentage of land irrigated

Z_3 Percentage cultivated area used for double cropping

X_{11} Percentage of labor force in agriculture.

X_{21} Population per physician.

X_{22} Infant deaths per 1000 live births

X_{23} Percentage improvement in maleria death rate

X_{24} Average number of smallpox vaccinations per year

X_{25} Average number of drinking wells constructed per year

X_{26} Average number of sanitary Latrines constructed per year

X_{31} Percentage literate

X_{32} Average number of primary schools opened per year

In Parenthesis t value for the coefficients; * significant at 95% confidence level

Source Reference (2)

some form of agricultural production as the dependent variable, and several indices of health appear among the independent variables.

An over-all view of the results in Table VI-4-1 shows that the health variables appear in all cases with the appropriate signs. However, only population per physician and infant deaths per 1,000 live births have coefficients significant at a 95% level. Unfortunately, the question of direction of the causal relationship is particularly difficult to settle in the case of these two variables.

VI-4-2 Estimates Based on the Decomposition of Technological Change

The method to be used is the one presented in references (4), (7), (9), (10), (11), (13), (16) and (17). It is based on some of the main components of the neo-classic model of economic growth, but it does not include as endogenous any of the determinants of growth. For this reason it cannot be identified with the neo-classic model of economic growth. This model will be presented in Chapter VII.

An economy in which conditions of perfect competition exist, and which can be described by a production function homogeneous and of degree one, is assumed in the method to be used, i.e.,

$$Y = F(A,K,L) \qquad \text{VI-4-1}$$

where

Y = net national income

A = technological level

K = physical capital services

L = labor services

F( ) = any homogeneous degree one function.

In agreement with the conclusions of Chapter V, it will be assumed here that

$$L = SHNE \qquad \text{VI-4-2}$$

where

S = size of the employed labor force

H = quality of labor as determined by level of health of the labor force

N = quality of labor as determined by level of nutrition of the labor force

It should be observed that additional determinants of the quality of the labor force can be considered in equation VI-4-2 without changing the argument below.

With the above assumptions, it can be shown that

$$\frac{dY}{Y} = \frac{1}{Y}\frac{F}{A}\,dA + a\,\frac{dK}{K} + (1-a)\frac{dS}{S} + (1-a)\frac{dH}{H} + (1-a)\frac{dN}{N} + (1-a)\frac{dE}{E} \qquad \text{VI-4-3}$$

where a and (1 - a) are the capital and labor shares of income, respectively.

The contribution of an increase in the size of the labor force can be further broken down. For this, let

$$S_{t+1} = S_t + B_{t+1} - D_{t+1} \qquad \text{VI-4-4}$$

where

S = number of workers in the labor force

B = number of entrants

D = number of retirements

t = subscript denotes time.

From equation VI-4-4 it is possible to write

$$\frac{dS_{t+1}}{S_t} = (\beta_{t+1} - \delta_t) + (\delta_t - \delta_{t+1}) \qquad \text{VI-4-5}$$

where

β is the entrance rate

δ is the retirement rate.

The first parenthesis on the right in equation VI-4-5 represents the portion of the growth rate of the labor force that can be attributed to new entrants, and the second parenthesis represents the portion that can be attributed to a reduction in retirement.

Equations VI-4-3 and VI-4-5 above break the growth rate of income down into 7 components, five of them dealing with the labor input, one

disability that causes work-loss days, and finally, temporary disability that results in a reduction in working capacity while it does not cause work-loss days. Of these four components, only the first and third will be considered below. Lack of data makes it impossible to study the other two.

It will be assumed here that the contribution to development of the reduction in the retirement rate is equal to that of the reduction of the death rate or persons in the labor force. However, limitations of data force the use of rates for the population as a whole.

The method used to estimate the number of work-loss days due to disease was described in Section III-3-3. The same procedure is used in the case of the 18 countries to which this section refers. The number of actual working days is estimated by subtracting from 275 the number of work-loss days. These results were used in the computation of $\frac{dH}{H}$.

The influence of nutrition on working capacity was subdivided previously into two parts. One is the influence of nutritional conditions during prenatal and early childhood development, that affect mental development, and as a consequence, educational achievement, and finally, productivity. The influence on productivity is caused, first, by the impact of nutrition on the educational achievement of the worker, and second, by the limitations imposed by a limited mental capacity on working capacity, regardless of educational achievement. An attempt to present quantitative estimates of these influences is described in Sections III-3-3 and III-3-4. However, further refinements are necessary if these methods are to be used to study the contribution of nutrition - through increased mental capacity - to economic growth, using the model in equation VI-4-3.

The second influence is that of the worker's nutritional conditions at the present time. The approach used to evaluate their impact on working capacity was described in Section III-4-5.

Below, only the modifications of that approach will be described. To evaluate the calorie intake of workers in 1950 and 1962, least squares straight lines were fitted to all the published data for each country. These figures were used to estimate the calorie intake of male adults by means of the method already described.

The method used to correct for differences in environmental temperature is not modified. Detailed information was used for LAC. For these countries, reference (18) includes - in addition to data on temperature - information about the main administrative subdivisions where the meteorological stations are located. The figures for the LAC are weighted averages, with weights equal to the population in the administrative subdivisions where the weather stations are located.

The computations used to include differences in body weight and in occupational structure of the labor force are those described in Section III-4-5.

At this stage, a second correction for age was introduced. It was assumed that, whatever the improvements in nutrition, the working capacity of men 60 years of age and over remains constant, while for lower age groups it increases at rates below those estimated with Table III-3-10. The one exception is workers between 15 and 30 years of age, for whom the results in Table III-3-10 are fully applicable.

The final step was to compute the average growth rate for working capacity in the labor force as a whole as a weighted average of the growth in each of the four occupational classifications. For weights, the U.N. data on labor force classified by industry for years as close

part of formula VI-4-3 were used to compute the contribution of nutrition to economic development in Table VI-4-3.

To complete the application of the model in equation VI-4-3, the method used to estimate the contribution of education will be explained. This contribution is presented here as a basis for comparison of the influence of different components of the quality of labor.

The starting point for constructing index E of the educational quality of the labor force is income by educational level. An index is constructed, transforming all the figures to percentages of the income of persons with 7-9 years of education. In reference (3), it is reported that among all the Latin American countries, estimates are available only for Chile, Colombia, Mexico and Venezuela. Unfortunately, these estimates are either lacking in detail or do not cover all the labor force. The data for Mexico in Table VI-4-2, column (2), will be used below.

In reference (2), it is stated that Mexican data do not show any significant relationship between income by level of education and father's occupation, industry, and city of occupation. It is concluded that most of the income differentials are actually due to education and age, or innate ability. Age would reflect in part experience and on-the-job training. The income index is corrected arbitrarily, attributing only 3/5 of the differentials to education, while the rest is assumed to be due to innate ability. No correction for age, experience or on-the-job training was introduced. The corrected indices for Mexico, Italy, the rest of Europe, and the U.S. appear in Table VI-4-2, columns (3) to (6). They exhibit the interesting characteristic that their spread is inversely correlated with level of development. For Mexico, the spread goes from 57 to 190, while for the U.S.A. it goes from 70 to

TABLE VI-4-2

Indices of Income by Level of Education

Years of school completed	Latin America		Europe		U.S.A. corrected index
	Income index	Corrected index	Corrected index Italy	Corrected index North-west	
(1)	(2)	(3)	(4)	(5)	(6)
0	28	57	50	66	70
1-6	48	68	78	82	84
7-9	100	100	100	100	100
10-12	157	134	120	118	119
13+	250	190	133	159	161

Sources: References (10) and (15)

TABLE VI-4-3

Disaggregation of Technological Changes in an Aggregate Production Function for 18 Countries

Countries	Total Capital		Employment Excluding Reduction Deaths		Health: Reduction Deaths		Health: Reduction Work-Loss Days		Nutrition		Health & Nutrition		Education		Residual		Total Econ. Growth	
(1)	Rate (2)	% (3)	Rate (4)	% (5)	Rate (6)	% (7)	Rate (8)	% (9)	Rate (10)	% (11)	Rate (12)	% (13)	Rate (14)	% (15)	Rate (16)	% (17)	Rate (18)	% (19)
Latin America																		
Argentina	1.43	44.90	.93	29.03	.01	.31	.11	3.45	.00	0.0	.12	3.76	.53	16.49	.18	5.64	3.19	100.0
Brazil	1.66	30.14	1.83	33.27	.03	.55	.17	3.12	.23	4.20	.43	7.87	.18	3.33	1.39	25.32	5.49	100.0
Chile	.32	7.54	.65	15.46	.02	.48	.13	3.02	.05	1.20	.20	4.70	.20	4.78	2.83	67.38	4.20	100.0
Colombia	1.04	21.78	1.66	34.75	.01	.21	.17	3.59	.31	6.41	.49	10.21	.20	4.13	1.40	29.23	4.79	100.0
Ecuador	1.07	22.74	1.92	19.53	.02	.42	.30	6.35	.00	0.0	.32	6.77	.23	4.93	2.18	46.19	4.72	100.0
Honduras	0.95	21.12	1.06	23.46	.02	.44	.40	8.90	.41	9.10	.82	18.44	.29	6.48	1.39	30.75	4.52	100.0
Mexico	2.82	47.25	1.43	23.96	.02	.34	.31	5.24	.60	10.08	.93	15.66	.05	.83	.74	12.40	5.97	100.0
Peru	1.40	24.82	.67	11.97	.00	0.0	.16	2.90	.43	7.60	.59	10.50	.14	2.53	2.83	50.27	5.63	100.0
Venezuela	2.40	26.36	2.19	28.34	.02	.26	.01	.09	.18	2.37	.21	2.72	.19	2.41	3.11	40.18	7.74	100.0
Europe and U.S.A.																		
Belgium	.41	14.0	.40	13.0	.00	0.0	.07	2.18	.02	.62	.09	2.80	0.43	14.0	1.87	58.44	3.20	100.0
Denmark	.96	29.0	.70	21.0	.00	0.0	.07	1.99	.00	0.0	.07	1.99	.14	4.0	1.64	46.72	3.51	100.0
France	.79	17.0	.07	1.8	.01	.20	.09	1.83	.05	1.01	.15	3.04	.29	6.0	3.62	73.58	4.92	100.0
Germany	1.41	19.0	1.49	21.0	.00	0.0	.12	1.65	.16	2.20	.28	3.85	.11	2.0	3.97	54.68	7.26	100.0
Italy	.70	12.0	.42	7.0	.00	0.0	.12	2.01	.16	2.68	.28	4.69	.40	7.0	4.16	69.79	5.96	100.0
Netherlands	1.04	23.0	.78	17.0	.00	0.0	.04	.84	.00	0.0	.04	.84	.24	5.0	2.68	56.07	4.73	100.0
Norway	.89	26.0	.13	4.0	.00	0.0	.14	4.05	.00	0.0	.14	4.05	.24	7.0	2.05	59.42	3.45	100.0
U. Kingdom	.51	21.0	.50	21.0	.00	0.0	-0.4	-1.75	.01	.44	-.03	-1.31	.29	12.0	1.38	60.26	2.29	100.0
U.S.A	.83	25.0	.90	27.0	.00	0.0	.02	.60	.00	0.0	.02	.60	.49	15.0	.98	30.43	3.22	100.0

Source: Reference (7).

161. This suggests that education has a higher remuneration in developing than in developed countries.

The index E of the educational quality of the labor force for LAC is a weighted average of the corrected index in Table VI-4-2, column (3) with weights equal to the number of workers with different levels of education obtained from references (19) and (20). A similar method is used for E-US in reference (10). This index is computed for the years 1950 and 1962 for each country. Since the spread of the index is inversely correlated with level of development, the use of Mexican data for all Latin American countries will tend to increase the value of E for 1962 for the countries more advanced than Mexico, while reducing it for those less advanced. The magnitude of this error is also unknown. As a consequence of the method of computation, index E does not reflect the influences of changes in the quality of education or in its content. The importance of these two aspects is verified in references (6) and (14), respectively.

The rate of growth of E and the relevant part of formula VI-4-3 were used to estimate the contribution of education to economic growth, both for LAC and for E-US in references (7) and (10).

The results obtained are presented in Table VI-4-3. The even-numbered columns show the values determined with the corresponding components of formula VI-4-3. Odd-numbered columns give the percentage of the computed rate with respect to the total rate in column (18).

Several observations can be made with respect to the results in Table VI-4-3. They show that the contribution of capital in LAC is, on the average, and despite the possibility of underestimation, higher than in E-US. The only exception is Chile, where the lowest contribution occurs. However, this result might be only the consequence of deficiencies

in the depreciation figures.

Despite the observed larger contribution of capital in LAC, the correlation coefficients of the contribution of capital with per capita income or the per capita growth rate of income are not significant (Table VI-4-4).

From the observation of columns (4) and (5) it follows that the contribution of the increases in employment attributable to new entrants tends to be larger for LAC than for Europe. However, a surprising result is that the U.S. and Germany are the countries that come nearest to the LAC levels. These irregularities in the relationship between the contribution of employment excluding deaths and level of development explain the low correlation coefficient between these two variables (Table VI-4-4).

Columns (6) to (13) show that the contributions of health and nutrition are larger in the LAC than in the E-US. The only exceptions to this statement with respect to nutrition are Argentina and Ecuador, countries for which the contribution of nutrition is zero. This result, especially in the case of Ecuador, is doubtful, due to the unrealiability of the data.

To complete the analysis of these columns, the percentages appearing in columns (7), (9), (11) and (13) of Table VI-4-3 are compared with the data on income per capita and rate of growth in each of the countries studied. The correlation coefficients obtained appear in Table VI-4-4. These coefficients show that the relative importance of the contributions of health and nutrition have the important and otherwise reasonable characteristics of being larger for developing than for developed countries. The E-US considered have already reached levels of health and calorie intake that eliminate the possibility of large-scale improvements. In Table VI-4-4 it can also be observed that the contribution of better

TABLE VI-4-4

Correlation coefficients of the contribution of various sources of economic growth with income per capita and rate of economic growth

Column	Percentage attributed to	Correlation with	
		Income per capita	Rate of growth of income
(3)	Capital	- .120	.009
(5)	Growth of employment (excluding deaths)	- .106	.091
(7)	Reduction death rate	-.593 *	.181
(9)	Reduction work-loss days	-.560 *	.056
(11)	Better nutrition	-.559 *	.422 *
(13)	Health and nutrition	-.646 *	.309
(15)	Education	.564 *	.739 *

* Significant at a .95 confidence level

Source: Reference (7)

growth. This result is somewhat surprising, because this is the only positive and significant correlation of the type observed in the study of the factor contribution to economic growth with the first method. This suggests once more that the contribution of nutrition to growth might be greater than suspected.

Columns (14) and (15) show that the percentage contribution of education tends to be low in LAC. The main exception is Argentina, where education makes the largest contribution, but in most of the other LAC the contribution of education does not reach the 5% level. Most E-US show a higher percentage contribution. These observations are confirmed in Table VI-4-4, where the correlation coefficient between the contribution of education and the level of economic development is presented. According to Table VI-4-4, the contribution of education increases with the level of economic development.

Second Approach

The second approach is that used in reference (11). The first assumption in this reference is that all technological change is labor-augmenting. As a consequence, once one considers the improvement in productivity due to better health, education, housing facilities, nutrition and benefits of social security of the labor force, there is no additional residual, i.e.,

$$\frac{1}{Y}\frac{\partial F}{\partial A}\, dA = 0 \qquad \text{VI-4-6}$$

It should be observed that the assumption in equation VI-4-6 not necessary for the evaluation of the components of equation VI-4-3, even with the method used in the second approach. The method used in this approach could also be used with the assumption that productivity

due to technological change that is simultaneously labor and capital-augmenting grows in time and at a constant rate.

In the first approach, attempts are made to use whatever experimental studies are available to estimate the changes in the quality of the labor force, i.e., in the notation before H, N, and E due to changes in the impact of health, nutrition and education. Perhaps the best example of these attempts are the efforts to evaluate the changes in the working capacity of the labor force due to changes in the intake of calories. In the second approach, no attempt is made to evaluate explicitly the changes in H, N and E. It is simply assumed that they are functions linear in the logarithms of their inputs. For instance, it is assumed that

$$H = \gamma_{11} X_{11}^{\alpha_{11}} X_{12}^{\alpha_{12}} \ldots X_{1N_1}^{\alpha_{1N_1}} \qquad \text{VI-4-7}$$

where

H as before, quality of labor as determined by health

X_{1i} $i=1,\ldots,N_1$ inputs of health, such as inhabitants per physician, hospital beds per 1,000 habitants, and infant mortality.

γ_{11} and α_{1i} $i=1,\ldots,N_1$ parameters

In the equation for nutrition in reference (11) the only input considered is calories per person. The educational inputs considered are primary educational enrollment, secondary educational enrollment, vocational educational enrollment, and higher educational enrollment.

In addition, in reference (11) it is assumed that the quality of labor is determined by the characteristics of dwellings and by the services of social security. In the first case, the changes in the quality of labor are assumed to depend upon dwellings completed per capita, and investments in dwellings. In the second case, it is assumed that the quality of labor depends upon social security benefits per

capita and social security benefits as a proportion of GNP.

Two additional transformations are used in reference (11). First, the variable

$$Z_o = \left(\frac{dY}{Y} - (1-a)\frac{dS}{S}\right) \Big/ (1-a) \qquad \text{VI-4-8}$$

is introduced. Second, the capital share of income a is replaced by

$$a = \frac{rK}{Y} \qquad \text{VI-4-9}$$

where

r = rate of profits.

With the assumptions in equations VI-4-6 to VI-4-9, it is possible to write VI-4-2 as

$$Z_o = r\frac{dK}{(1-a)Y} + \alpha_{11}\frac{dX_{11}}{X_{11}} + \ldots + \alpha_{1N_1}\frac{dX_{1N_1}}{X_{1N_1}} + \alpha_{21}\frac{dX_{21}}{X_{21}} + \ldots + \alpha_{2N_2}\frac{dX_{2N_2}}{X_{2N_2}} + \ldots \qquad \text{VI-4-10}$$

where the variables

X_{1i} $i=1,\ldots,N_1$ are the inputs in health

X_{2i} $i=1,\ldots,N_2$ are the inputs in nutrition, etc.

and the parameters

α_{1i} $i=1,\ldots,N_1$ are the parameters of the linear in logarithm functions relating quality of labor determined by health to the health inputs

α_{2i} $i=1,\ldots,N_2$ are the parameters of the quality of labor determined by nutrition, etc.

To estimate the parameters r and α in equation VI-4-10, samples of up to 38 countries, one observation per country, were used in reference (11). A survey of their results is presented in Table VI-4-5.

From the analysis of Table VI-4-5 and additional regressions not presented in it, the following conclusions can be reached.

1. Capital appears as the main determinant of the growth of income not explained by growth in the size of the labor force.

TABLE VI-4-5

Statistical Analysis of Technological Change in an Aggregate Production Function

Reference (1)	Number of Observations (2)	R^2 (3)	Capital Z_1 (4)	Health X_{11} (5)	Health X_{12} (6)	Health X_{13} (7)	Nutr. X_{21} (8)	Education X_{31} (9)	Education X_{32} (10)	Education X_{33} (11)	Education X_{34} (12)	Housing X_{41} (14)	Housing X_{42} (15)	Social Security X_{51} (15)	Social Security X_{52} (16)
(1) Nutrition & Health	32	.57	13.25 (1.75)	.21 (.11)	.01 (.08)	-.07 (.13)	1.71 (.38)								
(2) Nutrition	38	.37	13.23 (.92)				1.76 (.32)								
(3) Education	44	.07	12.11 (1.50)					-.15 (.16)	.08 (.08)	.04 (.05)	.17 (.06)				
(4) Housing	18	.21	8.63 (5.50)									-.16 (.24)	.70 (.35)		
(5) Social Security	28	.34	9.41 (2.60)											.22 (.06)	.06 (.07)
(6) Simultaneous effect	21	.65	9.66 (3.43)				2.27 .48)				.11 (.10)		.13 (.22)	.04 (.08)	

Z_1 = rdK/(1-a)Y

X_{11} inhabitants per physician

X_{12} hospital beds per 1000 inhabitants

X_{13} infant mortality

X_{21} calories per head

X_{31} primary educational enrollment

X_{32} secondary educational enrollment

X_{33} vocational educational enrollment

X_{34} higher educational output

X_{41} dwellings completed per head

X_{42} investment in dwellings

X_{51} social security benefits paid per head

X_{52} social security benefits as proportion of GNP

In Parenthesis ( ) standard deviations.

Source: Reference (11)

2. Calories per capita is the only determinant of the quality of labor that has a consistently significant coefficient. Also, the value of the coefficient and its significance increase when only developing countries are considered in the regression. These results confirm those obtained with Method 1. A similar conclusion is reached in reference (8) in which, with the method 2 just described, technological change in agricultural production is studied.

Problems that should be mentioned with respect to the statistical analysis of the model in equation VI-4-3 presented in Table VI-4-5 are: first, a high interdependence or multicolinearity is likely to exist among the explanatory variables selected. Second, the data used in the analysis do not consider the fact that lags are likely to exist between the changes in the inputs of the quality of labor and changes in the quality itself as output. Finally, changes in income are likely to modify such determinants of the quality of labor as calorie intake and inhabitants per doctor. As a consequence of these limitations, the regression results in Table VI-4-5 should be carefully interpreted.

The main value of reference (11) is that it provides an alternate way to study the model in equation VI-4-3 despite the fact that the intimate relationship between that equation and the statistical analysis in reference (11) is not explicitly stated.

VI-5 SIMULTANEOUS INFLUENCE OF POPULATION, HEALTH, NUTRITION, AND EDUCATION ON PER CAPITA PRODUCTION

With ample justification, per capita income or production, not total income, is considered as the most important index of economic growth. For this reason, it is useful to study the impact of increases in the size of

TABLE VI-5-1

Comparison of the positive contribution of the better labor quality to increases in per capita income, with the negative contribution of population growth

Country	Per capita income growth				Contribution of labor		
	$\frac{dY}{dY}$		$\frac{dP}{P}$	$\frac{dy}{y}$	Positive	Negative	Net
	Rate	%					
Argentina	3.19	100	1.8	1.39	1.58	1.8	-.22
Brazil	5.49	100	3.0	2.49	2.44	3.0	-.56
Chile	4.20	100	2.3	1.90	1.05	2.3	-1.25
Colombia	4.79	100	3.1	1.69	2.35	3.1	-.75
Ecuador	4.72	100	3.0	1.72	2.47	3.0	-.53
Honduras	4.52	100	3.1	1.42	2.17	3.1	-.93
Mexico	5.97	100	3.1	2187	2.41	3.1	-.69
Peru	5.63	100	1.8	3.83	1.40	1.8	-.40
Venezuela	7.74	100	3.9	3.84	2.59	3.9	-1.31
Belgium	3.20	100	.5	2.70	.92	.5	.42
Denmark	3.51	100	.7	2.81	.91	.7	.21
France	4.92	100	1.0	3.92	.51	1.0	-.49
Germany	7.26	100	1.1	6.16	1.88	1.1	.78
Italy	5.96	100	.6	5.36	1.10	.6	.50
Netherlands	4.73	100	1.3	3.43	1.06	1.3	-.24
Norway	3.45	100	.9	2.55	.51	.9	-.39
U. Kingdom	2.29	100	.5	1.79	.76	.5	.26
U.S.A.	3.22	100	1.7	1.52	1.41	1.7	-.39

Source: Explained in Text.

the population and in its quality on per capita income.

To introduce the simplest model, let

$$y = \frac{Y}{P} \qquad \text{VI-5-1}$$

where

y = per capita income

Y = total income

P = total population

From VI-5-1 it follows that

$$\frac{dy}{y} = \frac{dY}{Y} - \frac{dP}{P} \qquad \text{VI-5-2}$$

Also, if it is assumed that

$$S = \lambda P$$

where

S = size of the labor force

λ = labor participation ratio

it follows that

$$\frac{dS}{S} = \frac{dP}{P} + \frac{d\lambda}{\lambda} \qquad \text{VI-5-3}$$

With equations VI-4-3, VI-5-2, and VI-5-3 it is possible to evaluate the contributions of changes in the quantity and quality of labor and in the size of the population to per capita income growth. These three equations combine to give the following formula for the contribution of quantity and quality of population to per capita income growth:

$$(1-a)\left(\frac{d\lambda}{\lambda} + \frac{dP}{P} + \frac{dN}{N} + \frac{dH}{H} + \frac{dE}{E}\right) - \frac{dP}{P} \qquad \text{VI-5-4}$$

The first component of this expression gives the positive contribution of labor to per capita income growth. One element in this component is the $(1-a)\frac{dP}{P}$

contribution of population growth to per capita income growth through increments in the size of the labor force. The second component gives $\frac{dP}{P}$ the negative contribution of population to per capita income growth. The net effect of population growth on per capita income is $-a\frac{dP}{P}$, and is always negative. The values of the components of VI-5-4 for the 18 countries studied in Section VI-4 appear in Table VI-4-3. The results obtained with formula VI-5-4 appear in Table VI-5-1.

It should be observed that in equation VI-4-3 the influence of population growth - directly or through changes in per capita income - on health, nutrition, and education has not been considered. As a consequence, formula VI-5-4 is likely to underestimate the negative impact of population growth on per capita income.

REFERENCES

Section VI-2-1

(1) Dublin, L.I. and Lotka, Alfred J.
The Money Value of a Man
Ronald Press, New York, 1948 rev. edition

(2) Enke, Stephen
"Public Health and Effective Labor"
Economics for Development
Englewood Cliffs, N.J.: Prentice-Hall, 1963
pp. 398-414

(3) Klarman, Herbert E.
The Economics of Health
New York and London: Columbia University Press, 1965

(4) Mishan, E.J.
"Evaluation of Life and Limb: A Theoretical Approach"
Journal of Political Economy
Vo. 79, No. 4, July/Aug. 1971
pp. 687-705

(5) Perlman, Mark
"On Health and Economic Development: Some Problems, Methods and Conclusions Reviewed in a Perusal of the Literature"
Comparative Studies in Society and History
Vol. 8, No. 4, July, 1966
pp. 432-451

(6) Pettenkofer, Max von
"The Value of Health to a City: Two Lectures Delivered in 1873"
translated from German, with Introduction, by Henry E. Sigerist
Baltimore: Johns Hopkins Press, 1941

(7) Rice, D.P., and Cooper, R.S.
"The Economic Value of Human Life"
American Journal of Public Health
Vol. 57, Nov. 1967

(8) Rice, D.P.
"Estimating the Cost of Illness"
Health Economic Series No. 6
Public Health Service Publication No. 947-6
U.S. Government Printing Office, 1966

(9) Winslow, E.A.
"The Cost of Sickness and the Price of Health"
World Health Organization, Geneva
Monograph Series No. 7, 1951

(10) Woods, E.A., and Metzger, C.B.
America's Human Wealth: The Money Value of Human Life
New York, 1927

Section VI-2-2

Cancer

(1) U.S. Department of H.E.W., Public Health Services
Economic Costs of Cardiovascular Diseases and Cancer, 1962
Health Economics Series No. 5
Public Health Services Publication No. 947-5
U.S. Government Printing Office, 1965

(2) Weisbrod, B.A.
Economies of Public Health Measuring the Economic Impact of Disease
University of Pennsylvania Press, 1961

Cardiovascular Disease

(3) Klarman, H.E.
"Socio-Economic Impact of Heart Disease"
The Heart and Circulation
Second National Conference on Cardiovascular Diseases, 1964

(4) U.S. Department of H.E.W., Public Health Service
Economic Costs of Cardiovascular Diseases and Cancer, 1962
Health Economics Series No. 5
Public Health Services Publication No. 947-5
U.S. Government Printing Office, 1965

Dental Diseases

(5) Mitchell, G.E.
"The False Economy of Dental Neglect"
Economic Benefits from Public Health Services, Objectives, Methods and Examples of Measurement
Public Health Service Publication No. 1178
Washington, D.C.: Government Printing Office, 1969

Encephalitis

(6) Schwab, P.M.
Economic Cost of St. Louis Encephalitis Epidemic in Dallas, Texas, 1966
Public Health Reports, 83:860 - 2, Oct. 1968

Malaria

(7) Barlow, R.
Economic Effects of Malaria Eradication
American Economic Review (Papers and Proceedings)
57:130-148, May 1967

(8) Barlow, R.
Economic Effects of Malaria Eradication
Bureau of Public Health Research Series No. 15
School of Public Health, University of Michigan, 1968

(9) Kaser, M.C.
"Observations on the Likely Economic Efficiency of the Malaria Eradication Program"
The Economic Effects of Malaria Eradication, by Barlow, R.
Bureau of Public Health Research Series No. 15
School of Public Health, University of Michigan, 1968

(10) Livades, G., and Athamnssates, D.
"The Economic Benefits of Malaria Eradication in Greece"
Revista di Malariologia
42: 177-187, December 1963

(11) Ortiz, J.R.
"Estimate of the Cost of a Malaria Eradication Program"
Boletin de la Oficina sanitaria Pan Americana
64: 110-115. February 1968

Mental Illness

(12) Feim, R.
Economics of Mental Illness
Basic Books, Inc. 1958

Peptic Ulcer

(13) Blumenthal, I.S.
Social Cost of Peptic Ulcer
Rand Corporation, 1967

Poliomyelitis

(14) Weisbrod, B.A.
Economies of Public Health Measuring the Economic Impact of Diseases
University of Pennsylvania Press, 1961

Renal Diseases

(15) Klarman, H.E., Francis, J.O., Rosenthal, G.D.
"Cost-Effectiveness Analysis Applied to the Treatment of Chronic Renal Disease"
Medical Care VI
Jan./Feb. 1968

Schistocomiasis

(16) Fawog, M.
"A Possible Approach to the Evaluation of the Economic Burden Imposed on a Community by Schistocomiasis"
Annals of Tropical Medicine and Parasitology
57: 323-330, September 1963

(17) Foster, R.
"Schistosomiasis on an Irrigated Estate in East Africa, III: Effects of Asymptomatic Infection on Health and Industrial Efficiency"
Journal of Tropical Medicine and Hygiene
70: 185-95, 1967

(18) Gatteff, C., Lemarinier, G., Labasquiere, R., and Nebout, H.
"Influence de la Bilharziose Vesicale Sur la Mentabilite Economique d'une Population Adulte Jeune de Cameroun"
Annales de la Societe Belge de Medicine Tropicale
51: 309-29, 1971

Syphilis

(19) Klarman, H.E.
"Syphilis Control Programs"
Measuring Benefits of Government Investments, Dorfman, R. (ed.)
The Brookings Institute, 1965

Tuberculosis

(20) Dublin, L.I., and Whitney, J.
"On the Cost of Tuberculosis"
Journal of the American Statistical Association
Vol. XVII, December 1920

(21) Weisbrod, B.A.
Economies of Public Health Measuring the Economic Impact of Diseases
University of Pennsylvania Press, 1961

Section VI-2-3

(1) Rice, D.P.
"Estimating the Cost of Illness"
Health Economic Series No. 6
Public Health Service Publication No. 947-6
U.S. Government Printing Office, 1966

Section VI-2-4

(1) Mishan, E.J.
Cost-Benefit Analysis: An Introduction
Praeger Publishers 1971

(2) Mushkin, S.J.
"Health as an Investment"
The Journal of Political Economy
Vol. 70, No. 5, Part 2, Supplement, Oct. 1962

Section VI-3-1

(1) Belli, P.
"The Economic Implications of Malnutrition: The Dismal Science Revisited"
Economic Development and Cultural Change
Vol. 20, No. 1, Oct. 1971
pp. 1-23

Section VI-3-2

(1) Correa, Hector
The Economics of Human Resources
Amsterdam: North Holland Publishing Co., (2nd printing, 1967)
p. 113

(2) Mishan, E.J.
Cost-Benefit Analysis - An Introduction
Praeger Publishers, 1971

(3) Selowsky, M.
"An Attempt to Estimate Rates of Return to Invnvestment in Infant Nutrition Programs"
Paper presented in the International Conference on Nutrition National Development and Planning, M.I.T., Octo. 1971

Section VI-3-3

(1) Correa, Hector
"Nutrition, Health and Education"
Department of Economics and Center for Family Health and Population Dynamics, Tulane University, Mimeo

(2) U.S. Department of Commerce Statistical Abstract of the U.S.A., 1966

Section VI-4-1

(1) Baster, N., and Scott, W.
Levels of Living and Economic Growth
UN Research Institute for Social Development, 1969

(2) Malenbaum, W.
"Health and Productivity in Poor Areas"
Empirical Studies in Health Economics, Klarman, H.E. (ed.)
Baltimore: Johns Hopkins Press, 1970

(3) McGranaham, D.V., Richard-Proust, C., Sovani, N.V., and Subrananian, M.
Content and Measurement of Socio-Economic Development
UN Research Institute for Social Development, 1970

(4) UN Department of Economic and Social Affairs
Report on World Social Situation, United Nations, 1961

(5) UN Research Institute for Social Development, Aspects of Social and Economic Growth
Pilot statistical study
UNRISD, 1965

Section VI-4-2

(1) Bruno, M.
"Estimation of Factor Contribution to Growth under Structural Disequilibrium"
Studies in Development Planning, Chenery, H.B. (ed.)
Cambridge, Mass.: Harvard University Press, 1971

(2) Carnoy, Martin
"Earnings and Schooling in Mexico"
Economic Development and Cultural Change
July 1967
pp. 408-419

(3) Carnoy, Martin
"Rates of Return to Schooling in Latin America"
The Journal of Human Resources
Summer 1967
pp. 359-374

(4) Correa, Hector
The Economics of Human Resources
Amsterdam: North Holland Publishing Company, 1963

(5) Correa, Hector
"A Method for Eva. ating Underemployment - the Case of Brazil"
The Indian Economic Journal
July-September, 1964
pp. 82-6

(6) Correa, Hector
"Quality of Education and Socio-Economic Development"
Comparative Education Review
June, 1964
pp. 11-16

(7) Correa, Hector
"Sources of Economic Growth in Latin America"
The Southern Economic Journal
XXXVII, No. 1, July 1970

(8) Dayal, Ram
"The Impact of Selected Economic and Social Factors on Agricultural Output"
United Nations Research Institute for Social Development
Report No. 5
Geneva, November, 1966

(9) Denison, Edward F.
"The Sources of Economic Growth in the United States and the Alternatives Before Us"
Supplementary Paper No. 13
New York: Committee for Economic Development, 1966

(10) Denison, Edward F.
Why Growth Rates Differ
Washington, D.C.: The Brookings Institution, 1967

(11) Galenson, Walter, and Pyatt, Graham
The Quality of Labor and Economic Development in Certain Countries
Geneva, International Labor Office, 1964

(12) Leibenstein, Harvey
Economic Backwardness and Economic Growth
New York: John Wiley, 1957

(13) Massell, B.F.
"A Disaggregated View of Technical Change"
Journal of Political Economy, December, 1961, pp. 547-557

(14) McClelland, David C.
"Does Education Accelerate Economic Growth?"
Economic Development and Cultural Change
April 1966
pp. 257-278

(15) Secretaria de Industria y Comercio de Mexico
"La Poblacion Econmicamente Activa de Mexico, 1964-65"
Resumen General Tomo VII 1965

(16) Solow, R.M.
"Technical Change and the Aggregate Production Function"
The Review of Economics and Statistics
August, 1957
pp. 312-320

(17) Tinbergen, Jan
"On the Theory of Trend Movements"
Weltwirtschaftliches Archiv 55 Band (1942 I)
Reprinted in Selected Papers
Amsterdam: North Holland Publishing Co., 1959

(18) Union Panamaericana, Departamento de Estadistica
America en Cifras 1967, Situacion Fisica, Territorio y Clima

(19) UN Demographic Yearbook, several issues.

(20) UN Statistical Yearbook, several issues.

CHAPTER VII

INTERACTION AMONG DETERMINANTS OF WELL BEING: POPULATION AND ECONOMIC GROWTH

VII-I INTRODUCTION

In Section VI-4-2, the impact of observed growth rates of capital, labor and technological change, that can be attributed to improvements in health, nutrition and education, on the growth rate of total and per capita income was calculated. The growth rates of the inputs of the production process were considered as exogenous data. No attempt was made to specify their determinants.

In this Section, the attempts to explain the rate of growth of capital and labor-augmenting technological changes within an economic model will be studied. In this analysis, the framework used in Section VI-4-2 will be extended to form the neo-classic model of economic growth.

VII-2 THE NEO-CLASSIC MODEL OF ECONOMIC GROWTH WITH ENDOGENOUS CAPITAL AND EXOGENOUS POPULATION

VII-2-1 The Neo-Classic Model of Economic Growth With Savings Dependent Only on the Size of Income

Some elements of the basic neo-classic model of economic growth were presented in Section VI-4-2. For completeness, the whole model will be presented below.

For this, let

$Y(t)$ = total income

$P(t)$ = total population

$y = Y/P$

It is assumed that Y is determined by a production function homogeneous and of degree one, i.e.,

$$Y = F(K,L) = Lf(k_1) \qquad \text{VII-2-1}$$

where

K = capital services

L = labor services

$$k_1 = K/L \qquad \text{VII-2-2}$$

$$y_1 = Y/L$$

To complete the characterization of the production function, it will be assumed that

$$\lim_{k_1 \to \infty} f(k_1) = \infty$$

$$\lim_{k_1 \to \infty} f'(k_1) = 0 \qquad \text{VII-2-3}$$

$$f'_{k_1} > 0, \; f''_{k_1} < 0, \; \lim_{k_1 \to o} f'_{k_1} = \infty$$

for every k_1.

It will be assumed that population grows at an exogenously determined rate, i.e.,

$$P(t) = P_o \, e^{nt} \qquad \text{VII-2-4}$$

and that labor is a constant proportion of the population, i.e.,

$$L = \lambda P \qquad \text{VII-2-5}$$

With equations VII-2-2 and VII-2-5 it is possible to write

$$y = \lambda f(k/\lambda) \qquad \text{VII-2-6}$$

where

$$k = K/P = \lambda k_1 \qquad \text{VII-2-7}$$

Finally, it is assumed that

$$\dot{K} = Y - C = Z \qquad \text{VII-2-8}$$

i.e., that total production can be used for investment $\dot{K}$ or total consumption C, and that investment is equal to savings Z.

A crucial role in this model is played by the savings and consumption function. In the simplest version it is assumed that per capita consumption is a fixed proportion of per capita income, i.e

$$\frac{C}{P} = (1 - \sigma)\, y \qquad \text{VII-2-9}$$

where $(1 - \sigma)$ is the constant proportion of income consumed. From equation VII-2-9 it follows that total consumption is a constant proportion of total income, and <u>does not depend upon the size of the total population</u>.

From equation VII-2-8 it follows that savings is also a constant proportion of income that does not depend upon total population, i.e.,

$$Z = \sigma Y \qquad \text{VII-2-10}$$

From equations VII-2-1, VII-2-4, VII-2-5, and VII-2-8 to VII-2-10 it follows that

$$\frac{dY}{Y} = a\,\frac{\sigma Y}{K} + (1 - a)\, n \qquad \text{VII-2-11}$$

where, as in equation VI-4-3

a = capital share of income

$(1-a)$ = labor share of income.

One of the principal objectives of the neo-classic theory of economic growth is the determination of the conditions under which all variables grow at a constant rate, common to all of them. This common rate is known as the equilibrium rate of growth, and is determined by the rate of growth of the labor force. The question is to determine what value the rate of savings should take.

With the assumption that income and capital grow at the rate n, equation VII-2-11 becomes

$$n = a\,\frac{\sigma Y_o e^{nt}}{K_o e^{nt}} + (1-a)\, n \qquad \text{VII-2-12}$$

where Y_o and K_o are the initial values of production and capital, and Y_o/K_o is the initial capital output ratio. From equation VII-2-12 it follows that

$$\sigma = n \frac{K_o}{Y_o} \qquad \text{VII-2-13}$$

is the saving ratio needed for an equilibrium growth of income equal to the rate of population growth n. This equation also shows that σ is an increasing function of n.

To study the behavior of the model outside its equilibrium point and whether it approaches equilibrium, the following method will be used.

From the definition of k_1 it follows that

$$\frac{dk_1}{k_1} = \frac{dK}{K} - \frac{dL}{L} \qquad \text{VII-2-14}$$

Using equations VII-2-8 to VII-2-10 and the growth rate of labor in equation VII-2-14, it is reduced to

$$\frac{dk}{dt} = \sigma y_1 - nk_1 \qquad \text{VII-2-15}$$

Finally, with equation VII-2-1, equation VII-2-15 is reduced to

$$\frac{dk}{dt} = \sigma f(k_1) - nk_1 \qquad \text{VII-2-16}$$

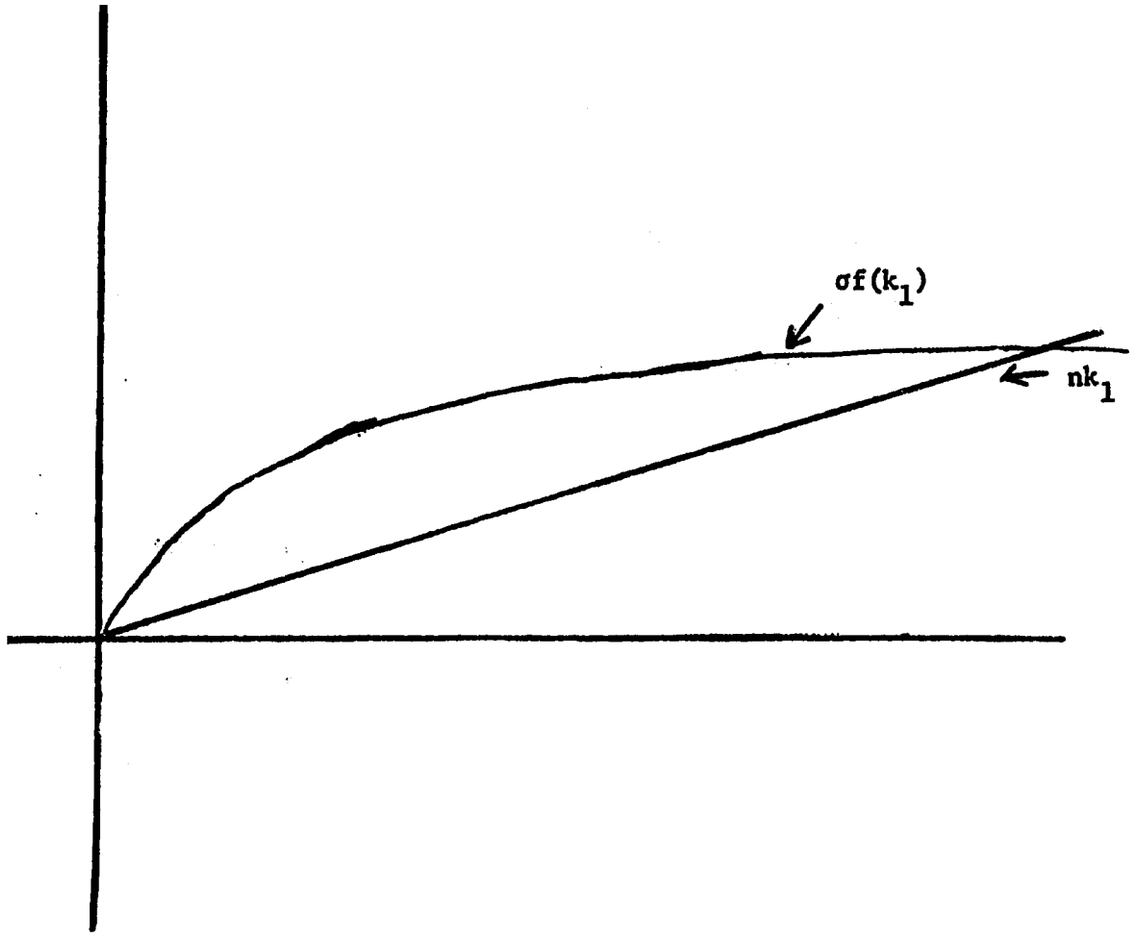
The advantage of equation VII-2-16 is that it can be represented in two dimensions as in Figure VII-2-1.

The characteristics of the graphs for $\sigma f(k_1)$ follow from the assumptions in VII-2-3. These assumptions show that there is one and only one equilibrium value characterized with $dk/dt = 0$ in equation VII-2-16. It can be shown that this equilibrium is stable.

If the value of σ obtained in VII-2-13 is used in the equilibrium value of equation VII-2-16, it can be shown that the equilibrium value of production per worker is independent of n. More explicitly, the equilibrium value of production per worker is:

Figure VII-2-1

Equilibrium in the neo-classic model of economic growth with exogenous population



$$f(k_1) = k_1 \frac{Y_o}{K_o} \qquad \text{VII-2-17}$$

VII-2-2 The Neo-Classic Model of Economic Growth with Savings Dependent on Income and Population

Statistical Evidence

In the neo-classic model of economic growth, population enters only as a determinant of the size and growth rate of the labor force. On the other hand, what empirical evidence is available suggests that savings and investments are decreasing functions of these variables. For example, reference (5) studies the following model:

$$\hat{\sigma} = \alpha_o + \alpha_1 \hat{y} + \alpha_2 \frac{dy}{y} + \alpha_3 D_1 + \alpha_4 D_2$$

$$\hat{\sigma} = \beta_o + \beta_1 y + \beta_2 \frac{dy}{y} + \beta_3 D_3$$

where

$\hat{\sigma}$ = logarithm of savings ratio, i.e., savings/income

$\hat{y}$ = logarithm of per capita income

$\frac{d\hat{y}}{\hat{y}}$ = logarithm of growth rate of per capita income

D_1 = logarithm of percentage of the population 0 - 14 years of age

D_2 = logarithm of percentage of population 65+ years of age

D_3 = logarithm of percentage of the population 0 - 14 + (65+) years of age

The results obtained are summarized in Table VII-2-1. They show that the age composition of the population has a significant effect on the savings ratio. More specifically, an increase in the proportion of the population 65 and over tends to decrease the savings ratio. The same is true for the proportion of the population 0 to 14, except in the case of the developing countries, where the opposite effect appears.

TABLE VII-2-1

Savings Function with Indices of Population Growth Considered Exogenous

Dependent Variable	Constant	$\hat{y}$	$d\hat{y}/\hat{y}$	D_1	D_2	D_3	R^2	F
Underdeveloped Countries		.1292* (1.8487)	.0227* (2.8079)	1.2297* (2.7636)	-.4455* (2.1554)		.2419	4.6685
Western Developed Countries		.0035* (.0296)	.2589* (1.6228)	-.4324* (1.7099)	-.4916* (2.6547)		.4395	4.7245
Total	7.3439* (5.7289)	.1596* (2.8776)	.0254* (3.2792)	-1.3520* (4.6406)	-.3990* (2.5623)		.5697	25.1604
	7.7762* (5.7914)	.1037* (2.3132)	.0234* (3.0428)			-1.4893* (4.8493)	.5729	33.6357

*Significant above .1 level or more

Source: Reference (5)

The Extended Neo-Classic Model

In references (1) to (6) attempts have been made to modify the savings and consumption equations of the neo-classic model. The main objective of these modifications is to make savings and consumption functions of the size of growth rate of the population. This topic will be studied below in detail. Several of the references mentioned above also consider savings and consumption as functions of welfare expenditures not directly related to production, the conditions of the balance of payments, etc. These aspects will not be considered here.

The basic assumption in references (1) to (4) is that savings per capita are a function of per capita income, i.e.,

$$z_t = f(y_t) \qquad \text{VII-2-18}$$

where

z_t savings per capita

y_t income per capita

Implicit in the text or in the values given to the coefficients of the functions used is the assumption that marginal propensity to save per capita income is constant, i.e.,

$$\frac{dz}{dy} = \sigma \qquad \text{VII-2-19}$$

From this assumption it follows that the saving per capita function has the form

$$z_t = \sigma y_t + \pi \qquad \text{VII-2-20}$$

where π is the integration constant, i.e., its value does not depend upon per capita income. For future reference, it is useful to observe that π represents the level of savings when income per capita is zero. As a consequence, it is reasonable to assume that $\pi < 0$.

At this stage, references (1) to (4) can be divided in two groups: the first including references (2) to (4), and the second reference (1).

In the first group π is determined from VII-2-20 with the values of z_t and y_t for t=0, and the assumption that total savings equals total investment, i.e., π is determined from

$$\pi = z_o - \sigma y_o \qquad \text{VII-2-21}$$

and

$$Z_o = I_o \qquad \text{VII-2-22}$$

With this, π has the value

$$\pi = -(\sigma Y_o - I_o)/P_1$$

used in references (2) to (4).

In reference (1) π is determined using as initial values for z_t and y_t in VII-2-20 those of period t-1. With this, π becomes

$$\pi = z_{t-1} - \sigma y_{t-1}$$

This expression can be used to obtain the value that modifies σY_t in reference (1). It is worthwhile to observe that π in reference (1) is a constant, despite that the values of z_t and y_t change with t.

The only point remaining is to study the implication of the savings function in VII-2-20 for the equilibrium rate of growth of income.

From the method used to obtain VII-2-11, and total savings obtained from VII-2-20, it follows that

$$\frac{dY}{Y} = a \frac{\sigma Y + \pi P}{K} + (1-a)n \qquad \text{VII-2-23}$$

From equation VII-2-23 it follows that

$$\sigma = n \frac{k_o}{Y_o} - \pi \frac{P_o}{Y_o} \qquad \text{VII-2-24}$$

i.e., if $\pi < 0$, the savings ratio in equilibrium is increased by the amount $-\pi P_o/Y_o$ over the level determined by the neo-classic model when population is not considered in the savings function.

Using the procedure in equations VII-2-14 to VII-2-16 it can be shown that the basic differential equation becomes

$$\frac{dk}{dt} = \sigma f(k_1) + \pi\lambda - nk_1 \qquad \text{VII-2-25}$$

From equations VII-2-24 and VII-2-25 with $dk/dt = 0$, it follows that

$$f(k_1) = (nk_1 - \pi\lambda)Y_o \;/\; (nK_o - \pi P_o) \qquad \text{VII-2-26}$$

It can be shown by direct comparison that the equilibrium value of income per worker in VII-2-26 is lower than that in VII-2-17 obtained under the assumption that total savings do not depend on total population.

In reference (6), to determine savings, the influence of population growth on consumption is considered first. The consumption function assumed is

$$C_t = (1-\sigma)\frac{Y_t}{P_{t-1}} P_{t-1} + (1-\sigma)\frac{Y_t}{P_{t-1}}(P_t - P_{t-1}) \qquad \text{VII-2-27}$$

The first component is the consumption of the population at date (t-1) when its income has increased to Y_t, and the second is the increment to that consumption due to the increment in population. In the same reference it is stated that from equation VII-2-27, it follows that

$$C_t = (1-\sigma)\frac{Y_t}{P_{t-1}} P_t = (1-\sigma) * (1 + n)\, Y_t \qquad \text{VII-2-28}$$

However, that this is not the case can be shown as follows: assume that the initial propensity to consume is $(1-\sigma_o)$. The argument above permits us to conclude that

$$C_1 = (1-\sigma_o)\,(1+n)Y_1$$

this means that the propensity to consume in year 1 is $(1-\sigma_o)(1+n)$. Repeating the argument, one obtains that

$$C_2 = (1-\sigma_o)(1+n)^2 Y_2$$

and so on in succession, so that the consumption function implied by VII-2-27 is

$$C_t = (1-\sigma_o)(1+n)^t Y_t$$

meaning that the marginal propensity to consume grows at the exponential rate n. Clearly, this result is not consistent with the accepted conclusion that consumption is at most equal to income.

Taking into consideration the fact that the consumption function in VII-2-28 is one of the functions that incorporates the results in Section VII-2-2, it is useful to explore its implications. However, it might be useful to repeat that it should not be derived from the assumptions in VII-2-27.

It follows from the consumption function in VII-2-28 that total savings is given by

$$Z_t = [\sigma - n(1 - \sigma)]Y_t \qquad \text{VII-2-29}$$

Replacing this total savings function in equations VII-2-11 or VII-2-23 it follows that

$$\sigma = \frac{n}{1+n}\left(1 + \frac{K_o}{Y_o}\right) \qquad \text{VII-2-30}$$

i.e., to achieve an equilibrium growth of n, savings must be increased by approximately $\frac{n}{1+n}$ over the value needed according to equation VII-2-13.

The basic differential equation presented in VII-2-15 and VII-2-25 becomes

$$\frac{dk_1}{dt} = [\sigma - n(1-\sigma)]\, f(k_1) - nk_1 \qquad \text{VII-2-31}$$

From the equilibrium values for σ in VII-2-30 and for $f(k_1)$ in VII-2-31, it follows that the equilibrium value of production per worker is, in the present case, equal to the value in equation VII-2-17.

VII-3 THE NEO-CLASSIC MODEL OF ECONOMIC GROWTH WITH ENDOGENOUS POPULATION

VII-3-1 Introduction

In the models considered in section VII-2 no attempt is made to explain the rate of population growth, and as a consequence, population size and growth themselves. These variables are determined outside the model, and considered as data. The investigations in which population growth appears as an endogenous variable will be considered below.

The Malthusian model - as elaborated in references (2), (7), (8), and (9) - should be considered as a starting point. In this model, population growth is determined by income, i.e., it is an endogenous variable, while capital formation is left unexplained. For this reason, a purely Malthusian approach is of only historical interest and will not be elaborated on here. Maintaining historical perspective, it is useful to consider the Malthusian model as a predecessor of both the statistical studies made to evaluate the influence of income on fertility, such as in references (1), (4), (5), (6), (10), (11), and (12), and also of the theoretical models of the relationship between economic conditions and family size that have been developed and studied. The main reference in this area is (3).

VII-3-2 The Neo-Classic Model With Endogenous Population and Savings Dependent Only on Per Capita Income

A more appealing approach to the study of population growth as an endogenous variable in an economic model is obtained by expanding the neo-classic model presented in Section VII-2. In this case, both capital and population

growth are considered endogenous to the model. This approach is used in reference (1) and is summarized below.

To extend the neo-classical model of economic growth, it is assumed that

$$\dot{P} = n(y)\,P \qquad \text{VII-3-1}$$

where n(v) is the rate of population growth given by

$$n(y) = \alpha(y) - \mu(y) \qquad \text{VII-3-2}$$

with

$\alpha(y)$ = birth rate

$\mu(y)$ = death rate

The empirical evidence available provides a basis for a more complete characterization of the function in VII-3-2.

It is assumed that

$$\lim_{y \to o} \alpha(y) = 0 \text{ and } \lim_{y \to o} \mu(y) \to \infty \qquad \text{VII-3-3}$$

so that

$$\lim_{y \to o} n(y) \to -\infty \qquad \text{VII-3-4}$$

For values of y above but near a subsistence level, it is assumed that

$$\begin{aligned} \alpha(y) &> \mu(y) \\ \alpha'(y) &> 0,\ \mu'(y) < 0 \\ \alpha''(y) &< 0,\ \mu''(y) > 0 \end{aligned} \qquad \text{VII-3-5}$$

so that for these values of y

$$\begin{aligned} n(y) &> 0 \\ n'(y) &> 0 \\ n''(y) &< 0 \end{aligned} \qquad \text{VII-3-6}$$

For intermediate and high levels of development, the characterization of $\mu(y)$ in VII-3-5 does not change, and it is complemented by the assumption that

$$\lim_{y \to \infty} \mu(y) = D \qquad \text{VII-3-7}$$

It is assumed that the function $\alpha(y)$ reaches a maximum value at y_M and then declines so that

$$\lim_{y \to \infty} \alpha(y) = A \qquad \text{VII-3-8}$$

As a consequence, n(y) will also increase to a maximum, and then decrease asymptotically to A-D. When approaching this asymptotic value,

$$n'(y) < 0 \text{ and } n''(y) > 0 \qquad \text{VII-3-9}$$

The sign of A-D remains an open question, but in the countries with the highest level of development at the present time, n(y) is positive. In this section, A-D will be restricted to positive values.

The function n(y) is graphically represented in Figure VII-3-1. It should be observed that from VII-2-6 it follows that n is a function of k, and since f'(k) is positive, the general shape of n(k) in Figure VII-3-1 does not change.

It is also assumed that

$$\lim_{k \to \infty} n'(k) \quad k = 0 \qquad \text{VII-3-10}$$

When the growth rate of population is determined by income, analysis of the growth rate of total income dY/Y with equations similar to VII-2-11 or VII-2-23 is not particularly fruitful. Below, only the basic differential equation equivalent to VII-2-15, and VII-2-25 will be studied. This equation takes the form

$$\dot{k} = y - c - n(y) * k \qquad \text{VII-3-11}$$

where

$$c = C/P$$

It is assumed that

$$c = c(y) \leq y \qquad \text{VII-3-12}$$

i.e., that c is a function of y, less than or equal to y for all y.

From equations VII-2-6 and VII-3-11 it follows that

$$\dot{y}/y = (f'_k/y) * (y-c-n(y) * k) \qquad \text{VII-3-13}$$

Figure VII-3-1

Rate of Growth of the population as a function of per capita income

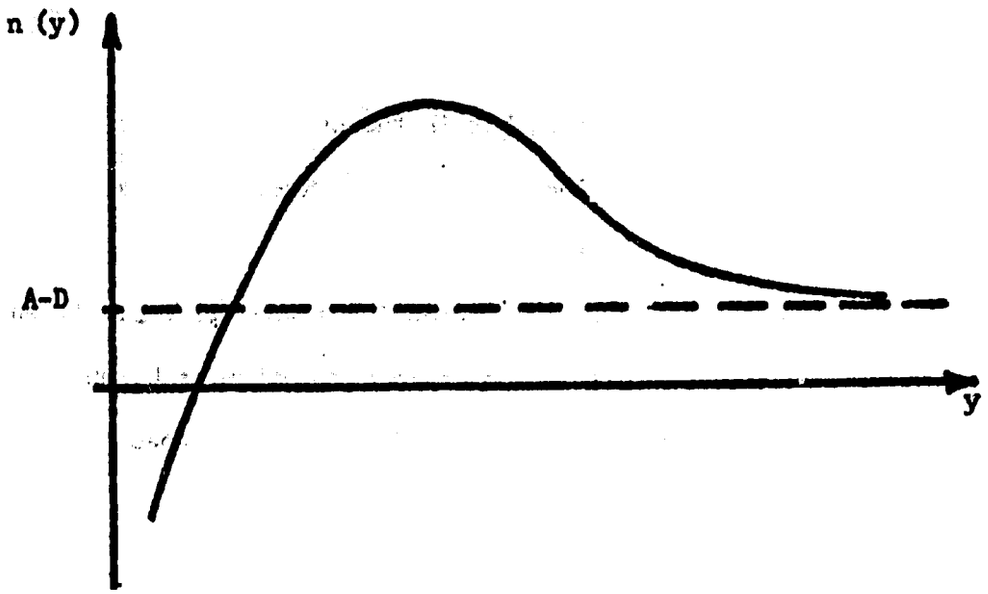


Figure VII-3-2

Equilibrium in the Neo-classic model of economic growth with endogenous population and savings dependent only on per capita income

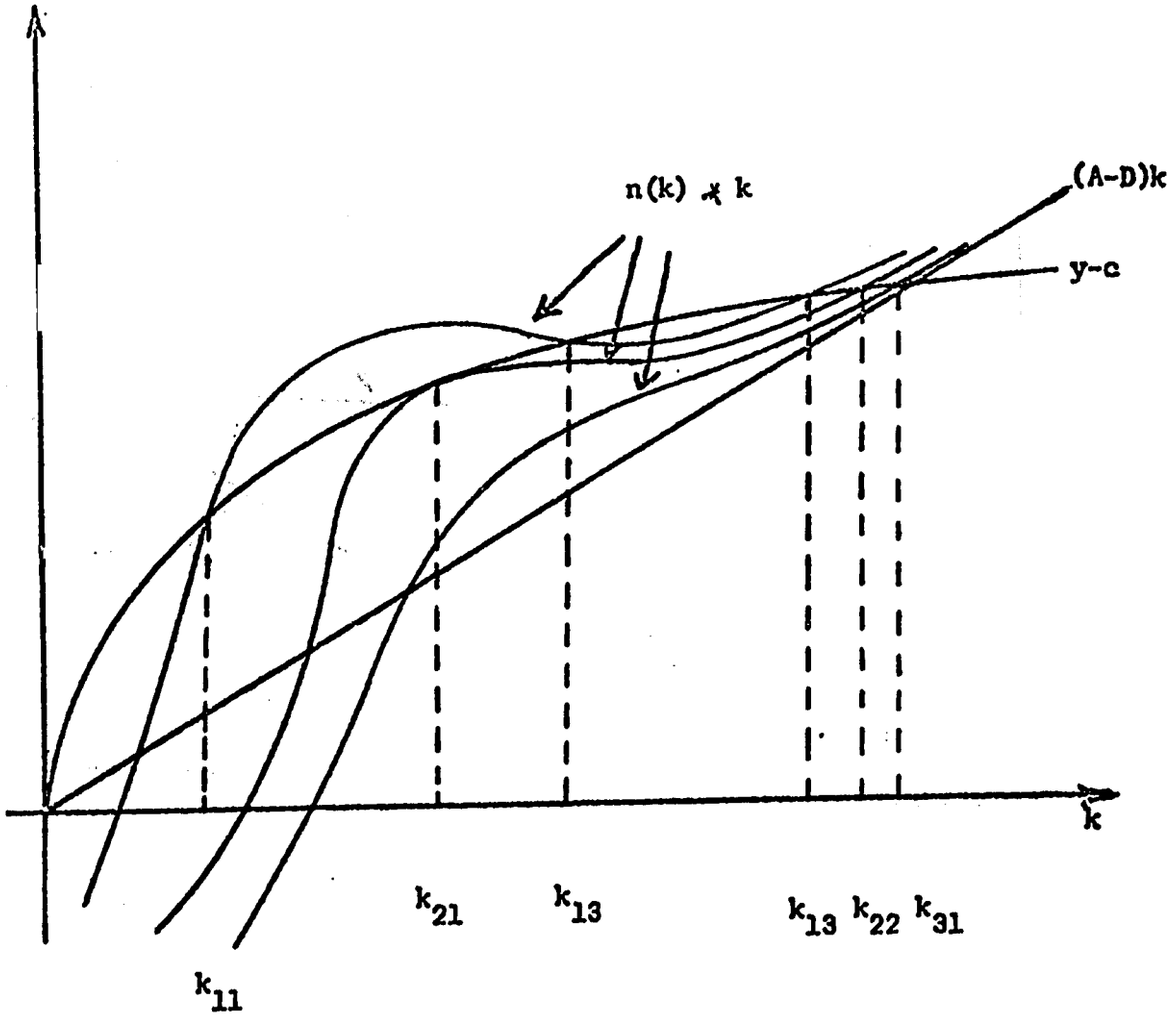


Figure VII-3-3

Savings ratio as a function of the rate of growth of population

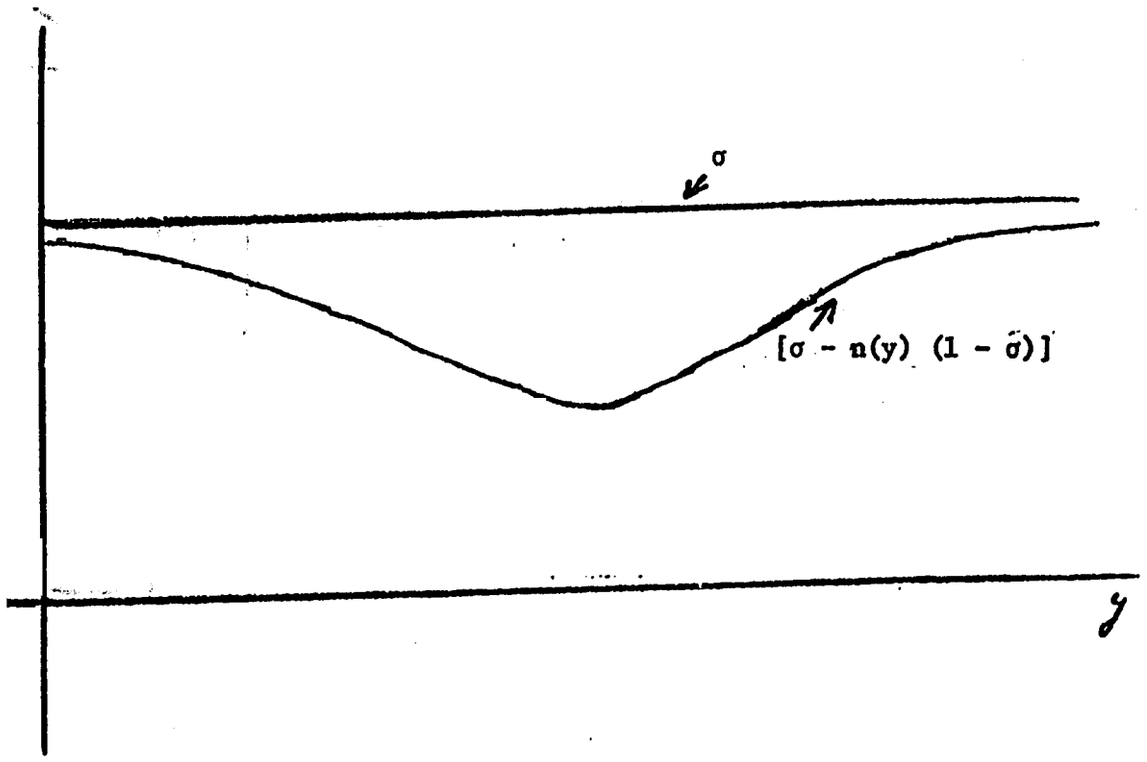
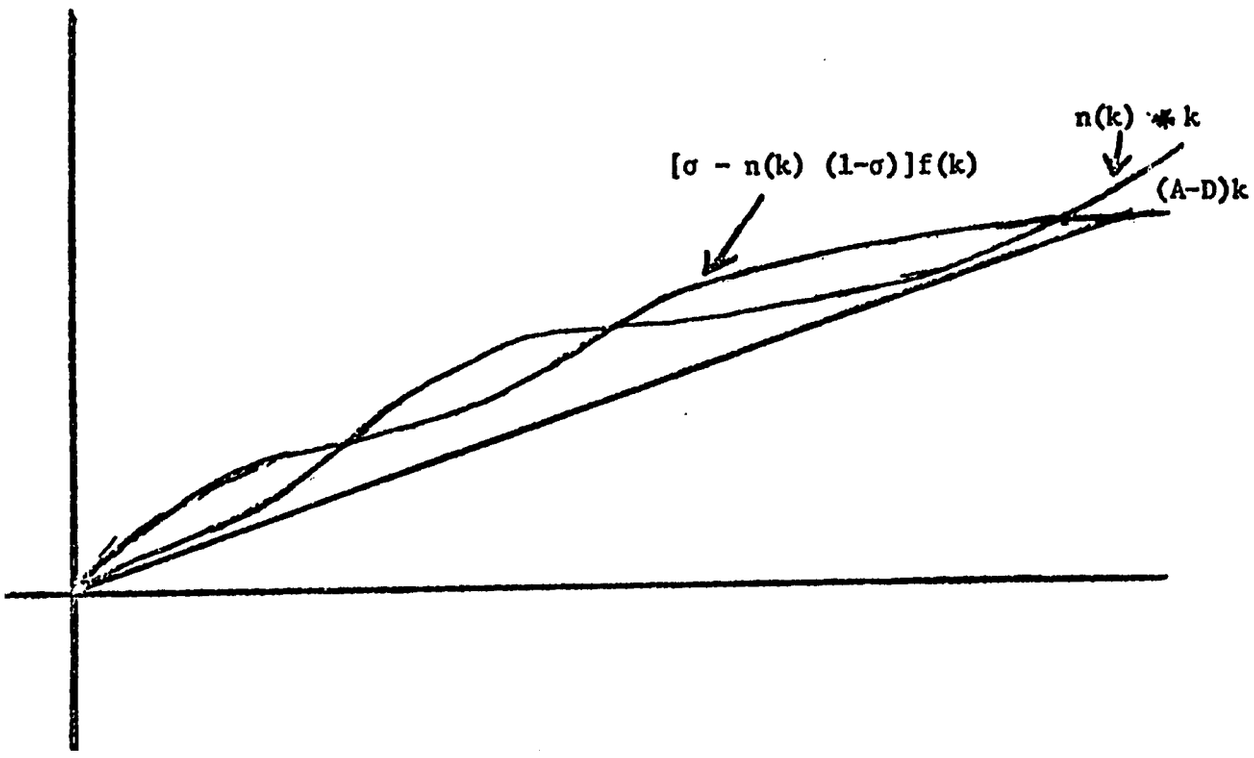


Figure VII-3-4

Equilibrium in the neo-classic model with endogenous population and savings dependent on per capita income and population growth.



The graphical representation of the functions y-c, n(k) * k and (A-D) * k in Figure VII-3-2 is useful for the study of the properties of differential equation VII-3-11. The graphs for y-c and (A-D) * k need no explanation. Only limited information can be obtained with respect to n(k) * k. For values of k above some threshold, n(k)> A-D and n(k) * k > (A-D) * k. The sign of the derivative of n(k) * k is, for a range of values of k, ambiguous. If n' (k) > 0, then n'(k) * k + n(k) > 0: however, if n'(k) < 0, the sign of the derivative cannot be determined from the information given above. Finally, from equations VII-3-7 to VII-3-10 it follows that

$$\lim_{k \to 0} [n'(k) * k + n(k)] = A-D \qquad \text{VII-3-17}$$

From figure VII-3-2 it follows that for k = 0, equation VII-3-11 can have one, two or three real roots. Furthermore, the phase diagrams derived from Figure VII-3-2 show that roots k_{11}, k_{13}, k_{22} and k_{31} are stable. Root k_{21} is stable for $k < k_{21}$ and unstable for $k > k_{21}$. Finally, root k_{12} is unstable.

The case with three roots shows that countries starting with low values of y-c and high rates of population growth are likely to reach a stable equilibrium with $k = k_{11}$ and a low per capita income. Countries without these characteristics might reach the equilibrium $k = k_{31}$ directly. The analysis shows the importance of increasing savings or reducing n(k).

Finally, the golden rule of capital accumulation is briefly considered. The growth of the economy is chosen such that at the equilibrium value of k, the consumption per capita is maximized. The necessary condition for this optimization is that

$$f'_k = x'(k) \cdot k + n(k) \qquad \text{VII-3-15}$$

From figure VII-3-2 it follows that equation VII-3-15 might have multiple solutions in k; some of them might give a maximum for c with n(k) < 0, while other solutions will give a minimum for c.

VII-3-3 The Neo-Classic Model with Endogeneous Population and Savings Dependent on Income Per Capita and Rate of Population Growth

To introduce the influence of population growth on consumption and savings, the following marginal propensity to save will be used:

$$[\sigma - n(y)\ (1 - \sigma)]$$

This marginal propensity to save is presented in Figure VII-3-3, assuming that σ is constant and that $n(y)$ is as presented in Figure VII-3-1. As a consequence, Figure VII-2-1 and VII-3-2 now become Figure VII-3-4. The observations made with Figure VII-3-2 now become Figure VII-3-4. The observations made with Figure VII-3-2 with respect to the number of roots of the basic differential equation and the stability of the equilibrium points are still maintained.

REFERENCES

Section VII-2-2

(1) Barlow, R.
"The Economic Aspects of Malaria Eradication"
American Economic Review
Papers and Proceedings, Vol. LVII
May 1967, No. 2

(2) Coale, A. J. and Hoover, E. M.
Population Growth and Economic Development in Low Income Countries
Princeton University Press, 1958

(3) Demeny, P.
"Investment Allocation and Population Growth"
Demography
1965, Vol. 2
Pp. 203-232

(4) Hoover, E. M. and Perlman, M.
"Measuring the Effects of Population Control on Economic Development: A Case Study of Pakistan"
The Pakistan Development Review
Vol. VI, Winter 1966, No. 4
Pp. 545-566

(5) Leff, N. H.
"Dependency Rates and Saving Rates"
The American Economic Review
Dec. 1969, Vol. LIX, No. 5
Pp. 886-896

(6) Walsh, B. T.
Economic Development and Population Control: A Fifty-Year Projection For Jamaica
Praeger, 1970

Section VII-3-1

(1) Adelman, I.
"An Econometric Analysis of Population Growth"
American Economic Review
1963, Vol. 53, No. 3
Pp. 314-329

(2) Baumol, W. J.
Economic Dynamics
The MacMillan Co., 1966, Second edition
Pp. 266-268

(3) Becker, G.
"An Economic Analysis of Fertility"
Demographic and Economic Changes in Developed Countries
A conference of the Universities National Bureau of Economic Research
Princeton University Press, 1960

(4) Blake, J.
"Income and Reproductive Motivation"
Population Studies
Vol. 21, No. 3, 1967
Pp. 185-206

(5) Friedman, D.
"The Relation of Economic Status to Fertility"
American Economic Review
Vol. 53, No. 3, 1963
Pp. 414-426

(6) Friedlander, S. and Silver, M.
"A Qualitative Study of the Determinants of Fertility Behavior
Demography
Vol. 4, No. 1, 1967
Pp. 30-70

(7) Leibenstein, H.
A Theory of Economic-Demographic Development
Princeton University Press, 1954

(8) Ohlin, G.
Population Control and Economic Development
Organization for Economic Cooperation and Development, 1967

(9) Peacock. A. T.
"Theory of Population and Modern Economic Analysis"
Population Studies
Nov. 1952, pp. 114-122, and
March, 1957, pp. 227-234

(10) Phillips, L., Votey, H. L. Jr., and Maxwell, D. E.
"A Synthesis of the Economic and Demographic Models of Fertility: an Econometric Test"
Review of Economics and Statistics
Vol. 51, No. 3, 1959, pp. 298-308

(11) Schultz, T. P.
"An Economic Model of Family Planning and Fertility"
Journal of Political Economy
Vol. 77, No. 2, 1969
Pp. 471-477

(13) Weintraub, R.
"The Birth Rate and Economic Development: An Empirical Study"
Econometrica
Vol. 40, No. 4, 1966
Pp. 812-817

Section VII-3-2

(1) Correa H. and Evanco, W.
A Demographic-Economic Neo-classic Model and Optimum Population Control Program
Graduate School of Public and International Affairs
University of Pittsburgh (mimeo)

CHAPTER VIII

INTERRELATIONS AMONG THE DETERMINANTS OF WELL-BEING: POPULATION, HEALTH, NUTRITION, EDUCATION, PRODUCTION, AND INTERPERSONAL RELATIONS

VIII-1 INDICES OF INTERPERSONAL RELATIONS TO BE USED

As in the case of practically all the determinants of individual well-being, there is no universally accepted index of the characteristics of interpersonal relations. As in the case of health conditions, the most easily accessible indices of interpersonal relations are those of deficiency. Thus, the indices to be used below are indices of crime and of group violence.

No attempt will be made to characterize crime or delinquency and group violence precisely. The indices accepted by criminologists, and in particular the agencies in charge of collecting statistical data, will be used without discussion. The reader interested in detailed studies of statistics on crime should see reference (1).

A systematic attempt will be made below to study the influence of population, health, nutrition, education, and economic variables on crime and group violence, the two indices of interpersonal relations to be used in this study.

VIII-2 POPULATION SIZE AND GROWTH AND CRIME

VIII-2-1 Experimental studies in Animals

Some evidence on the realtionship between antisocial behavior and population density comes from experiments with animals. For example, in reference (1) the effects of overcrowded conditions on Norway rats are reported. In these experiments, the only disadvantageous condition was the size of the dwelling units. Plenty of food was provided.

Internal peace and stability were not maintained under these conditions. Through lack of care of the young and poor distribution of the space and food available, health conditions deteriorated, antisocial behavior became common, mortality was high, and the population of rats stabilized at a number not too much above what would be considered a reasonable level.

VIII-2-2 Family Size and Crime Rates

The relationship between numbers of children per family and population size and growth does not need to be emphasized.

In reference (2), 13 studies of family size of delinquents and criminals are reported. In all these studies, the size of the families of criminals is larger than that of non-criminals. A summary of the results appears in Table VIII-2-1.

The positive relationship between delinquency and family size has been attributed to the conflict between family size and parental attention. Some support for this hypothesis comes from the fact that criminality is more frequent in persons who have been intermediate children, i.e., who had both older and younger siblings. (1)

VIII-2-3 Population Density and Crime Rate

The statistical data available shows that crime rates tend to increase with the size of the communities measured in terms of number of inhabitants. However, this statistical correlation hardly constitutes a theory for explaining crime rates.

The attempt in reference (3) to explain crime rates in terms of population density can be summarized as follows. It is first assumed that each person in a population interacts with n other persons, where n is a function of the density of the community, i.e.

Table VIII-2-1

Average Family Size of Delinquents and Controls

Origin of Samples	N Y Samples	Families of Delinquents	Families of controls
British studies	4	5.37	3.31
U.S.A. studies	9	5.74	4.75

The differences between the means are signified at a 5% confidence level in the Mann-Whitney U test

Reference (2).

$$n = a\frac{P}{A} \qquad \text{VIII-2-1}$$

where

a constant

P number of persons in the community

A area of the community.

From this it follows that the total number of interactions -- to be denoted with N -- is

$$N = nP \qquad \text{VIII-2-2}$$

In addition, it is assumed that the total number of crimes -- to be denoted with C -- is a constant proportion of the number of interactions, i.e.,

$$C = bN \qquad \text{VIII-2-3}$$

From formulas VIII-2-1 to VIII-2-3 it follows that the crime rate -- to be denoted with c -- is

$$c = ab\frac{P}{A} \qquad \text{VIII-2-4}$$

i.e., crime rate is a constant proportion ab of population density.

In reference (3), the hypothesis in VIII-2-4 is tested for Canada in the period between 1901 and 1921. The percentage of urban population with respect to total population is used as an index of population density. To test the hypothesis in VIII-2-4, indices of the values of c and P/A are computed. The results for selected years appear in Table VIII-2-2. These results show, first, that either the assumptions in equations VIII-2-1 to VIII-2-4 do not hold true or the index of population density in those equations is not satisfactory, and second, that whatever the limitations of the approach, the difference between c and ab shows that population density explains a large part of the changes in crime rates.

TABLE VIII-2-2

CANADA: INDICES OF CRIME AND POPULATION DENSITY

Year	Index of c	Index of P/A
1901	100	100
1910	196.1	113.1
1920	189.8	129.9
1929	266.3	161.2

Source Reference (3).

Reference (2) uses the same basic idea as the model just presented. However, in this case social interactions are considered identical to collisions between atoms or nuclei in the interior of a star. The different types of crime, such as assault, robbery, rape and murder are identified with collisions having different energy. Finally, population density in numbers per square mile is considered equivalent to density of atoms and nuclei, expressed in numbers per cubic centimeter. On the basis of these somewhat far-fetched assumptions, some surprisingly good fits are obtained to describe the relationship between density and crime rate in American cities in 1940, 1950 and 1960. However, no attempt is made to describe the changes in crime rate from one date to the next. Since density in certain areas decreased from 1940 to 1960 while crime rate increased, it is likely that the model will not give satisfactory results.

A possible criticism of the references above is that they do not take into consideration all the determinants of social interaction, or the reasons why such interactions might have criminal outcomes.

More specifically, equation VIII-2-1 does not explain the fact that the use of automobile transportation is likely to increase the number of interactions, even if density remains constant or even decreases.

In reference (1) a more detailed study is made of the reasons why interactions might have a criminal outcome. For this purpose, an analysis is made of crime rates in a small city, first in a period of increasing population and (likely) density, and second, during a period of decreasing population. During both periods, the crime rate increased. The author states that this phenomenon is due to the influence of socio-cultural factors, but unfortunately, he leaves these unspecified.

VIII-3 HEALTH AND CRIME

An attempt will be made here to summarize the explanations available of crime rates based on intergenerational and genetic aspects of physical and mental health and conditions in the different stages of life.

It is worthwhile to notice that criminology is among the first sciences in which attempts have been made to relate physical characteristics with personal behavior, as in the case in the classical studies of Lombroso.

VIII-3-1 Hereditary and Genetic Determinants of Crime

A distinction will be made here between hereditary influences, on the one hand, and genetic on the other, even though such a distinction might not be accepted by biologists. Under the heading of genetic influence, some observations with respect to abnormalities in the chromosomes will be presented. These abnormalities are not, in a strict sense, determined by the characteristics of the parents. On the other hand, the hypothesis has been formulated that a propensity to crime is inherited from the parents.

The physical and mental characteristics of a person, as far as heredity is concerned, are determined by the chromosomes he receives from his parents. The normal number of chromosomes is 46 in each cell except those directly involved in reproduction. These have only 23 chromosomes. In this way the descendants receive 23 chromosomes from the father and 23 from the mother.

The sex characteristics of a person are determined by two chromosomes, designated X and Y. A woman has two X chromosomes and a man one X and one Y.

In 1961 an abnormality was observed with respect to these chromosomes. A few persons have more than two sex chromosomes, in combinations XXY,

XYY, XXXY, XXYY, with totals of 47 or 48 chromosomes. These abnormalities have been associated with high mortality in infancy, mongolism, extraordinary height, etc. They have also been associated with a propensity to crime. However, according to references (2) and (3), the evidence collected so far indicates that such conclusions are at least premature, and might even be false.

So far, genetic abnormalities have been considered. These abnormalities are not hereditary in the sense of transmission from the parents.

Evidence of hereditary transmission of criminal tendencies has been sought in studies of identical twins. A survey of these studies is found in reference (1). The results obtained show that a higher proportion of identical twins than of non-identical twins and other siblings become criminals. However, no studies seem to be available of identical twins reared apart. As a consequence, the studies made show at best that hereditary plus environmental influence bring about a propensity to crime.

VIII-3-2 Health Conditions in Infancy and Childhood and Their Relationship to Crime

According to Reference (4), a .64 significant correlation coefficient was found between infant mortality and delinquency rates in Chicago. In reference (1) it is observed that the areas of American cities where crime is most serious also have the highest incidence of childhood diseases such as measles and mumps, sometimes 50% higher than that of the city as a whole.

These studies do not show that health conditions during the early life of a person influence his or her criminal behavior late in life. This point is directly studied in reference (2) and (3). The results of these studies are presented in Table VIII-3-1.

Table VIII-3-1

Health Conditions in Infancy of Delinquents and Non-Delinquents

Health Conditions	Percentage among Delinquents	Percentage among Non-Delinquents
General poor health	14.7(1) 25.0(2)	9.3(1) 18.0(2)
Susceptibility to contagion	27.0(1)	20.0(1)

All differences between percentages are significant at least at a .05 confidence level

Sources: (1), Reference (3)
(2), Reference (2)

VIII-3-3 Physical Health and Delinquency

Conditions in this case are similar to those described in the relationship between health conditions during infancy and delinquency. In reference (3) a .93 significant correlation is found between incidence of tuberculosis and crime rates. In reference (1) it is stated that the areas in American cities where crime is most serious have a lower life expectancy, and sometimes a death rate 25% higher than for the city as a whole. However, these observations only show the connection between several social problems. In reference (4), a summary of 21 studies in England and the USA concludes as follows (p. 128): "The evidence of these studies thus does not support the view that delinquents are characterized by their poor health. Any suggestion to the contrary seem to be the result of the relatively crude methods of investigation formerly employed. In more recent work, as definitions have become more precise, and comparisons are made with appropriately selected control groups, differences between the health records of delinquents and non-delinquents have tended to disappear."

In Reference (2) the influence of more specific aspects of health and crime are studied. In this reference, mention is made of analysis of characteristics of the brain and nervous sytem of delinquents and non-delinquents. The results obtained show evidence that some brain injuries produce criminal tendencies. Also, some studies show that a high percentage of delinquents have abnormal electro-encephalograms. Finally, some investigators have observed that signs of neural disorders such as ticks, tremors, and irregular reflexes appear frequently among delinquents.

VIII-3-4 Mental Health and Crime

Deficiencies in mental capacities and in mental health have frequently been assumed to be associated with crime. The fact that as much as 25% of some prison populations are mentally retarded has been used as evidence to support this hypothesis (1). However, more detailed studies have not been able to sustain this result (2), (3). It has been suggested that the larger proportion of mentally defective in prison is a consequence of the fact that criminals having these characteristics are more easily apprehended.

VIII-4 NUTRITIONAL CONDITIONS AND CRIME

Information on nutritional conditions of delinquents during their early lives and at the time of the criminal offense is extremely scarce. In reference (1) it is observed that 14.1 percent of the delinquent and 10.6 percent of the controls said that they had gone "short of food through (their) mothers' finding it difficult to make both ends meet". In the same reference it is observed that about 25% of the delinquents showed signs of deficient nutrition.

VIII-5 EDUCATION AND CRIME

VIII-5-1 Introduction

As the concept of education used in this Section is an extended one, it should include not only formal schooling, but also the socialization process in the family and in peer groups. To outline a complete study let us assume that the conditions in family, formal schools and peer groups could be classified as favorable and unfavorable to crime. For instance, a broken home is one condition favorable to crime. Similar examples can be given for the school and peer groups.

Eight combinations of these conditions with respect to crime can be formed. An example would be the following: favorable in the family,

unfavorable in school, unfavorable in the peer group. A complete study of the influence of education on crime would require a sample of delinquents and non-delinquents in each of the eight combinations described. In this way it would be possible to discover, for instance, whether family conditions have an overwhelming influence, or if they can be reversed by - say - school conditions.

Several drastic simplifications included in this outline should be mentioned. One of these is that no mention has been made of the differences in physical and intellectual conditions of the students, or of their family background, etc. Another aspect is that formal education can take place before, at the same time, or after a person has been involved in criminal activities, whether or not he or she has been apprehended. If the criminal is apprehended, the education can take place in correctional institutions. These aspects are only examples of the many questions not included in the outline described for a study of the relationship between education and crime.

A systematic analysis like the one described does not seem to be available, although fragments have been covered by different authors. The basic problem with partial studies is that the information excluded might be that which leads to the conclusions reached. For instance, most sociologists would be willing to agree that a low level of education is not a determinant of a criminal career, but rather that these two characteristics are a consequence of deficient family background including - say - a broken home. This hypothesis cannot be tested on the basis of data now available.

Below, attention will be concentrated on formal education in the schools. The reader interested in the impact of family education should

consult, for instance, references (3), (4), (5), (6), (7), (8). The impact of peer groups is studied in references (1), (2), (3), (4), (8).

VIII-5-2 Formal Education and Crime

In this section only two topics will be considered: the delinquent activities of students and drop-outs, and the school achievement of the delinquent. Other topics of interest such as the role of the school in identifying children with incipient behavior problems in order that they might be referred to the proper agencies for early treatment (see references (3) and (4)) will not be considered.

Delinquent Activities of Students and Dropouts

In reference (1) a study is made of the delinquent activities of 743 tenth grade boys in two high schools in an American city. The basic hypotheses are that 1) the rate of delinquency is greater for boys while out of school than while in school, regardless of whether they leave school as dropouts or as graduates; and 2) delinquents who drop out have a higher delinquency rate while in than while out of school.

The results in Table VIII-5-1 show that offense rates are reduced substantially when the person changes from student to non-student status. This result contradicts, to a large extent, the expected one that school attendance will reduce criminal behavior, and sustains the idea that youths attempt to achieve specific objectives, either with delinquent behavior or by dropping out of school. The specific objective attempted could be the avoidance of frustration provoked by unfair competition.

A limitation of the study commented on here is that it does not give any indication of the relative importance of the offenses of dropouts before and after leaving school, nor does it compare the delinquent behavior of graduates vs. that of dropouts. It might be that boys with a higher number of offenses who remained in school have a lower crime

TABLE VIII-5-1

Offense Rates Among Boys In and Out of School

School Status	Offense rates*
I In School	
I - 1 Future graduates	4.34
I - 2 Future dropouts	
I-2-1 Delinquents while in school	60.78
I-2-2 All dropouts	8.03
II Out of School Dropouts	
II - 1 Delinquents while in school	31.01
II - 2 All dropouts	2.75

* Number of official contracts reported by law enforcement agencies per 10,000 days

Source: Reference (1)

TABLE VIII-5-2

Percentage of Delinquents and Controls with Below Normal Educational Achievement

Studies in	Percentages for Delinquents	Percentages for Non-Delinquents
England*	42.3	18.3
U.S.A.**	79.2	43.9

*Average of 3 studies quoted in reference (5).

**Average of 3 studies, 2 quoted in reference (5) and 1 in reference (2).

rate as adults than boys with a similar number of offenses who dropped out.

Educational Achievement of Criminals

In Table VIII-5-2 a summary of statistical data from numerous studies is presented. These data show the reason why "there is fairly good agreement that those who are found guilty of offenses tend to have poor school records" (5). All the different authors emphasize that the delinquents seem to perform below capacity.

VIII-6 ECONOMIC CONDITIONS AND CRIME

In this Section the methods of economic theory are applied to the study of criminal behavior. In Subsection VIII-6-1, an economic model of criminal behavior is presented, and in VIII-6-2 the scarce evidence available is used to verify whether the results of the model are reasonable.

VIII-6-1 An Economic Model of Rational Choice Between Criminal and Non-Criminal Activities

Economic Theory is a collection of models describing how a perfectly rational economic unit would behave. Rationality is defined in this case as the use of the means under the control of the economic unit in such a way as to optimize the objective it wishes to achieve. For instance, in the economic theory of consumer behavior, the question of how a consumer unit would allocate its income in order to maximize its well-being is studied.

Similar problems of allocation of scarce resources can be considered in the study of crime. Reference (1) studies the problem of using the resources available in such a way as to minimize crime. The possibility to be studied in this chapter deals with the allocation of the time available to a "typical person" between criminal and legal activities,

assuming that his objective is to maximize the returns he receives.

The first step in this analysis is the specification of the returns an individual receives from his activities.

It will be assumed that the return per unit of time in criminal behavior is r_1, where r_1 is a finite positive number, i.e. $0 < r_1 < \infty$. A criminal would enjoy this return if he is not apprehended and punished. This means that if p denotes the probability of apprehension and punishment, the expected return per unit of time is $(1 - p)\, r_1$. In addition, it will be assumed that the penalty suffered by those criminals that are apprehended can be represented by a monetary value. This cost of apprehension and punishment for the criminal per unit of criminal activities will be denoted with c, where c is also a finite positive number. As a consequence, the expected cost of apprhension and punishment is pc. From the observations above it follows that the expected total return per unit of time devoted to criminal activities is

$$R_1 = - pc + (1 - p)r_1 \qquad \text{VIII-6-1}$$

It will be assumed that the expected return per unit of time used in legal activities (to be denoted with R_2) is received with certainty, and that R_2 is also a positive finite number.

Finally, if x_1 is the number of units of time used in criminal activities, and x_2 is the number of units used in legal activities, the total return that a person receives from the use of his time is

$$Z = R_1x_1 + R_2x_2 \qquad \text{VIII-6-2}$$

Below it will be assumed that the objective of a typical person is to distribute his time, i.e., to specify x_1 and x_2, in such a way as to maximize Z.

The objective function in VIII-6-2 includes the implicit assumption that the person evaluates correctly the probability p of detection,

and that risk itself does not bring him any satisfaction or dissatisfaction. However, p will be subjectively evaluated, and this evaluation can be above or below its actual value. Also, a risk taker will enjoy the risk itself, while the opposite is true for a risk avoider. These assumptions will be modified later. For the time being the assumptions in VIII-6-2 will be maintained.

The next step is the determination of the constraints that a person faces in assigning values to x_1 and x_2. Three constraints will be considered here. First it will be assumed that moral principles restrict the amount of time a person devotes to criminal activities, i.e.

$$0 \leq x_1 \leq a_1 \qquad \text{VIII-6-3}$$

It will also be assumed that conditions of un and underemployment set a bound a_2 to the time that a person can give to legal activities. If full employment prevails, a_2 would be infinity. These observations show that x_2 must satisfy the constraint

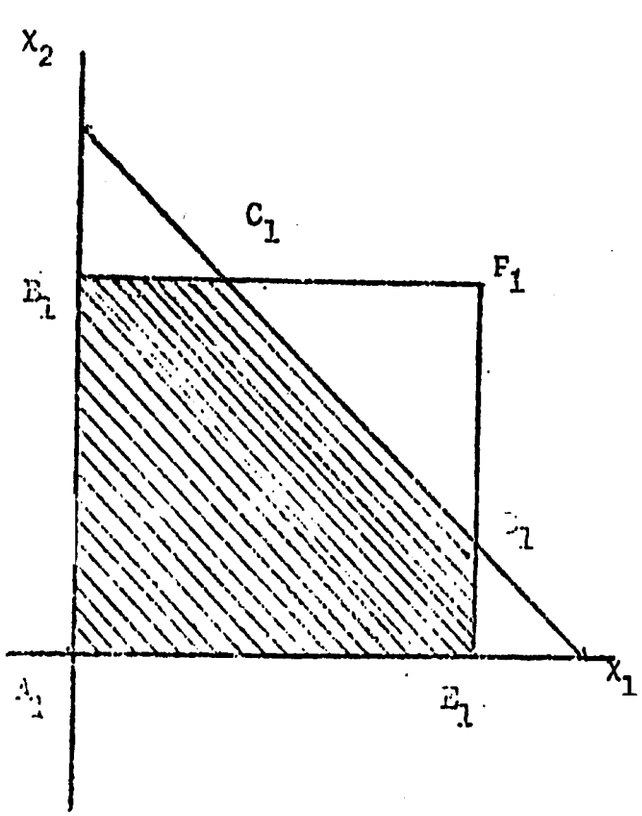
$$0 \leq x_2 \leq a_2 \qquad \text{VIII-6-4}$$

Finally, the constraint of total time available to a person should be considered. Denoting this time with a_3, the constraint takes the form

$$0 \leq x_1 + x_2 \leq a_3 \qquad \text{VIII-6-5}$$

In summary, the problem of distribution of time between legal and illegal activities has been reduced to that of optimizing VIII-6-2 subject to the constraints in VIII-6-1 and VIII-6-3 to VIII-6-5.

An advantage of the problem presented above is that it can be studied graphically. This will be done below with the aid of Figures VIII-6-1a and 1b. The shaded area of these figures represents the sets in which constraints VIII-6-3 to VIII-6-5 are satisfied. Fig. 1a corresponds to the case in which under and unemployment are assumed, while Figure 1b represents the case in which full employment is assumed. In Figure 1a it is also assumed that the point F_1 lies to the right of the line determined by the upper boundary of constraint VIII-6-5. This

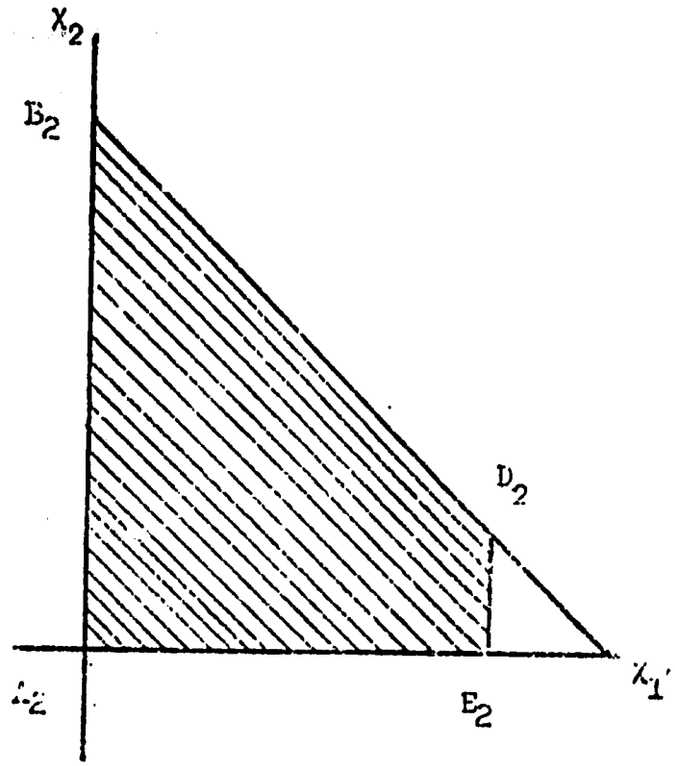


1(a)

$a_1 \leq a_3$

$a_2 \leq a_3$

with under and unemployment



1(b)

$a_1 \leq a_3$

without under or unemployment

means that, despite the employment and moral constraints, a person can use all the time available to him. However, it is also possible that the values of a_1 and a_2 will force him to waste some of his time. In this case F_1 will be at the left of the line $x_1 + x_2 = a_3$, and the boundary of the set of feasible uses of time will be reduced from the segment C_1D_1 to the point F_1. The analysis below will refer to Fig. 1a as it stands now. Its adaptation to the case in which F_1 is at the left of the line $x_1 + x_2 = a_3$ presents no problem and will be left to the reader.

To determine the values of x_1 and x_2 that maximize the objective function in VIII-6-2, it is necessary to specify the points that are common to both the locus of the function in VIII-6-2 and the shaded areas in Fig. 1, with the added condition that the locus of the function in VIII-6-2 should not have any common points with the interior of the shaded areas in Fig 1. In mathematical terms this can be expressed by saying that the values of x_1 and x_2 are determined from the "intersection' of the locus of the objective function with the set formed only by the boundary points of the shaded areas in Fig 1. The term "intersection" will be used frequently below with the meaning just given.

The precise location of the intersections of the locus of the function in VIII-6-2 with the shaded areas in Fig. 1 depend on the values of the slope $-R_1/R_2$ of the line

$$x_2 = Z/R_2 - R_1x_1/R_2 \qquad \text{VIII-6-6}$$

obtained from VIII-6-2. With changes of the slope on VIII-6-6 each of the boundary points of the shaded areas can be the one that determines the maximum of VIII-6-2. All the existing possibilities are classified in five sets below.

1. Since the possibility of having the line in VIII-6-6 parallel to the x_2 axis is excluded with the assumption that R_2 is a positive number, the first possible intersections, moving clockwise, are in the points B_1 or B_2 depending on whether or not un and underemployment is assumed. Intersections at these points mean that a rational person would devote as much time as possible to legal activities and none to illegal ones, even though with un and underemployment he will have to waste some time. This result would be achieved if the slope $-R_1/R_2$ is positive, i.e., with $R_2 > 0$ if $R_1 < 0$ meaning that crime should have a negative return. According to VIII-6-1 this is possible if

$$r_1/(r_1 + c) < p \leq 1 \qquad \text{VIII-6-7}$$

Formula VIII-6-7 established a relationship between the cost c for a criminal of being detected and the probability p of detection, with the assumption that r_1 is a constant. According to this formula, with low values of c, only high probabilities of detection will make points of B_1 and B_2 the determinants of the values of x_1 and x_2. With high values of c, even low values of p are sufficient to deter crime.

2. Moving clockwise, the second possible intersections are at the points in the segment B_1 to C_1 in Fig. 1a and still in point B_2 in Fig. 1b. This means that a rational person, in conditions of un and underemployment, could devote some time to criminal activities, but this will not increase his return Z. On the other hand, with full employment the optimum choice is still to devote all the time available to legal activities. These results are possible if the slope of VIII-6-2 is determined by $R_2 > 0$, and $R_1 = 0$, i.e., with equality in the left hand side of VIII-6-7. As a consequence, the relationship between p and c noted in 1 still holds.

3. The next possibility consists of intersections at points C_1 and B_2. This means that with un and underemployment, the optimum choice for a rational person includes some criminal activities. However, with full employment, the choice would still be legal activities only. For the intersections to be in C_1 or B_2, it is necessary that $-1 < -R_1/R_2 < 0$. These conditions are satisfied if

$$(r_1 - R_2)/(r_1 + c) < p < r_1/(r_1 + c) \qquad \text{VIII-6-8}$$

Since the right hand boundary of the inequality in VIII-6-8 has already been commented on in 2, only the left hand side will be discussed below. This side shows that, with fixed r_1 and c, the range of p increases with R_2. With $R_2 \geq r_1$, values of $p = 0$ are admissible. This shows that a rational person will choose the distribution of time implied by C_1 or B_2, even without any probability of detection, if the returns of legal activities are sufficiently higher than those of illegal ones. It should be emphasized that, in the present case, with the values of x_1 and x_2 determined in conditions of full employment, no time is allocated to illegal activities. It should also be observed that $r_1 > R_2$ is possible only if the person victimized others whose income and wealth are greater than his own. In this sense the difference $r_1 - R_2$ can be considered an index of concentration of the distribution of income. The inequality in VIII-6-8 shows that to maintain the distribution of time implied by intersections at the points C_1 or B_2, the probability of detection should increase with the concentration in the distribution of income.

4. The next possibility is that of intersection along the segments C_1 to D_1 or B_2 to D_2. In this case, the returns received will maintain the value reached with the distribution of time implied by the intersection at C_1 or B_2. However, some time could be devoted to criminal activities. This result is obtained with $p = (r_1 - R_2)/(r_1 + c)$, i.e., with the

left hand side of VIII-6-8 transformed to an equality. For this reason, most of the comments in 3 are also valid in the present case, and will not be repeated.

5. A final possibility is the distribution of time implied by intersections at points D_1 and D_2. In this case, as much time as permitted by moral constraints is devoted to criminal activities. For this, the probability of detection must satisfy $0 \leq p \leq (r_1 - R_2)/(r_1 + c)$. This shows that moral constraints play a role in restricting criminal activities only when the probability of detection is low. However, even in this case, these activities will be continued as far as the moral constraints permit. Only particularly strong moral convictions would eliminate crime entirely.

The following conclusions can be presented as a summary of the previous results: a high probability of detection, severe punishment, full employment and equality of income distribution seem to play a more important role than moral convictions as deterents of criminal activities.

Brief mention will be made below of the consequences of removing the assumptions included in VIII-6-2. First consideration will be given to the assumption that the typical person evaluates correctly the probability of being apprehended and punished for criminal activities. For this it should be observed that the subjectively evaluated p, rather than the actual one, is the determinant of the expected return Z. As a consequence, a subjectively high p is as effective a deterent as one that is actually high. The opposite is true for a subjectively low p.

The other assumption to be considered deals with the preference for risk. This preference modifies psychologically the real values of r_1 and c. A risk taker will act as if r_1 were higher and c lower than they actually are. The opposite is true for a risk avoider.

VIII-6-2 Economic conditions and crime: empirical evidence

The conclusions of the model in Section VIII-6-1 can be summarized in the following equation:

$$y = f(x_1, x_2, x_3, x_4, x_5) \qquad \text{VIII-6-9}$$

where

- y index of crime
- x_1 probability of detection
- x_2 index of cost of detection for criminal
- x_3 employment conditions
- x_4 index of income concentration
- x_5 index of moral values or some proxy for them, such as level of education

and statements made with respect to the derivatives $\delta y/\delta x_i$, $i = 1,\ldots,5$. Once the form of the function in VIII-6-9 is specified and data for the variables collected, the conclusions of Section VIII-6-1 with respect to the signs of the derivatives $\delta y/\delta x_i$ could be tested, using, for example, the technique of regression analysis.

The systematic analysis just described does not appear to be available. Reference will be made below to several partial studies.

Most, if not all, the studies on the influence of economic conditions on crime analyse the hypothesis that crime is associated with poverty. A first problem of this hypothesis is the lack of a uniformly accepted definition of poverty. As a consequence, it is difficult to integrate this hypothesis with any scientific explanation of criminal behavior. There are also serious problems in testing it, because it is difficult, if not impossible, to select samples of delinquents and controls with similar characteristics, except for the amount of income and wealth available to them. An overview of the results obtained in several investigations (1), (5), (8), (9) does not provide a basis for either

acceptance or rejection of the hypothesis, but suggests that an eventual rejection is more likely.

In some theories, deviant behavior is presented as a consequence of the frustration felt by some members of a society. This frustration is attributed to their inability to achieve desired goals (3), (6). The source of these goals is not clearly specified. However, a hypothesis valid in sociology and economics (2), (7) is that the standard of living of the upper classes of a society is among the main determinants of the aspirations of the lower classes. The standard of living is determined, to a large extent, by the income and wealth available to an economic unit. From this observation it follows that the larger the difference between the economic resources avaiable to "rich" and "poor", the larger the discrepancy between the standards of living, the larger the discrepancy between actual and desired consumption patterns for the poor, and finally, the larger the likelihood of frustration in the poor.

Several regression analyses that confirm the hypothesis described above appear in reference (4). In these regressions, crime rates appear as explained variables, and among the explanatory ones mean incomes in the lowest and highest quartiles of families are included. In most of the regressions the average income of the lowest quartile has a coefficient with a negative sign, while the mean income of the highest quartile has one with a positive sign. This means that an increase in the income of the first group of families will reduce the crime rate, while a reduction of the income of the second group of families will have the same effect. These reactions are in agreement with the conclusions of section VIII-6-1.

So far, only the difference in resources available to "rich" and "poor" has been considered. However, the likelihood of persons with criminal behavior increases with the number of poor people. The indices of income distribution take into consideration both different levels

of income, and the number of persons receiving income. As a consequence, these indices would be more appropriate than those used in the studies mentioned above.

Employment Conditions and Crime

The relationship between employment conditions and crime can be studied from several points of view. First is the employment status of a person when he or she commits a crime. The information available is contradictory. The analysis of cross-section data suggests that unemployment is closely associated with crime. In reference (9) three studies performed in England are summarized. The average proportion of unemployment among delinquents derived from these studies is 41.41%, while among non-delinquents it is only 8.25%. Several regressions with crime rates as dependent variable and unemployment rates among the explanatory variables appear in reference (4). In most of these regressions, the coefficient of unemployment is positive, showing that as unemployment increases crime increases. The author concludes that a 1% change in unemployment will cause a .15% change in the delinquency rate in the same direction.

These results are contradicted in the following references. In reference (8), cross-section data for several geographical areas is used to show that no statistical relationship exists between crime incidence and unemployment. In reference (5) the number of delinquents in the USA from 1940 to 1965 are compared with the number of persons employed over the same period. This comparison shows that the two time series move in a parallel fashion: when employment increases, so does the number of offenses.

It is interesting to observe that a similar phenomenon has been noted in the relationship between consumption and income. Cross section studies show that the higher the income of an economic unit, the lower the

proportion used for consumption. As a consequence, it can be assumed that when income increases in time, the proportion of income consumed tends to decrease. However, time series data fail to verify this point. The proportion of income consumed remained approximately constant despite the fact that income per economic unit has increased more than two fold in less than 70 years.

Another question that can be studied with respect to employment and crime deals with the employment record of delinquents and non-delinquents. As a summary of several studies, the following conclusion is presented in reference (9): "All investigators (among those considered in the reference) British or American, who have explored the subject are agreed that their subjects tend to be characterized by poor work records", i.e., poor job performance and high mobility.

VIII-7 HEALTH AND GROUP VIOLENCE

In this section the analysis made in reference (1) with respect to the relationship between group violence and health conditions will be presented.

The index of group violence used is the number of people killed per 1,000,000 population in all forms of domestic violence of an intergroup nature, thus excluding murder and execution. The period covered is from 1950 to 1962. In Table VIII-7-1 the correlation coefficients relating this index with several indices of health is presented and compared with the correlation with GNP per capita. These correlations show that there is a closer association between health and group violence indicators that between GNP and group violence indicators. This suggests that deficient health conditions could have a larger influence on group violence than purely economic conditions. Further analyses of the topic are needed. In them, attempts should be made to eliminate the statistical relationship

TABLE VIII-7-1

Correlations Between Health and Nutrition Indicators and an Index of Group Violence

Health and Nutrition Indicators	Correlations with an Index of Group Violence	
	Sample Size	Correlation
1. Death Rate	42	.42*
2. Life Expectancy females age 0	55	-.56*
3. Infant mortality, rates	36	.47*
4. Inhabitants per physician	71	.36*
5. Inhabitants per hospital bed	74	.36*
6. Calories per day	62	-.13
7. Protein grms. per day	62	-.15
8. GNP per capita	74	-.43*

Sources: Correlations 1 to 5 and 8, reference (1).
Correlations 6 and 7 elicited from data in reference (1) and (2).

caused by the influence of GNP on both group violence and health.

REFERENCES

Section VIII-1

(1) Wolfgang, M. E., Savitz, L., and Johnston N.
The Sociology of Crime and Delinquency
(Section II) John Wiley and Sons, Inc. 1970, Second Edition.

Section VIII-2-1

(1) Calhoun, P. B.
The Ecology and Sociology of the Norway Rat,
Public Health Service Publication No. 1008,
U.S. Department of Health Education and Welfare,
U.S. Gov. Printing Office, 1962.

Section VIII-2-2

(1) Lees, J. P. and Newson, L. J.
"Family or Sibling Position and Aspects of Juvenile Delinquency",
British Journal of Delinquency, Vol. 5, 1954,
pp. 46-65.

(2) Wootton, B.
Social Science and Social Pathology
(Chapter III, Section 1), George Allen and Unwin Ltd.
Fourth Printing, 1962.

Section VIII-2-3

(1) Alix, E. N.
"The Functional Interdependence of Crime and Community Social Structure,"
The Journal of Criminal Law, Criminology and Political Science,
Vol. 60, No. 3, 1969,
pp. 332-339.

(2) Kyllomen, R. L.
"Crime Rate Vs. Population Density in United States Cities,
A Model" General Systems, Vol. 12, 1967,
pp. 137-145.

(3) Watts, R. E.
"The Influence of Population Density on Crime,"
American Statistical Association Journal, Vol. 26, 1931,
pp. 11-20.

Section VIII-3-1

(1) McCord, W.
"The Biological Basis of Juvenile Delinquency", in Roucek, J.S.
Juvenile Delinquency
Philosophical Library, Inc., 1958.

(2) National Institute of Mental Health Center for Studies of Crime and Delinquency.
Report on the XYY Chromosomal Abnormality,
Public Health Service Publication 2102, U.S. Government Printing Office, 1970.

(3) West, D. J. (ed.).
Criminological Implications of Chromosome Abnormalities,
University of Cambridge, 1963.

Section VIII-3-2

(1) Clark, R.
Crime in America,
Simon and Schuster, 1970.

(2) Bagot, J. H.
Juvenile Delinquency, Cape 1941, as quoted in Wootton, B.,
Social Science and Social Pathology,
George Allen and Unwin Ltd., Fourth Impression, 1967.

(3) Glueck, S. and Gleuck, E.
Physique and Delinquency,
Harper and Brothers, 1956.

(4) Shaw, C.R., and McKay, H. D.
Juvenile Deliquency in Urban Areas,
The University of Chicago Press, 1942.

Section VIII-3-3

(1) Clark, R.
Crime in America
Simon and Schuster, 1970.

(2) McCord, W.
"The Biological Basis of Juvenile Delinquency" in Roucek, J.S.
Juvenile Deliquency
Philosophical Library Inc., 1958.

(3) Shaw, C. R., and McKay, H. D.
Juvenile Delinquency in Urban Areas
The University of Chicago Press, 1942.

(4) Wootton, B.
Social Science and Social Pathology
(Chapter III, Section II),
George Allen and Unwin, Ltd., Fourth Impression, 1967.

Section VIII-3-4

(1) Clark, R.
Crime in America
Simon and Schuster, 1970.

(2) Lunden, W. A.
Statistics on Delinquents and Delinquency
(Part III) Charles C. Thomas, Publisher, 1964

(3) McCord, W.
"The Biological Basis of Juvenile Delinquency", in Roucek, J. S.
Juvenile Delinquency
Philosophical Library Inc., 1958.

Section VIII-4

(1) Bagot, J. H.
Juvenile Delinquency,
1941, as quoted in Wootton, B.
Social Science and Social Pathology
George Allen and Unwin, Ltd., Fourth Impression 1967

Section VIII-5-1

(1) Cohen, B.
"Interneccine Conflict: The Offender",
in Sellin, T. and Wolfgang, M., (eds.)
Delinquency: Selected Studies
Wiley 1969.

(2) Cohen, C.
"The Delinquency of Gangs and Spontaneous Groups
in Sellin, T. and Wolfgang, M. (eds.)
Delinquency: Selected Studies
Wiley 1969.

(3) Hirschi, T.
Causes of Delinquency
University of California Press, 1969.

(4) Lunden, W. A.
Statistics on Delinquents and Delinquency
Charles C. Thomas, Publisher, 1964.

(5) Rodman, H. and Grams, P.
"Family and Delinquency" in Teele, J. E. (ed.)
Juvenile Delinquency: A Reader
F. E. Peacock, Publishers, 1970.

(6) Rosen, L.
"The Broken Home and Male Delinquency"
in Wolfgang, M. E., Savitz, L. and Johnston, N.
The Sociology of Crime and Delinquency
Wiley, 1970.

(7) Stanfield, R. E.
"The Interaction of Family Variables and Gang Variables in the Aetiology of Delinquency", in Teele, J. E. (ed.)
Juvenile Delinquency: A Reader
F. E. Peacock, Publishers, Inc., 1970.

(8) Wootton, B.
Social Science and Social Pathology
George Allen and Unwin, Ltd. Fourth Impression. 1967

Sections VIII-5-2-3 and 4

(1) Elliott, D. S.
"Delinquency, School Attendance and Dropout"
in Wolfgang, H. E., Savitz, L., and Johnston, N.
The Sociology of Crime and Delinquency
Wiley, 1970.

(2) Lunden, W. A.
Statistics on Delinquents and Delinquency
Charles C. Thomas, Publisher, 1964.

(3) Schafer, W. E. and Polk, U.
"What the Schools Must Do to Help Prevent Delinquency'
in Teele, J. E. (ed.)
Juvenile Delinquency: A Reader
F. E. Peacock, Publishers, Inc., 1970.

(4) Smith, P. H.
"The School as a Factor", in J. S. Raucek (ed.)
Juvenile Delinquency
Philosophical Library, 1958.

(5) Wootton, B.
Social Science and Social Pathology
George Allen and Unwin, Ltd., Fourth Impression, 1967.

Section VIII-6-1

(1) Becker, G. S.
"Crime and Punishment: An Economic Approach"
The Journal of Political Economy
Vol. 76, No. 2, March/April 1968.

Section VIII-6-2

(1) Dirkson, C.
Economic Factors of Delinquency
Bruce Publishing Co., 1948.

(2) Duesenberry, S.
Income, Saving and the Theory of Consumer Behavior
Harvard University Press, 1949.

(3) Festingler, L.
A Theory of Cognitive Dissonance
Stanford University Press, 1957.

(4) Fleisher, B. M.
The Economics of Delinquency
Quadrangle Books, 1966.

(5) Lunden, W. A.
Statistics on Delinquents and Delinquency
Charles C. Thomas, Publisher, 1964.

(6) Merton, R. U.
Social Theory and Social Structure
Free Press, 1957
pp. 161-197.

(7) Nurkse, R.
Problems of Capital Formation in Underdeveloped Countries
Basil Blackwell, Seventh Edition, 1960
pp. 58-61.

(8) Turner, S.
"The Ecology of Delinquency" in Sellin, T. and Wolfgang, M.E.
Delinquency: Selected Studies
Wiley, 1969.

(9) Wootton, B.
Social Science and Social Pathology
George Allen and Unwin, Ltd., Fourth Impression, 1967.

Section VII-7

(1) Russet, B. M. et. al.
World Handbook of Political and Social Indications
Yale University Press, 1964.

(2) UN Statistical Yearbook
Several Issues.

CHAPTER IX

SIMULATION MODELS FOR POPULATION PLANNING

IX-1 INTRODUCTION

As has been observed, the final objective of population planning is to improve the welfare of the population, whether of the world as a whole or of specific country. If migration policies are ignored, the only way to improve welfare by changes in population size and structure is through changes in the birth and death rates.

The models for forecasting future population make it possible to project the size and structure of the future population on the basis of present conditions. From the study of the influence of the forecasted population on the levels of welfare, it is possible to specify what population size and structure is advisable. This information can be used to determine what modifications are needed in birth rates, death rates etc., in order to achieve a desirable size and structure for the population. Once the required changes in the determinants of future population have been specified, it is possible to compute the costs associated with achieving them, such as the cost of reducing the number of births.

The simplest models used for population forecast will be presented in this Chapter.

IX-2 A MODEL FOR FORECASTING TOTAL POPULATION AND ITS USE IN POPULATION PLANNING

It is useful to present a model for forecasting total population because in this way it is possible to emphasize the main elements involved.

First it is assumed that P_o, total population at date t=0, is known. This basic information is used to estimate births, deaths and (if needed) migrations.

The birth rates observed in the past are used to estimate the number of births. These rates are defined by

$$\beta_t = \frac{\text{Number of births between t and t+1}}{\text{Total population date t}}$$

A simplifying assumption is that β_t will remain constant. As a consequence, the estimated number of births between dates zero and one will be

where

B_1 births between t=0 and t=1

β birth rate (assumed to be constant and, as a consequence, without subscript)

More refined projections can be obtained by making valid assumptions about the way birth rates will change over a period of time. For example, it can be assumed that there is an overall tendency toward a decrease in birth rates with the passage of time.

Other factors besides total population might be considered in projecting births, such as the tendency of education to reduce natality. The effects of contraception on the birth rate will be explored extensively in later sections. The inclusion of such factors would give rise to new methods of projection and lead to different results.

Death rates or survival rates are used to estimate the number of deaths. The death rates are defined by

$$\delta_t = \frac{\text{Number of deaths between t and t+1}}{\text{Total population date t}}$$

The definition of the survival rates σ_t is similar. It should be clear that

$$\sigma_t = (1 - \delta_t)$$

Assuming that δ and σ remain constant, the projection of deaths is

$$D_1 = \delta P_o$$

and of survivals

$$S_1 = \sigma P_o$$

where

D_1 number of deaths between t=o and t=1

S_1 number of survivals at date t=1

In preparing projections of deaths, it may be useful to assume different death rates, in order to provide for various unforeseen contingencies. This technique is frequently employed to allow for changes in the factors determining the death rates, even though such factors could be explicitly considered. For more refined projections, it is essential to give explicit consideration to these factors; for example, mortality tends to decrease with an increase in income.

When projecting the rates of more or less closed groups, such as the population of a country, no attention is paid to the effects of migration. This approach will be used below.

Given projections of births and deaths, do we have enough information to make population projections? Not altogether. An important factor is still missing: the order in which the components must be combined. In order to project the population, we must proceed by stages, and, for each stage, we must project the whole population. Beginning with the year 0, we can obtain births and deaths up to date 1 so that we can construct the population at that date. Once all the figures for date 1 are available, it is possible to go to date 2, and so on. In this process the following formula is used:

$$P_{t+1} = \sigma_t P_t + \beta_t P_t = (\sigma_t + \beta_t) P_t \qquad \text{IX-2-1}$$

In the methods described above for computing birth, death and survival rates, only first rough approximations were used. The methods used by demographers expand upon these basic elements in order to eliminate sources of error not considered here.

From the repeated application of formula IX-2-1 it is clear that

$$P_t = (\sigma + \beta)^t P_o$$

To apply the model described to demographic planning, assume that the target population for year t is $\hat{P}_t$, such that $\hat{P}_t < P_t$, and that the only instrument that can be used is the birth rate. The first problem is to find the birth rate needed to reduce the population size in year t from P_t to $\hat{P}_t$. This can easily be done with the logarithmic equation

$$\frac{\log \hat{P}_t - \log P_t}{t} = \log (\sigma + \hat{\beta})$$

where

$\hat{\beta}$ is the required birth rate to be determined.

Once $\hat{\beta}$ is known, the next problem is to evaluate the human and physical resources needed to achieve the reduction from β to $\hat{\beta}$. For this determination, let us denote with

L_1 population that does not use any contraception method

L_2 population that used some contraceptive method

β_i the birth rate in populations 1 and 2 above.

Observe that

$$L_1 + L_2 = P_o$$

i.e., the total population is equal to the sum of those who use contraceptive methods plus those who use none.

This means that

$$\beta = \frac{\beta_1 L_1 + \beta_2 L_2}{L_1 + L_2}$$

i.e., the birth rate in the total population is the weighted average of the births in population L_1 and L_2.

Assuming that

$$\beta_2 < \hat{\beta} < \beta_1$$

i.e., that the birth rate of the population using contraception techniques is higher than that desired for the population as a whole, the problem is how to increase L_2 and reduce L_1 so that the average birth rate is reduced to $\hat{\beta}$.

With P_o known, the formula to determine the required size of the population that uses contraceptives to be denoted with $\hat{L}_2$ becomes

$$\frac{(\hat{\beta} - \beta_1)P_o}{\beta_2 - \beta_1} = \hat{L}_2$$

The proportion $\hat{L}_2/P_o$ can be used to compute the number of persons in the population that should use contraceptive techniques during each of the periods during which the demographic plan is in progress.

Once the number of persons that should use contraceptive techniques is known, it is possible to determine the number of doctors needed to attend them, the number of contraceptive implements to be used, and finally, the total financial cost. For these computations, doctor/population, implement/population ratios should be used. Once the numbers of doctors and implements are determined, it is possible to compute costs.

IX-3 A MODEL FOR FORECASTING POPULATION BY SEX, WITH CONSTANT RATES - ITS USE IN POPULATION PLANNING

The model in IX-2 has important limitations, both from the point of view of theory and that of applications.

A theoretical limitation of the model in Section IX-2 is that no attention is paid to the relationships between changes in total population, changes in the age and sex structure of the population, and changes in the birth and death rates. This can be explained in some detail as follows: in a growing population, not only will the total size tend to increase, but also the proportion of young people as compared with old. This means that the proportion of persons at ages of high fertility is also changing, and, as a consequence, so are the birth rates. The death rate will also tend to change, because mortality affects the different age groups of the population in different ways. The error introduced if these interrelations are ignored might not be large. However, other limitations of the model in Section IX-2 suggest that its results should be complemented with a more complete analysis.

In order to evaluate future population growth and the measures required to influence it in desired directions, birth and death rates must be modified. However, these modifications cannot be the same for all age groups. The number of

births to women at ages of high fertility can be substantially reduced, while for ages of low fertility only a small modification means that the number of births in the model would fall below the natural minimum of zero. Similarly, the number of deaths for different ages cannot be modified according to a scale that affects all ages in the same way. For these reasons, the model in Section IX-2 is extended below to include a more detailed consideration of the age and sex structure of the population.

To begin, attention will be paid only to the sex structure of the population. It will be assumed that the number of births in the population depends only on the number of women. The method to be used is the following, Let

$$\sigma_{st} = \frac{\text{Population sex s, moment t}}{\text{Population sex s, moment t-1}}$$

be the survival rate for population sex s at moment t;

$$\beta_t = \frac{\text{Number of children born between t-1 and t}}{\text{Number of women at date t-1}}$$

i.e., the β_t's are now computed with respect to the number of women in the population, instead of with respect to total population. Finally,

$$\chi = \frac{\text{Number of males born}}{\text{Total number of children born}}$$

With the definitions just introduced, the following equations can be written

$$M_t = \sigma_M M_{t-1} + \sigma_M \chi \beta F_{t-1}$$

$$F_t = \sigma_F [1 + (1 - \chi) \beta] F_{t-1}$$

where

M_t denotes number of males; and

F_t denotes number of females

These equations, with matrix notations, take the form

$$\begin{bmatrix} M \\ F \end{bmatrix}_t = \begin{bmatrix} \sigma_M & \sigma_M \chi \beta \\ 0 & \sigma_F [1+ (1-\chi) \beta] \end{bmatrix} \begin{bmatrix} M \\ F \end{bmatrix}_{t-1}$$

The method used to evaluate the proportion of persons in the population

who should use contraceptive techniques applies, without modification, to the case where it is assumed that only the number of women determines the number of births. For this reason, the method will not be explained again.

In the model presented in this section it is assumed that only the number of women determines the number of births. This assumption could be modified in several ways. Perhaps the simplest one is to assume that

$$B_t = \beta[\gamma M_t + (1-\gamma) F_t]$$

where the definition of β has to be modified in an obvious way, and γ ranges between zero and one.

There is no simple answer to the question of how many men and women should adopt contraception in order to reduce the birth rate to a desired target when it is assumed that the number of births depends both on the number of men and on the number of women.

IX-4 A MODEL FOR FORECASTING POPULATION BY SEX AND AGE WITH CONSTANT RATES - ITS USES IN POPULATION PLANNING

An immediate extension of the models discussed in IX-3 is to consider not only the sex structure of the population, but also its age structure. The modifications needed for this purpose are based on the following considerations:

(1) The number of births affects the size of the youngest age group of the population;

(2) It is necessary to keep track of the changes in age of the population.

As before, the number of women is considered to be the main determinant of the number of births.

In order to take into consideration these observations, the following elements will be used:

(a) Survival rates by age and sex, defined by

$$\sigma_{sh} = \frac{\text{Population sex s, age h+1, date t}}{\text{Population sex s, age h, date t-1}}$$

It should be observed that the date of reference, t-1 and t, are not explicitly indicated in the σ_{sh}. Only occasionally will this be necessary, and in

this case the symbol σ_{sht} will be used.

(b) Fertility rate defined by

$$\beta_h = \frac{\text{Number of children born to women of age h between t-1 and t}}{\text{Number of women of age h date t-1}}$$

As in the case of the survival rates, the dates of reference do not appear explicitly in the symbol β_h.

(c) Sex ratios defined by

$$\chi_h = \frac{\text{Number of males of age h date t}}{\text{Total population of age h date t}}$$

Table IX-4-1 presents a series of equations relating the size of each segment of the total population at time t+1 to a segment of the total population at time t. The first equation in the table states:

$$M_{1,t+1} = \sum_{i=n}^{n+k} \sigma_{MO}\, \chi_o\, \beta_i\, F_{it} \qquad \text{IX-4-1}$$

This equation indicates that the number of males age 1 at time t+1 equals the number of surviving males born to women of all fertile age groups between t and t+1. The right hand side of the equation is formed in the following manner:

a) The number of births between t and t+1 to women age i at date t is

$$\beta_i F_{it} \qquad i = n, n+1, \ldots, n+k$$

It is assumed that fertility begins at age n and ends at age n+k The exact values of n, n+1,..., differ from case to case.

b) The number of males among the children born between t and t+1 is

$$\chi_0 \beta_i F_{it}$$

c) The number of males surviving at date t+1 from those born between t and t+1:

$$\sigma_{MO}\, \chi_o\, \beta_i\, F_{it}$$

The total number of males age one at date t+1 is obtained by adding this number for all women ages n,n+1,..., n+x, i.e., equation IX-4-1

The second equation in Table IX-4-1 states:

Table IX-4-1

Equations Relating Population by sex and age in year t

to Population in year t+1

$$M_{1t+1} = \sum_{i=n}^{n+k} \sigma_{M0} \chi_0 \beta_i F_{it}$$

$$M_{2t+1} = \sigma_{M1} M_{1t}$$

$$M_{3t+1} = \sigma_{M2} M_{2t}$$

$$\vdots$$

$$M_{\ell t+1} = \sigma_{M\ell-1} M_{\ell-1t}$$

$$F_{1t+1} = \sum_{1=n}^{n+k} \sigma_{F0} (1-\chi_o) \beta_i F_{it}$$

$$F_{2t+1} = \sigma_{F1} F_{1t}$$

$$F_{3t+1} = \sigma_{F2} F_{2t}$$

$$\vdots$$

$$F_{\ell t+1} = \sigma_{F\ell-1} F_{\ell-1t}$$

where

M_{ht} number of males of age h, moment t

F_{ht} number of females of age h at moment t

ℓ last age interval considered

The other symbols were defined on the preceding pages.

$$M_{2,t+1} = \sigma_{M1} M_{1t} \qquad \text{IX-4-2}$$

This indicates that the number of males age 2 at time t+1 equals the number of males who were age 1 at time t and survived until time t+1. The other equations in the upper part of Table IX-4-1 have a similar form, that is, each one gives the number of males of age h+1 at date t+1 as the proportion surviving of those of age h at date t. In Table IX-4-1 it is assumed that ℓ is the oldest age achieved by any member of the population.

The lower part of Table IX-4-1 is similar to the upper part, except that it refers to women. The first equation of this part gives the number of girls born between t and t+1 and surviving at date t+1. The other equations give the number of women of age h+1 at date t+1 as a proportion of those of age h at date t.

One of the advantages of these equations is that they can be summarized in the following matrix equation:

$$\begin{bmatrix} M \\ F \end{bmatrix}_{t+1} = \begin{bmatrix} S_M & B_M \\ 0 & S_F + B_F \end{bmatrix} \begin{bmatrix} M \\ F_t \end{bmatrix} \qquad \text{IX-4-3}$$

where

$\begin{bmatrix} M \\ F \end{bmatrix}_t$ is a column vector denoting the number of males and females in each age group, time t. The dimensions of the vector are determined by the number of age groups:

males $\quad i = 1,2,\ldots,\ell$

females $\quad i = \ell+1,\ell+2,\ldots,2\ell$

S_M is the following $\ell x \ell$ matrix

$$S_M = \begin{bmatrix} 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\ \sigma_1 & 0 & 0 & 0 & \cdots & 0 & 0 \\ 0 & \sigma_2 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \sigma_3 & 0 & & 0 & 0 \\ 0 & 0 & 0 & \sigma_4 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & & \vdots & \vdots \\ 0 & 0 & 0 & 0 & & \sigma_{\ell-1} & 0 \end{bmatrix}$$

B_M is the ℓ xℓ matrix in the upper right hand quadrant of the matrix in IX-4-3 that has as the only non-zero components those in the first row giving the products of the survival ratio for boys of ages between 0 and 1 times the sex ratio for the same age and times the fertility rates, i.e.

$$B_M = \begin{bmatrix} 0 & 0 \cdots 0 & 0 & \sigma_{M0}\chi_0\ \beta_n & \cdots \sigma_{M0}\ \chi_0\ \beta_{n+k} & 0 \cdots 0 & 0 \\ 0 & 0 \cdots 0 & 0 & 0 & \cdots & 0 & 0 \cdots 0 & 0 \\ 0 & 0 \cdots 0 & 0 & 0 & \cdots & 0 & 0 \cdots 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & 0 & 0 \cdots 0 & 0 \end{bmatrix}$$

0 is a ℓ x ℓ matrix in the lower left hand corner quadrant of the matrix in equation IX-4-3 and it is formed only with zeros.

Finally

$S_F + B_F$ is the ℓ x ℓ matrix in the lower right hand quadrant of the matrix in IX-4-3 that combines the components of matrices S_M and B_M with the modifications required to describe births and survival by ages for women.

From equation IX-4-3 it follows that:

$$\begin{bmatrix} M \\ F \end{bmatrix}_{t+n} = \begin{bmatrix} S_M & B_M \\ 0 & S_F + B_F \end{bmatrix}^n \cdot \begin{bmatrix} M \\ F_t \end{bmatrix} \qquad \text{IX-4-4}$$

Thus, the size, sex and age structure of the population at time t+n can be forecasted.

Equation IX-4-4 shows that it is possible to forecast the size, age and sex structure of a population when:

(a) the age and sex structure at year t is known

(b) the matrices of survival rates S_M and S_F and those of birth, sex and survival rates B_M and B_F are known

(c) one is willing to assume that these rates do not change in time.

This assumption will be modified in Section IX-5.

One of the main advantages of the model in equation IX-4-4 is that the age and sex structure of the population in year t+n for any "n" can be obtained with the use of a very simple computer program.

No clear link can be established between population planning and growth with the model as stated. To do this, the following approach will be used: it will be assumed that women are classified not only by age, but also by participation in a family planning program. This determines first the fertility rate, and second the cost of the family planning program. In passing from one date t to the next t+1 women in each class have two possibilities: to participate or not in the program from t+1 to t+2. This means that the transformation matrix has the form in Table IX-4-2, where the following notation is used:

M_i Males age group i, $i=1,\ldots,\ell$

F_{ij} Females age group i, $i=1,\ldots,\ell$

j=1 not participating in population program

j=2 participating in program

The meaning of σ, χ, β, remains as before.

The meaning of p is explained below. Comparing the matrix in Table IX-4-2 to the one in equation IX-4-3, the following observations can be made:

(a) The general structure of the matrix remains the same. In both cases, the transformation matrix can be partitioned

TABLE IX-4-2

TRANSITION MATRIX FOR FORECASTING POPULATION WITH WOMEN PARTICIPATING IN POPULATION CONTROL PROGRAM

Vector t+1 \ Vector t	M_1	M_2		...	M_ℓ	F_{11}	F_{12}	F_{21}	F_{22}	F_{31}	F_{32}	...	$F_{\ell 1}$	$F_{\ell 2}$
M_1	0	0	0	...	0	0	0	$\sigma_{M1}x\beta_{21}$	$\sigma_{M1}x\beta_{22}$	$\sigma_{M1}x\beta_{31}$	$\sigma_{M1}x\beta_{32}$	...	0	0
M_2	σ_{M2}	0	0	...	0	0	0	0	0	0	0	...	0	0
M_3		σ_{M3}	0	...	0	0	0	0	0	0	0	...	0	0
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
M_ℓ	0	0	0	...	0	0	0	0	0	0	0	...	0	0
F_{11}	0	0	0	...	0	0	0	$\sigma_{F1}(1-x)\beta_{21}$	$\sigma_{F1}(1-x)\beta_{22}$	$\sigma_{F1}(1-x)\beta_{31}$	$\sigma_{F1}(1-x)\beta_{32}$	...	0	0
F_{12}	0	0	0	...	0	0	0	0	0	0	0	...	0	0
F_{21}	0	0	0	...	0	P_{211}	P_{212}	0	0	0	0	...	0	0
F_{22}	0	0	0	...	0	P_{221}	P_{222}	0	0	0	0	...	0	0
F_{31}	0	0	0	...	0	0	0	P_{311}	P_{312}	0	0	...	0	0
F_{32}	0	0	0	...	0	0	0	P_{321}	P_{322}	0	0	...	0	0
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
.	.	.	.	...	.	.	.	.	.	.	.	...	.	.
$F_{\ell 1}$	0	0	0	...	0	0	0	0	0	0	0	...	0	0
$F_{\ell 2}$	0	0	0	...	0	0	0	0	0	0	0	...	0	0

into four submatrices: male survival, male births, zero matrix, and female survival and births.

(b) The male survival matrix does not have any change.

(c) The male births presents now 2 columns for each age group, the first corresponding to women not practicing birth control, the second to women practicing it.

(d) The zero matrix remains the same except that it has twice as many rows as columns.

(e) The row corresponding to female births in the fourth submatrix has the same modifications as that corresponding to male births. No additional comments on them will be made. Important changes are made in the female survival part of the matrix. Each survival rate σ_{Fi} has been changed into the following four parameters:

$p_{i+1,1,1}$ is the proportion of women of age i not in the program who reach age i+1, and remain out of the program;

$p_{i+1,1,2}$ is the proportion of women of age i in the program who reach age i+1 and leave the program;

$p_{i+1,2,1}$ is the proportion of women of age i not in the program who reach age i+1 and enter the program;

$p_{i+1,2,2}$ is the proportion of women of age i in the program who reach age i+1 and remain in the program.

Since the women not in the program have only two alternatives, to remain out or to enter the program, it follows that:

$$\sigma_{Fi+1} = p_{i+1,1,1} + p_{1+1,2,1}$$

A similar equation is valid for the proportion of women in the program, i.e.,

$$\sigma_{Fi+1} = p_{i+1,1,2} + p_{1+1,2,2}.$$

The parameters p just described can be considered as policy variables. Their value can be changed to find out the impact on population growth and costs of different levels of participation in population control programs.

The total cost of the program can be computed as follows:

$$C = c' * P$$

C Total cost

c Vector with the following characteristics

$$c = \begin{bmatrix} 0 \\ 0 \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ 0 \\ c \\ 0 \\ c \\ \cdot \\ \cdot \\ \cdot \\ 0 \\ c \end{bmatrix} \begin{matrix} \left.\vphantom{\begin{matrix}0\\0\\\cdot\\\cdot\\\cdot\\0\end{matrix}}\right\} \ell \text{ components} \\ \left.\vphantom{\begin{matrix}0\\c\\0\\c\\\cdot\\\cdot\\\cdot\\0\\c\end{matrix}}\right\} 2\ell \text{ components} \end{matrix}$$

where the component c is the cost per year per woman

P Population vector

IX-5 FORECASTING POPULATION BY SEX AND AGE WITH CHANGING RATES

In the model in Section IX-4 the full impact of the changing age and sex distribution in birth and death is taken into consideration. However, the factors changing the birth and death rates themselves are ignored. This question will be considered briefly below.

The first step is to specify the factors influencing age and sex specific birth and death rates. Several come to mind, such as average level of education of the population, level of nutrition, health facilities available, participation of women in the labor force, etc. An index that can frequently be used to reflect the impact of all these factors is per capita income. Whatever the factor considered, the influence on the specific birth and death rates can be evaluated by means of regression analysis.

The parameters of the regression equations make it possible to evaluate the birth and death rates corresponding to any values of the determining factors. As a consequence, if a population forecast for years t+1, t+2,...,t+n is desired, the following procedure can be used:

(a) Forecasts for year t+1,...,t+n for all the determining factors of the birth and death rates must be obtained

(b) With the forecasts in (a) it is possible to estimate the values of all the age and sex specific birth and death rates for dates t+1 to t+n

(c) These values should be used in the matrix in equation IX-4-3. A simple change in the computer program used makes it possible to include the new values of the rates.

IX-6 LIMITATIONS OF THE MODELS IN SECTIONS IX-2 AND IX-3 AS PLANNING MODELS

In the previous sections it was observed that simulation models permit the determination of changes required in the birth, death and migration rates in order to achieve the size and structure of the population desired for a future date. It is also possible to estimate the human and financial resources needed to bring about the changes in the birth, death and migration processes. To estimate these resources, average figures of the fertility rate with and without the use of contraceptives, and the average resources needed are required. However, it is clear that some population groups are much more receptive to contraception methods than others, so that the use of resources in these groups might bring about larger reductions in fertility. It is also clear that there are contraceptive methods that bring about greater reductions in fertility, or have lower costs. The question that immediately comes to mind is why not identify these population groups, or these contraceptive methods, and obtain the same results with lower costs, or vice versa, why not use the resources available to reduce births as much as possible. This is the question optimization models solve.

CHAPTER X

POPULATION PLANNING: OPTIMUM DETERMINATION OF A TARGET POPULATION

X-1 INTRODUCTION

As mentioned before, optimization models seek to increase efficiency in the utilization of the resources available for population planning. In the present chapter, the question to be considered is that of selecting from among all the women who have reached the age of fertility those should receive contraceptive advice and service. This selection should take into consideration the fertility rates of the women of different ages and social strata, both with and without the use of contraceptives, their motivation to use contraceptives, their personal and financial ability to do so, and the cost of providing contraceptive advice.

The intuitive solution of the problem is quite obvious. The human and financial resources available should be used to provide advice to women for whom the reduction in fertility is the highest per unit of cost. To actually specify this group without a systematic procedure might be impossible in practice.

The object of this Chapter is to present several mathematical models that provide such procedures. The simplest case is considered, in Section X-2, and in the following sections more complex and realistic cases are studied. However, all the models in this Chapter are intended only as examples that should be adapted and modified to the needs of each specific program.

From the previous Chapter it should be clear that the basic parameters to consider are the fertility rates of women with and without the use of contraceptives. They will be denoted by

α_h fertility rate of women of age h without contraceptive

and

β_h fertility rate of women of age h with contraceptives.

The precise definition of these rates will be discussed below. To begin with, it should be stated that a non-critical application of the definitions in Chapter IX would give unreasonable results. This is a consequence of the fact that some women are likely to be using contraceptives before the initiation of a population program. Thus it is necessary to determine, from the point of view of the program, what is the fertility rate of these women with and without contraceptives. It seems reasonable to assume that the fertility rate without contraception of women who used contraceptives before the initiation of the program is that of other women in the population who do not use them. However, for the purposes of a population program, this is incorrect. For the administrators of a population program, the correct question is, what is the fertitily rate <u>without contraceptive services and implements provided by the program</u>. The emphasis here is on the fertility rates with or without contraceptives provided by the program, and not those with or without any contraceptives. The resources of the program can be allocated more effectively on this basis. For a group of women who were using contraception before the initiation of a population program, and from the point of view of the administrators of the program, their α_h rates will be those with the use of contraception <u>not</u> provided by the program and their β_h rates will be those with the use of contraceptives provided by the program.

Another example of the same problem occurs in the case of women who do not use contraceptives properly or who want more children. The medical or biological fertility rate with contraceptives might be low, but the rate meaningful from the point of view of the program is high. That is, the expenditures on contraceptive advice and services for these women do not bring about any reduction in their fertility rate.

X-2 CHOICE OF TARGET POPULATION WHEN ONLY DIFFERENCES IN FERTILITY DUE TO AGE ARE CONSIDERED

X-2-1 Minimization of Births with Costs of Prenatal and Delivery Care Excluded

The simplest model will be introduced in this Section. Since it is assumed that the objective desired is to minimize the number of births, women in different age groups should be induced to adopt contraceptive techniques. The basic question is how to select these women. Two restrictions have to be considered. The first is the obvious one that the number of women participating in the program for each age group cannot be larger than the total number of women in the same age group. The second constraint is that the cost should not exceed the financial resources available.

In the formulation of this model it will be assumed that the time horizon of the program goes from date 0 to date T, i.e., the subscript t that will denote time, ranges from t=o to t=T. The time unit between two consecutive values of t will be designated below as one year, in order to simplify presentation. In the numerical example, the time period between t and t+1 will be five years.

In this Section it will be assumed that T is small enough so that the changes in fertility during the program will not affect the number of women in the new generations who reach the age of fertility during the duration of the program. This means that the time horizon is fifteen years at most. With a longer time horizon, the births avoided at the beginning of the program would modify the number of women who reach the age of fertility and enter the program fifteen years later--assuming that this is the age when fertility begins. The problems brought about by an extension of the time horizon will be considered later.

To simplify the notation, the age at which a women becomes fertile will be denoted with 0, and the age at which her fertility ends, with H. The age specific fertility rates without contraception will be denoted with α_h and the same with contraception will be denoted with β_h. These rates are assumed to be known. It should be clear that α_h and β_h are both zero for all women younger

and older than the ages of fertility; i.e.

$$\alpha_h = \beta_h = 0 \qquad \text{for:} \quad \begin{matrix} h < 0 \\ h > H \end{matrix}$$

The number of women of age h in year t will be denoted with $P_{h,t}$. With this notation, groups of women below the age of fertility have a negative age subscript, and for women at the beginning of fertility, say fifteen years, the subscript h=0. The number of women in all age groups in all time periods is assumed to be known.

The main unknowns in the model are those representing the number of women that should receive contraceptive advice and service in each of the years that the program is active. These variables will be denoted with $m_{h,t}$. The solution of the problem is to determine admissible values of $m_{h,t}$ that minimize births.

A first characteristic that the values of the $m_{h,t}$ must satisfy in order to be admissible is that

$$m_{h,t} \geq 0, \qquad \begin{matrix} h = o,\ldots,H \\ t = o,\ldots,T \end{matrix} \qquad \text{X-2-1}$$

i.e., the number of women participating in the program cannot fall below zero.

A natural constraint is that the number of women in the program must be less than or equal to the total number of women in the participating age groups, i.e.,

$$P_{ht} \geq m_{h,t} \qquad \begin{matrix} h = o,\ldots,H \\ t = o,\ldots,T \end{matrix} \qquad \text{X-2-2}$$

Next the constraint imposed by the resources available can be considered. To begin with, attention will be paid only to the financial resources needed for current expenditures in population control. Cost of prenatal and delivery care will be excluded from the formulation up to Section X-2-2. To consider resources, let γ denote the current expenditures/patient ratio. Then the total expenditures require in year t will be

$$\gamma \sum_{h=o}^{H} m_{ht}$$

One of two assumptions can be made with respect to the resources available. One is that a lump sum is available for all the periods of the program. The other is that new resources become available each year. To simplify, the first assumption will be adopted here, and again for simplification, it will be assumed that the part of the funds that remain idle during the program do not accrue any interest. Under these assumptions, if R is the total value of the resources available for the whole period, the resource constraint is

$$R \geq \sum_{t=o}^{T} \gamma \sum_{h=o}^{H} m_{h,t} \qquad \text{X-2-3}$$

The equations presented so far give the basic frame of reference for the model. They show: (a) the number of women in the population; (b) the number of participants in the program; (c) the relationship between (a) and (b); and (d) the relationship between participants and expenditures. The next step is to evaluate the number of births, taking into consideration the number of women participating in the program ($m_{h,t}$ $h = 0,\ldots,H$ and $t = 0,\ldots,T$).

In any period between t and t+1, the number of births will be

$$B_t = \sum_{h=0}^{H} [\alpha_h(P_{h,t} - m_{h,t}) + \beta_h m_{h,t}] \qquad \text{X-2-4}$$

The first term on the right side of X-2-4 refers to the women not participating in the population program, while the second refers to the women who are participating.

The total number of births during the period of duration of the program will be

$$B = \sum_{t=0}^{T} \sum_{h=0}^{H} [\alpha_h P_{h,t} + (\beta_h - \alpha_h) m_{h,t}] \qquad \text{X-2-5}$$

The objective of a population control program is assumed to be the minimization of B by the proper selection of $m_{h,t}$. The optimal target population for demographic planning will be formed with those $m_{h,t}$ that minimize B. The selection should be made under the constraints in equations (X-2-1) and (X-2-2) with

respect to the number of women and (X-2-3) with respect to the financial resources available.

To complete the presentation of the model in equations (X-2-1), (X-2-2), (X-2-3) and (X-2-5), a simple numerical example is included below. In this example it will be assumed that the period of time between two consecutive values of t is five years. A total interval of fifteen years will be considered; i.e., T=2.

The data required for the application of this model are:

(a) The number of fertile women in age groups of five years in dates t = 0,1,2. These data appear in Table X-2-1. These figures are used in the objective function (X-2-5) and constraints (X-2-2).

(b) The fertility rates α_h and β_h with and without contraceptives. They appear in Table X-2-2. These rates are also used in the objective function (X-2-5).

(c) The cost per patient γ is assumed to be $10.00 per year.

The total resources available R are assumed to equal $10,000,000.00. Useful information that can be derived from the data in Tables X-2-1 and X-2-2 is that the number of births without the use of contraceptives would be 457,000.

The values of the $m_{h,t}$ that minimize the number of births in equation (X-2-5), according to the data in Tables X-2-1 and X-2-2 appear in Table X-2-3. With these values, the number of births is 200,000. This is the minimum that can be achieved with the resources available, taking into consideration the total number of women, their age distribution, and fertility rates.

It should be observed that the solution in Table X-2-3 not only has a clear intuitive meaning, but also that it could be obtained without lengthy computations. This can be seen as follows. Since the cost of participation for women is constant for all ages, the way to minimize births is to provide contraceptive services to those women for whom the difference in fertility rates with and without contraceptives is the largest, i.e., when $\alpha_h - \beta_h$ is the largest.

Table X-2-1

Population of Women from which the target population for a demographic plan should be selected
(in thousands)

Age Groups	h	Year 0 t=o	Year 5 t=1	Year 10 t=2
15-19	0	158	175	211
20-24	1	145	153	170
25-29	2	122	140	148
30-34	3	100	118	135
35-39	4	88	96	113
40-44	5	74	84	92
45-49	6	60	70	81
50-54	7	49	56	66
55-59	8	38	45	52

Table X-2-2

Fertility rates for 5-year periods with and without contraceptives

Age Groups	h	Without Contraceptives α_h	With Contraceptives β_h
15-19	0	.134	.005
20-24	1	.280	.015
25-29	2	.280	.018
30-34	3	.224	.016
35-39	4	.124	.016
40-44	5	.059	.010
45-49	6	.025	.010
50-54	7	.010	.005
55-59	8	.005	.000

TABLE X-2-3

Number of women that should participate in the program to minimize the number of births according to the model in Section XVI-2-1

(Thousands)

Age Group	h	Year 0 t=0 $m_{h,0}$	Year 5 t=1 $m_{h,1}$	Year 10 t=2 $_{h,2}$
15-19	0	0	0	0
20-24	1	145	153	170
25-29	2	122	140	148
30-34	3	100	22	0
35-39	4	0	0	0
40-44	5	0	0	0
45-49	6	0	0	0
50-54	7	0	0	0
55-59	8	0	0	0
TOTAL		367	315	318

This clearly occurs in the case of women in the 20-24 age group, and as a consequence, as many women of age 20-24 for t = 0,1,2 should be included. The actual period chosen from the three available does not make any difference, as long as we are concerned with a time horizon of only fifteen years. (Obviously, if the time horizon were longer, the resources should be applied in the earlier years of the program in order to reduce the number of women entering the fertile age groups in later years). If funds remain after all women between the ages of 20-24 in all the years have been included in the program, members of the age group with the next highest fertility rate (i.e., 25-29) should be included. If several age groups have the same fertility rates, it makes no difference which receives attention first.

This procedure for choosing target groups should continue as long as funds are available.

The importance of the model in this section is that it provides a point of departure for the construction of more complex models.

X-2-2 Minimization of Births With Costs of Prenatal and Delivery Care Included

The question of whether to include prenatal and delivery costs as part of the costs of a population program depends upon the point of view adopted. An agency in charge only of advice and service with respect to methods of birth control would not be interested in prenatal and delivery costs. However, in many cases, both contraception and prenatal and delivery services are provided by the same agency. To consider this case, equation X-2-3 must be modified. To do this, let d denote cost per patient of prenatal and delivery care.

Then the total cost of this service would be

$$d * \sum_{t=o}^{T} \sum_{h=o}^{H} [\alpha_h P_{h,t} + (\beta_h - \alpha_h) m_{h,t}]$$

This cost should be added to that of contraceptive services to obtain the total costs of the services. These total costs should be less than or equal to the resources R available. The remaining equations in the model do not change.

It is obvious that the number of patients that can be served with a fixed amount of resources is larger when the program has only contraception expenditures, instead of expenditures for both contraception and prenatal and delivery care. In other words, the costs when only contraception services are provided is lower than those in the case in which both contraceptive services and prenatal and delivery care are provided. This conclusion brings up a problem.

Since the cost per birth avoided is lower without prenatal and delivery care, why are these services provided? This simply shows that all population and family plans have implicit objectives that override the explicit one of minimizing births.

Another point is that in actual practice, the cost per patient of contraceptive techniques usually is lower if these services are provided together with prenatal and delivery care. This seem to contradict the conclusion reached before. The reason is that the question studied with the model and the practical situation mentioned are not identical. In the model, the question is whether to provide prenatal and delivery care at all. The practical situation is whether to establish one service to be in charge of both contraception and prenatal and delivery care, or to operate two separate services. When these are the alternatives considered, it will be found that frequently one service will provide contraception and prenatal and delivery care at a lower cost than two specialized services. However, the rule stated can have exceptions, and every case should be solved on its own merits.

X-3 CHOICE OF A TARGET POPULATION WHEN WITHDRAWAL FROM THE PROGRAM IS NOT CONTROLLED BY THE PLANNER

The analysis of the results in Table 2-3 shows that in the model in Section X-2 it is assumed that women enter and leave the population control program at the will of the planners. For instance, none of the 140,000 women of age 25-29 in year 5 remain in the program in year 10. This assumption might or might not be reasonable. One possible alternative that will be considered in this section

the women remain in the program as long as they wish. As a consequence, the program has to provide services to all the women remaining in it from previous years, and also take into consideration those that abandon the program by their own will. To consider these aspects in a mathematical model, the formation of any $m_{h,t}$ has to be considered, as well as its final distribution.

The formation of any $m_{h,t}$ is given by the equation:

$$m_{h+1,\ t+1} = n_{h+1,\ t+1} + r_{h,t} \qquad \text{for } h = 0,\ldots, H \quad t = -1,\ldots,T \qquad \text{X-3-1}$$

where

$n_{h,t}$ is the number of women of age h entering the program between t and t+1

$r_{h,t}$ is the number of women of age h+1 remaining in the program at time t+1 from those of age h who were in the program at time t.

It should be observed that in X-3-1, t ranges from -1 to T. This permits us to assume that some women were using contraceptives before the initiation of the program, and that once the program was initiated, they became a part of it. The values of $r_{h,-1}$ for h=o,...,H are assumed to be known.

Alternative forms of behavior for the women in the program at date t are described in the following formula:

$$m_{h,t} = r_{h,t} + b_{h,t} + d_{h,t} \qquad \text{X-3-2}$$

where

$b_{h,t}$ denotes the number of women that abandon the program between t and t+1

$d_{h,t}$ denotes the number of deaths between t and t+1 among the women of age h in the program at date t.

To introduce the elements in formulas (X-3-1) and (X-3-2) into the model in Section X-2, several assumptions are required.

It will be assumed that

where

σ_h is the survival rate for women of age h, that

$$r_{h,t} = \mu_h m_{h,t} \qquad \text{X-3-3}$$

where

μ_h is the probability that a woman in the program at date t will remain in it up to date t+1.

The probabilities μ_h of remaining in the program are formed by the product of the probability σ_h of surviving from one age to the next and the probability that a survivor remains in the program. If this latter probability is denoted with μ'_h, then

$$\mu_h = \sigma_h \mu'_h$$

In the formulation above, several reasons for leaving a population control program are excluded. It might be more reasonable to assume that the probability of leaving a program depends not on the age of the patient, but of the number of years that she has participated in the program. To include this assumption in the model complicates its formulation substantially, because it adds a third dimension to all the variables (the number of years in the program is added to age and time). For this reason, this possibility will not be explored here.

Finally it follows that

$$b_{h,t} = \eta_h m_{h,t} \qquad \text{X-3-4}$$

where $\eta_h = (1 - \mu'_h)\, \sigma_h$

To consider the number of women that abandon the program, their total for a fixed age has to be evaluated. The total number of women of age h that have abandoned the program at date t is the total of those that abandon the program between t-1 and t, plus those who abandoned it before and survived up to date t-1, i.e.,

$$a_{h,t} = b_{h-1,t-1} + \sigma_{h-1} a_{h-1,t-1} \qquad \text{X-3-5}$$

where

$a_{h,t}$ is the total number of women of age h that have abandoned the program up to date t, and $a_{h,0} = 0$ for all h's, i.e., no one abandoned the program at its beginning.

The formulas above make it possible to modify the model in equations X-2-1, X-2-2, X-2-3 and X-2-5 to consider:

(a) That a proportion of the women in the program at date t will remain in it at date t+1, and some dropouts of previous years might re-enter the program.

(b) That a proportion of the women in the program will abandon it and never return.

(c) A combination of the alternatives (a) and (b) above.

The introduction of alternative (a) does not imply any explicit modification of formulas X-2-1 to X-2-3 and X-2-5. However, in the solution of the problem, equations X-3-1 to X-3-5 must be considered explicitly. One possible way to do this is to express all the formulas in the model in terms of the $n_{h,t}$. The results obtained using this approach are presented in the example below.

In addition to the data presented for the example in Section X-2, data on the rate μ_h are needed for the model in this section. They are presented in Table X-3-1. To simplify, the values of $m_{h,-1}$ are assumed to be zero. The results obtained are presented in Table X-3-2 in terms of $n_{h,t}$ using formula X-3-1 and in Table X-3-3 in terms of $m_{h,t}$. A comparison of Tables X-2-3 and X-3-3 shows the impact of the different assumptions. In the second case, the program grows from one year to the next. In the first case, the program remains stable with respect to the number of participants. The minimum number of births in the second case is 207,000, i.e., fewer births are avoided. This is a consequence of the additional restrictions imposed.

In order to consider possibility (b) above (i.e., that a proportion of women leaves the program and never returns to it), constraint X-2-2 in the earlier model must be modified with the explicit use of $a_{h,t}$. In this case it becomes:

$$P_{h,t} - a_{h,t} \geq n_{h,t} \qquad h=0,\ldots,H \quad t=0,\ldots,T \qquad \text{X-3-6}$$

Table X-3-1

Survival rates and probability that women remain in the program.

Age Groups	h	Survival Rates σ	Probability of Remaining μ'	μ
15-19	0	.97	.93	.90
20-24	1	.97	.88	.85
25-29	2	.97	.82	.80
30-34	3	.96	.78	.75
35-39	4	.95	.74	.70
40-44	5	.94	.69	.65
45-49	6	.93	.65	.60
50-54	7	.92	.60	.55
55-59	8	.89	.56	.50

Table X-3-2

Number of women by age and year of entrance that should enter in the population control program to minimize the number of births.

(Thousands)

Age Groups	h	Year 0 t=o $n_{h,o}$	Year 5 t=1 $n_{h,1}$	Year 10 t=2 $n_{h,2}$
15-19	0	0	0	0
20-24	1	145	153	170
25-29	2	45	17	18
30-34	3	0	0	23
35-39	4	0	0	0
40-44	5	0	0	0
45-49	6	0	0	0
50-54	7	0	0	0
55-59	8	0	0	0

Table X-3-3

Number of Women that should participate in the program to minimize the number of births, according to the model in Section VII-3

(Thousands)

Age Groups	h	Year 0 t=o $m_{h,o}$	Year 5 t=1 $m_{h,1}$	Year 10 t=2 $m_{h,2}$
15-19	0	0	0	0
20-24	1	145	153	170
25-29	2	45	140	148
30-34	3	0	36	135
35-39	4	0	0	27
40-44	5	0	0	0
45-49	6	0	0	0
50-54	7	0	0	0
55-59	8	0	0	0
Total		190	329	480

The other equations in the model do not need to be modified. The problem now is to minimize the objective function in X-2-5 subject to the constraints in equations X-2-1, X-2-3, and X-3-1 to X-3-6.

X-4 CHOICE OF TARGET POPULATION WHEN THE PLANNERS CAN INFLUENCE THE PROPORTION OF WOMEN WITHDRAWING FROM THE PROGRAM

In the model in Section X-3 it is assumed that the proportion of women abandoning a population program in a given period is fixed. In reality this is not the case. That proportion would vary, depending on the efforts made to retain the women. Several actual programs employ social workers who telephone or visit patients who have missed appointments, whether for a medical check up or to receive contraceptive materials. These efforts reduce the number of women abandoning a program, but naturally they add some cost. As a consequence, a choice can be made between using resources to retain women in the program, or to increase the number that begin to participate in the program, even if a large proportion of them drop out. In this Section the model in Sections X-2 and X-3 will be extended to include the problem described above.

In the model in Section X-3 it is assumed that the patients in a family planning program will abandon it in fixed and known proportions. In the present case, several alternative dropout possibilities will be assumed. To do so, equations X-3-1 and X-3-2 are modified as follows:

$$m_{i,h+1,t+1} = n_{i,h+1,t+1} + r_{i,h,t} \qquad \text{X-4-1}$$

and

$$m_{i,h,t} = r_{i,h,t} + b_{i,h,t} + d_{i,h,t} \qquad \text{X-4-2}$$

where the subscript i denotes that the women will be treated in the manner i. For instance, i=1 could mean that a woman does not receive reminders of her appointment when she misses one; i=2, that she receives one telephone reminder; i=3, one telephone reminder and a personal visit, etc. It will be assumed that i ranges from 1 to I.

Following equations X-4-1 and X-4-2, equations X-3-3 and X-3-4 should also be modified to consider the alternatives $i=1,\ldots,I$.

To relate the new variables with those in the models in Section X-3, the following definitions will be used:

$$m_{h,t} = \sum_{i=1}^{I} m_{i,h,t}$$

$$b_{h,t} = \sum_{i=1}^{I} b_{i,h,t}$$

With these definitions, the objective in X-2-5, equation X-2-1, and the constraint X-3-6 are not modified and can be used in determining programs for minimizing births that involve different drop out rates for participating women.

In the model in X-3 the cost per participant in the program remains the same as in Section X-2. In the present section, there is a different cost for each alternative i. As a consequence, the cost of $m_{i,h,t}$ women participating would be $\gamma_i m_{i,h,t}$. The total cost for a fixed age and date is:

$$C_{h,t} = \sum_{i=1}^{I} \gamma_i m_{i,h,t} \qquad \text{X-4-3}$$

and the total cost of the program is:

$$C = \sum_{t=o}^{T} \sum_{h=0}^{H} C_{h,t} \qquad \text{X-4-4}$$

In consequence, the financial resources constraint in equation X-2-3 becomes

$$R \geq \sum_{i=1}^{I} \sum_{t=o}^{T} \sum_{h=o}^{H} \gamma_i m_{i,h,t} \qquad \text{X-4-5}$$

In summary, the problem of minimizing births, when resources can be used both to provide contraceptive advice and services to women in the program and to attempt to retain them in the program whenever convenient, reduces to the minimization of equation X-2-5 subject to constraints, X-2-1, X-3-3, and X-4-5, and taking into consideration the definitions in X-4-1 and X-4-2.

X-5 EXTENSION OF THE PLANNING PERIOD SO THAT BIRTHS AVOIDED INFLUENCE THE NUMBER OF WOMEN IN THE POPULATION

One of the assumptions of the models described is that the planning period cannot extend beyond the time when the reduction of births affect the number of women of the age of fertility. This assumption will be discarded in this Section.

To do so, the planning period is divided into two parts. In the first, from t=o, to t=T', the number of women in the population is determined by births before date t=0. In this case the values of $P_{h,t}$ are not influenced by the population control program and are assumed to be known. In the second period, covering from t=T' +1 to t+T, the number of women in the population is determined by the number of births in years t=0,...,T' or years following them. In this case the number of women reaching fertile age would be:

$$P_{ot} = \delta \left(\prod_{h=-j}^{-1} \sigma_h \right) B_{t-j} \qquad t=T'+1,T \qquad \text{X-5-1}$$

where

- j denotes the number of years between birth and the beginning of fertility
- B is the number of births in years between t-j and t-j+1
- $\left(\prod_{h=-j}^{-1} \sigma_h \right)$ is the probability of surviving between t-j and 0
- δ is the proportion of women with respect to total number of births.

Formula X-2-5 provides the information required to compute the B_t in formula X-5-1, and as a consequence, the values of P_{ot} for t=T' + 1,...,T. Apart from the explicit consideration of equation X-5-1, no other modification is introduced in the models in Sections X-2, X-3 or X-4.

X-6 ADDITIONAL GENERALIZATIONS

The models in Sections X-2 to X-5 constitute a basic framework for the

determination of an optimum target population in demographic planning. They can be expanded to include several other aspects. Some of them will be mentioned here; however, their mathematical formulation will not be presented.

A first set of possible expansions is related to the possibility of considering criteria in addition to age for subdividing the population. These criteria should be chosen by their impact on fertility rates. Examples could be the subdivision of the population by social class, education, level of income, family size, etc.

Another set of possible expansions is related to the possibility of a more detailed consideration of the costs of a family planning program. In the models above, only the current financial expenditures are included. A first extension would also include capital expenditures. Explicit consideration can be made of other forms of cost, such as costs in human resources and in physical facilities.

Another possibility is to modify the objective functions. Several alternatives are discussed in later chapters. Finally, the different contraceptive methods could be explicitly considered. This question will be studied in Chapter XI.

CHAPTER XI

POPULATION PLANNING: OPTIMUM USE OF CONTRACEPTIVE METHODS

XI-1 INTRODUCTION

In Chapter X models to determine population targets for demographic planning are presented. An obvious limitation of these models is that they do not take into consideration the different contraceptive techniques available. In this Chapter, attention will be focused on the question of choosing among various contraceptive methods.

It is useful to classify contraceptive methods in two distinct categories. Direct contraceptive methods include the "rhythm method", oral contraceptives, or other devices designed to avoid pregnancies. An indirect contraceptive method can be classified as any factor that affects the motivation or ability to use a direct method. The education and employment of women can be included in this category. In the analysis to be made here, only direct methods are considered. However, it is possible to use part of the resources of a population and family planning program to improve education or to create employment opportunities for women, rather than for providing direct methods. There are no theoretical difficulties in modifying the models to be presented in order to take into consideration the effects of increased education or additional employment opportunities, either on pregnancy rates or on the expenditures required. The modifications required in order to include these indirect techniques do not affect their basic structure. Only a change in the meaning of the symbols is necessary. This Chapter will not consider models for choosing indirect contraceptive methods, because serious problems exist in the estimation of the required parameters. This is due to the fact that only a part of the costs of education or of increased employment opportunities should be assigned to a population and family planning program. Most of the costs should be assigned to the other benefits of education and employment. Any determination of these parts of the costs will be somewhat arbitrary.

The definition and estimation of the fertility rates which are meaningful from the point of view of a population program presents problems even when only direct contraceptive methods are considered. Some of these problems were already observed in Section X-1. In addition, a distinction should be made between the reduction of fertility obtained using a method under experimental conditions and that obtained in actual practice. Some reasons for this possible difference will be explained below.

First, it should be remembered that the fertility rate for couples using a contraceptive method is computed by dividing the number of pregnancies for women using a contraceptive method during a specific period of time by the total number of women using that method during the same period. In experimental studies the total number of women remains constant. In actual practice, some women within the tested population may wish to discontinue the use of the contraceptive method. There are several reasons for this, ranging from the appearance of detrimental side effects to simple lack of interest and even a change of mind and desire to have children. This poses the question of who are the couples using contraceptive method i. Should the test group include all the couples that begin using the method, or should it include only the couples that use the method for a certain period, or finally, only the couples that use it during the entire period. To answer this question and choose among the alternatives, the final purpose of the information obtained should be considered Here it will be assumed that the final purpose is to plan population growth and family size in large population groups, and that a "natural" phenomenon in these groups is that some couples who begin using a contraceptive method stop doing so before the end of the reference period, regardless of reason. As a consequence, in evaluating the fertility rates when using contraceptive i, to be denoted with β_i, the important question is not the proportion of pregnancies that could have been avoided if couples had used the method under experimental conditions during the entire period under investigation. On the contrary, in evaluating the β_i, it should be taken into consideration that some contraceptive methods have characteristics that tend to reduce the

length of time during which couples continue to use them, or the proportion of couples who use the method over the whole period.

These observations also apply to the second reason for differences between fertility rates evaluated under experimental and actual conditions. This reason is that contraceptive methods might be used incorrectly, and pregnancy result. If a method, due to its characteristics, is easier to use, and for this reason the couples using it have fewer pregnancies, it has an advantage over the other methods that should be included in the computation of the β_i. In other words, it is possible to devise experimental conditions under which most if not all methods of contraception are 100% effective. The question is whether these experimental conditions will hold up in actual practice.

In summary, all the couples who begin using or declare that they will use a contraceptive method should be included in the evaluation of the β_i, regardless of whether they continue to do so during the whole reference period, or whether they use it correctly.

A problem that is more technical than conceptual appears in the case of couples who begin using one contraceptive method, say method i, and shift to another, say h, during the period covered by the investigation. In this case, the educational efforts used to induce couples to use contraceptives cannot be considered lost. However, from the point of view of method i, the couples stopped using it, and thereafter the risk of pregnancy would be the same as that for non-protected couples. The computation of β_i should take this assumption into consideration, despite the fact that the actual risk of pregnancy is that of couples using method h. On the other hand, these couples may or may not be included in the computation of β_h. If they are not included, the computation of β_h with the initial group is correct. If they are included, it should be assumed that they have already initiated contraceptive practice using method h, and at that moment they are included in the test group. That is, their previous use of method i should not be considered.

These observations show that in the computations of the β_i, two elements should be considered: one is the risk of pregnancy when a contraceptive method is used, and the other is the risk of discontinuing the use of the method or of misusing it. These two aspects should be considered when the β_i coefficients for several periods are estimated from the data in one period. Any estimation based only on the risk of pregnancy is seriously biased.

XI-2 CHOOSING A CONTRACEPTIVE METHOD WHEN ONLY TOTAL COST IS CONSIDERED

XI-2-1 Minimization of Pregnancies

In the model to be presented, it is assumed, as in Chapter X, that the objective of population planning is to minimize the number of pregnancies through the use of direct contraceptive techniques, such as condoms, pills, foams, etc. It will be assumed that there are "n" direct methods of contraception, where "n" is any positive number. The methods will be designated with a number that ranges from 1 to n. Only the mean effect of each method on the rate of pregnancy is considered. That is, the differences in effectiveness of the methods of contraception, for example, when couples having different socio-economic status use them, are not considered. Finally, only the financial costs of using contraceptive techniques are considered. The final conclusion reached with the model is the one that could be logically expected: the method having the lowest cost per pregnancy avoided is the one that should be used.

The following notation will be used below:

α = normal yearly rate of pregnancy

β_i = rate of pregnancy among women in couples using contraceptive method i; i=1,...,n, during one year. By definition, these parameters β_i are obtained by dividing the number of pregnancies occurring among women in couples using contraceptive method i during one year, by the number of couples. Problems in applying this definition were mentioned in Section XI-1.

c_i = cost per couple using contraceptive method i, i=1,...,n during one year.

N_i = number of couples that should use contraceptive method i in order to maximize the number of pregnancies avoided.

R = total resources available.

The number of pregnancies in the group of women using contraceptive method i would be

$$\alpha N_i \quad i=1,\ldots,n$$

if they had used no contraceptives at all.

From the definition of β_i and N_i it follows that the total number of pregnancies among women in couples using method i is

$$\beta_i N_i; \quad i=1,\ldots,n.$$

As a consequence, the number of pregnancies avoided among women in couples using the ith method would be

$$(\alpha - \beta_i)N_i; \quad i=1,\ldots,n$$

and the total number of pregnancies avoided would be

$$B = \sum_{i=1}^{n} (\alpha - \beta_i)N_i \qquad \text{XI-2-1}$$

It is assumed in this section that the maximization of this total is the objective of a population or family planning program. The procedure for maximizing the total number of pregnancies avoided is the modification of the size N_i of the groups of women using contraceptive method i. In determining the values that the N_i should have, attention should be paid not only to the effectiveness of the contraceptive method, i.e., to the yearly number of pregnancies avoided; but also to the cost of using the different contraceptive methods. For this, with the notation above, the total cost of using method i during one year will be equal to

$$c_i N_i,$$

and the total cost of a population plan would be

$$\sum_{i=1}^{n} c_i N_i$$

This total cost should be less than or equal to the resources available, i.e.,

$$R \geq \sum_{i=1}^{n} c_i N_i \qquad \text{XI-2-2}$$

In summary, the problem reduces to the maximization of the number of pregnancies avoided, i.e., (XI-2-1), subject to the resource constraint XI-2-2 and to

$$N_i \geq 0. \quad i = 1, \ldots, n. \qquad \text{XI-2-3}$$

Condition XI-2-3, that the number of women using contraceptive method i cannot have a negative value, does not need any justification.

In order to solve explicitly the problem in equations XI-2-1 through XI-2-3 two simplifying assumptions will be made:

(a) only two direct contraceptive methods will be considered, and

(b) all available resources will be utilized

With these assumptions, the problem reduces to the maximization of

$$B = (\alpha - \beta_1) N_1 + (\alpha - \beta_2) N_2 \qquad \text{XI-2-4}$$

subject to

$$R = c_1 N_1 + c_2 N_2 \qquad \text{XI-2-5}$$

and to

$$N_i \geq 0 \quad i = 1, 2. \qquad \text{XI-2-6}$$

To solve explicitly the problem in equations XI-2-4 through XI-2-6, let

$$N_1 = \frac{R}{c_1} - \frac{c_2}{c_1} N_2 \qquad \text{XI-2-7}$$

and from XI-2-4 and XI-2-7, it follows that

$$B = R \frac{\alpha - \beta 1}{c_1} + [(\alpha - \beta_2) - \frac{c_2}{c_1} (\alpha \quad \beta_1)] N_2 \qquad \text{XI-2-8}$$

According to equation XI-2-8, the number of pregnancies avoided will increase when N_2 increases, if

$$(\alpha - \beta_2) - \frac{c_2}{c_1} (\alpha - \beta_1) > 0,$$

otherwise it will decrease. This means that contraceptive method two should be used as often as possible, if

$$\frac{c_1}{\alpha - \beta_1} > \frac{c_2}{\alpha - \beta_2} \qquad \text{XI-2-9}$$

If the inequality in XI-2-9 is reversed, contraceptive method one should be utilized.

To interpret inequality XI-2-9, observe that the cost of avoiding $(\alpha - \beta_i)N_i$ pregnancies is c_iN_i. As a consequence, the cost of avoiding one pregnancy is

$$\frac{c_iN_i}{(\alpha - \beta_i)N_i} = \frac{c_i}{\alpha - \beta_i}$$

thus, inequality XI-2-9 clearly demonstrates that in order to maximize the number of pregnancies avoided, method two should be used if it has the lowest cost per pregnancy avoided.

Assuming that method 1 brings about the greatest reduction in the number of pregnancies, the formula for the actual number of pregnancies avoided can be obtained. For this, from equation XI-2-2, the value of N_1 would be $N_1 = \frac{R}{c_1}$ and $N_2 = 0$ and from equation XI-2-1, the number of pregnancies avoided would be

$$B = \frac{\alpha - \beta_1}{c_1} R \qquad \text{XI-2-10}$$

therefore, if $\frac{c_1}{\alpha - \beta_1}$ is the cost of reducing the total by one pregnancy, then the total number of pregnancies that can be avoided with a total amount R of resources is

$$\frac{\alpha - \beta_1}{c_1} R$$

To avoid unnecessary algebraic manipulation, the method of solution of the model in equations XI-2-1 through XI-2-3 will not be discussed here. However, the conclusion derived from it can be presented. It is that the contraceptive method that keeps

$$\frac{c_i}{\alpha - \beta_i} \qquad \text{XI-2-11}$$

to a minimum should be used. With this method, the number of pregnancies avoided will be maximized, when using a fixed amount R of resources.

A numerical example of the previous model will be presented below. The information required appears in Table XI-2-1. The value of α is found in column 3, corresponding to no contraceptive method. The values of β_i, i.e., pregnancy rates per 100 women also appear in column 3. The total cost in dollars, c_i, appear in column 7. These figures reflect the information which is available. However, they have strong limitations, and should not be taken as real data.

The results in Table XI-2-2 are obtained by applying formula XI-2-11. They show that the intrauterine devices are the most effective contraceptive method. Since the values in Table XI-2-1 are only examples, the same is true for the results in Table XI-2-2. These results could be altered if any of the values used in formula XI-2-11 are changed.

XI-2-2 Minimization of Births

An immediate extension of the model in Section XI-2-1 is that which considers the objective to be the minimization of the number of births, rather than the minimization of the number of pregnancies. It is useful to consider this case because it permits us to consider the costs of prenatal and delivery care, as well as including abortion as one of the methods of avoiding births. As in the case of Chapter X, it will be assumed that all pregnant women who do not choose abortion will receive prenatal and delivery care.

The first step in the extension of the model in Section XI-2-1 is to consider the rate of live births by pregnant women. This ratio will be denoted by τ.

Using the notation in section XI-2-1, the number of live births in αN_i pregnant women would be

$$\tau\alpha N_i$$

Table XI-2-1

Information required to apply the model in sections II-1 and II-3

i	Contraceptive Method	Pregnancy rate per 100 women	Costs: Doctor's Visits	Costs: Doctor's Dollars	Costs: Implements Dollars	Costs: Total Dollars
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	None	30	---	---	---	---
1	Condom	11	---	---	40.0	40.0
2	Diaphragm with cream	15	1	10.0	20.0	30.0
3	Foam Tablets	15	---	---	14.0	14.0
4	I.U.D.	6	2	20.0	.5	20.5
5	Oral	3	3	30.0	25	55.0

Source: The figures in this Table reflect actual conditions but cannot be considered real data. Elaborated from:

(1) Searly, G.D. and Co.
A prescription for family planning

(2) The Consumers Union Report on
Family Planning

Table XI-2-2

Determination of the most effective contraceptive method

i	Contraceptive method	$\alpha - \beta_i$	$\frac{c_i}{\alpha - \beta_i}$	rank
1	Condom	19	2.11	5
2	Diaphragm	15	2.0	4
3	Foam Tablets	15	.93	2
4	I.U.D.	24	.83	1
5	Oral	27	1.95	3

SOURCE: Explained in the text

This number, due to the use of contraceptive technique i, would be reduced to

$$\tau\beta_i N_i$$

As a consequence, the reduction in the number of births due to the use of contraceptive method i is

$$\tau(\alpha - \beta_i)N_i$$

and the total reduction in number of births is

$$T = \sum_{i=1}^{n} \tau(\alpha - \beta_i)N_i \qquad \text{XI-2-12}$$

The objective of population and family planning is assumed to be the maximization of this reduction.

To introduce prenatal and delivery costs, let

d = cost per patient of prenatal and delivery care.

Then the total cost of these services, assuming that all pregnant women receive them, and without a population program, will be

$$\sum_{i=1}^{n} d\alpha N_i$$

The reduction of this cost when a population program is in effect is

$$\sum_{i=1}^{n} d(\alpha - \beta_i)N_i;$$

as a consequence, the total cost of prenatal and delivery care with a population program will be

$$\sum_{i=1}^{n} d\beta_i N_i.$$

This prenatal and delivery cost should be added to that of contraception to obtain the total cost of the plan. This total cost must be less than or equal to the resources available, i.e.,

$$R \geq \sum_{i+1}^{n} (c_i + d\beta_i)N_i \qquad \text{XI-2-13}$$

Finally, condition XI-2-3 above must also be satisfied in the present case.

Before discussing the solution of the problem in equations XI-2-3, XI-2-12 and XI-2-13 the inclusion of abortion will be considered. It can be assumed that abortion simply reduces the number of births to zero, i.e., the number of births

avoided would be

$$\alpha N_{n+1}$$

where n+1 is the identification assigned to abortion as a method of reducing number of births.

The cost of abortions would be

$$c_{n+1}N_{n+1}$$

where

c_{n+1} is the cost per abortion.

The two expressions dealing with abortion can be introduced in equations XI-2-3, XI-2-12 and XI-2-13. The same result is obtained, making

$$\beta_{n+1} = 0$$

and extending the range of variation of i up to n+1.

Comparing the problem in equations XI-2-3, XI-2-12 and XI-2-13 with that in equations XI-2-1 to XI-2-3 it should be clear that the optimum technique, including contraception and abortion

$$\frac{c_i + d\beta_i}{\alpha - \beta_i} \qquad \text{XI-2-14}$$

Comparing costs XI-2-11 and XI-2-14 it is clear that

$$\frac{c_i + d\beta_i}{\alpha - \beta_i} > \frac{c_i}{\alpha - \beta_i} , \qquad \text{XI-2-15}$$

meaning that the cost per patient of contraceptive techniques is always lower than that for both contraception and prenatal and delivery services. Some observations with respect to these results were made in Section X-2-2.

XI-3 CHOOSING A CONTRACEPTIVE METHOD WHEN THE COSTS OF "SIDE EFFECTS" ARE CONSIDERED

The treatment of costs in the models presented in the previous sections of this Chapter and of Chapter X has two obvious limitations: (a) only costs directly related to contraception and pregnancy are considered; and (b) it is assumed that all the costs of using a contraceptive method can be expressed in terms of money, and that only financial resources are limited. In this section the fact

that a population program might have costs not directly related to pregnancy will be considered. Among these, explicit attention will be paid only to the medical costs associated with the side effects caused in some cases by the use of contraceptives. The modification required in the models to include this case is quite simple. The following information is required. First, the proportion of persons in couples using contraceptive method i who will suffer side effects must be known. This proportion will be called π_i. Second, the cost of treating these side effects, denoted with k_i must be known. With this notation, the number of persons in couples using contraceptive i who suffer side effects will be

$$\pi_i N_i$$

and the cost of treating these persons will be:

$$k_i \pi_i N_i$$

as a consequence, the total cost of the population and family planning will be

$$\sum_{i=1}^{n} (c_i + k_i \pi_i) N_i$$

and this value should replace the total cost in condition XI-2-2. The modification needed to consider the minimization of births instead of that of pregnancies should be quite clear and will not be explained here.

XI-4 CHOOSING A CONTRACEPTIVE METHOD WHEN A DETAILED BREAKDOWN OF COSTS IS CONSIDERED

It was observed in Section XI-3 that one of the limitations of the treatment of costs in the previous sections is the assumption that all costs of using a contraceptive method can be expressed in terms of money and that only financial resources are limited.

The real costs--as opposed to the financial costs--of using a contraceptive method are the human and physical resources employed. In this sense, the costs should be measured in the time of physicians, nurses, and other auxiliary personnel employed; in the depreciation of buildings and other implements, and in the amount

of pills, foams or other contraceptive devices utilized. For instance, the cost in doctor's time for one patient over a period of a year could be 3 hours; of nurses' time, 5 hours, and so on. In this example it can be seen that the real costs per patient can be measured in their natural units, for example, in hours of time spent by a doctor.

Even when the disaggregated real costs are explicitly considered, it is still necessary to take the financial costs into consideration.

It might seem that to consider both the real and the financial constraints is a misleading duplication. However, when only the financial constraints are considered, it is assumed that it is possible to obtain at a fixed monetary cost additional units of all the resources required. If more doctors' time is needed, it can be obtained; the same for nurses' time, and the same for any physical resources needed. However, in many cases it might happen that financial resources are not the actual constraint. Money might be available; however, it might not be possible to obtain any additional well-trained physicians. In this case, if only the financial constraints are considered, the solution obtained with the model will not be feasible. Lack of doctors, or nurses, or implements, will make its implementation impossible. If none of these limitations appear, financial resources become the binding constraint.

In order to consider real and financial constraints in the model in equations XI-2-1 through XI-2-3, the inequality XI-2-2 should be replaced by two sets of inequalities. In the first one, those referring to real resources are included, i.e.,

$$\sum_{i=1}^{n} c_{hi} N_i \leq R_h \qquad h = 1, \ldots, p \qquad \text{XI-4-1}$$

where

c_{hi} = use of resource h per couple using contraceptive method i

R_h = total availability of resource h

p = number of cost elements considered.

The second set includes the inequalities dealing with financial resources.

To construct it, the monetary cost per unit of doctor's time, nurses, etc. has to be known. Let

a_h = monetary cost per unit of resource h used

then

$$a_h \sum_{i=1}^{n} c_{hi} N_i \qquad h = 1, \ldots, p \qquad \text{XI-4-2}$$

is the monetary cost of using resources h. The total monetary cost of using all the resources is obtained by adding XI-4-2 over h. This total should be less than or equal to R, the total financial resources available, i.e.,

$$\sum_{h=1}^{p} \sum_{i=1}^{n} a_h c_{hi} N_i \leq R \qquad \text{XI-4-3}$$

In the model formed by equations XI-2-1, XI-2-3, XI-4-1 and XI-4-3, the limitations of real and financial resources are considered. This model can be modified to consider the case when births are minimized. In these modifications, the principles already used are the only ones employed. For this reason, these modifications will not be presented in detail.

XI-5 CHOOSING A TARGET POPULATION AND A CONTRACEPTIVE METHOD

In Chapter X, the problem of choosing a target population is studied without considering the availability of several contraceptive techniques. This means that it is assumed that only one method or combination of methods can be used. So far in the present Chapter, only the different methods of contraception have received attention. This implies that any method of contraception produces the same effect on any person in the population. However, this is not the case. Different methods produce different results due not only to the age of the persons using them, but also to their motivation to reduce pregnancies and to their ability to use a method in the appropriate way. In this section the influence of motivation and ability of the population will be considered. The impact of age will not be included in the analysis.

In order to consider the influence of motivation and ability, the first step is to classify the couples according to the criteria considered to have

most influence on the effectiveness of the contraceptive methods. Couples could be classified by social class, employment status of the wife, etc. If needed, the classification could consider several of the criteria mentioned. It will be assumed here that couples are classified in j=1,...,m groups according to the criteria above. This will be called classification by effectiveness.

When this classification is considered, the problem in equations XI-2-1 through XI-2-3 becomes that of maximizing

$$B = \sum_{j=1}^{m} \sum_{i=1}^{n} (\alpha_j - \beta_{ij})N_{ij} \qquad \text{XI-5-1}$$

subject to

$$R \geq \sum_{j=1}^{m} \sum_{i=1}^{n} c_{ij}N_{ij} \qquad \text{XI-5-2}$$

to

$$\bar{N}_j \geq \sum_{i=1}^{n} N_{ij} \qquad j-1,\ldots,m \qquad \text{XI-5-3}$$

and to

$$N_{ij} \geq 0 \qquad i-1,\ldots,n; \quad j=1,\ldots,m \qquad \text{XI-5-4}$$

where

B = as before, number of pregnancies avoided;

α_j = "normal" pregnancy rate among women in effectiveness group j.

β_{ij} = pregnancy rates among women in effectiveness group j using contraceptive method i.

N_{ij} = number of women who should use contraceptive method i among those in effectiveness group j.

R = as before, total resources available.

c_{ij} = cost per patient in effectiveness group j of using contraceptive method i.

$\bar{N}_j$ = total number of women in effectiveness group j.

The model in equations XI-5-1 through XI-5-4 is not very different from that in equations XI-2-1 through XI-2-3. Actually, to obtain the model in equations

XI-5-1 through XI-5-4 it is only necessary to introduce in equations XI-2-1 through XI-2-3 the subdivisions of couples into effectiveness groups. Only in equation XI-5-3 does a new element appear: that of number of women in effectiveness group j.

The results that can be obtained with the model in equations XI-5-1 through XI-5-4 do not refer only to contraceptive technique, but also to effectiveness groups. They indicate that the resources available for a population and family planning program should be used to provide the contraceptive method and in the effectiveness group where the cost per pregnancy avoided is minimum. This result could be interpreted to mean that the resources for a population and family plan should be used in those socio-economic groups having higher income and education, because there the contraceptive techniques will be better utilized, and in this way the number of pregnancies avoided will be maximized. Such a result is unacceptable on two grounds. First, it would not be reasonable to use the resources of a population or family planning program on those socio-economic groups that already have low pregnancy rates, in part due to the use of contraceptive methods that they obtain with their own resources. Second, many of the social and economic benefits of a population and family planning program are derived from the reduction of pregnancies in socio-economic groups having low levels of income and education.

Fortunately, these two points do not effect the model in equations XI-5-1 through XI-5-4. Its results would favor expenditures in socio-economic groups having high levels of income and education only when it is wrongly applied, in the sense that the values of the parameters α_j, β_{ij} and c_{ij} are not the appropriate ones. These parameters should reflect the impact of the use of the resources on a population and family planning program, and not simply the impact of contraceptive methods on biological processes. More specifically, due to the use of contraceptive methods obtained with their own resources, socio-economic groups with high levels of income and education have a low "normal" pregnancy rate α_j.

Little or no modification of this α_j would be obtained with the use of the resources of a population and family planning program. Actually, α_j and β_{ij} might be quite similar. The opposite is true in socio-economic groups with low levels of income and education. There, the "normal" rate of pregnancy will be high, and it can be reduced substantially by using the resources of a population or family planning program. When these correctly computed parameters are used in the model of equations XI-5-1 through XI-5-4, it is highly unlikely that the model will advise the use of resources in socio-economic groups with high levels of income and education while ignoring those with low levels.

XI-6 CHOOSING A METHOD TO ACHIEVE OPTIMUM FAMILY SIZE

XI-6-1 Optimum Family Size: Minimization of Number of Excess Children

In the analysis above attention has not been given to the right of parents to determine the size of their families. This can be considered as a particular case within the context of the problem in discussion, because as a first step, it simply introduces a classification of the fertile women in the population into two distinct categories: Those who would like to have additional children, and those who would not like to have them. When this classification is introduced, it is clear that the target population for a demographic plan should include only those women who do not desire additional children. It can be assumed that only they will use the contraceptive advise and service provided by the programs. Once this point of view is adopted, any of the models in this or the previous chapters can be applied. Actually, the most effective application of the models should begin with the classification of the women in the two categories mentioned above, and the analysis should be applied only to those who do not desire more children.

In the application of the previous models to women who do not desire more children, the fact that women can exceed their desired number of children by varying amounts has not been taken into account. This point will be considered below. First, it can be assumed that the disutility of one excess child is the same for all women, regardless of whether excess already exists. This means that

one more child brings as much disutility for a woman, whether she has zero excess children or five excess children. In this case very little modification of the model in Section XI-5 is required. Basically, all that is required is to change the meaning of the symbols in formula XI-5-2 so that N_{ij} becomes the number of women with excess number of children j that should use contraceptives i, and the meaning of α_j, β_{ij}, etc. is modified accordingly. With this modification XI-5-2 becomes the maximization of pregnancies avoided for those women who do not desire more children.

The modification of the model in Section XI-5 just described can be used as a basis for studying the case where the disutility of one additional child increases with the number of excess children.

To consider this case, it will be assumed that the time horizon for the demographic plan is just one year. The usefulness of this assumption derives from the fact that the number of women who have j children does not change. If more than one year is considered, that number will change, mainly because some women with j-1 children had an additional child between dates t and t+1.

By limiting the time horizon of the population plan to just one year, only the objective function of the model in Section XI-5 and above has to be changed. In the present case, it becomes necessary to maximize

$$B = \sum_{j=1}^{m} \sum_{i=1}^{n} W(j)\,(\alpha_j - \beta_{ij})N_{ij} \qquad \text{XI-6-1}$$

where

W(j) reflects the change in disutility and is an increasing function of j.

The simplest assumption would be to set

$$W(j) = j \qquad j=1,\ldots,m$$

The basic problem in this case is that of specifying W(j) in a reasonable way, keeping in mind that any specification is only a more or less acceptable approximation. The method in Chapter II might be applied to solving this problem.

When the time horizon of the population plan is more than one year, the

possibility that some women who had j children in year t will have j+1 children in year t+1 must be considered. The method for doing this is quite similar to that used in Chapter X to deal with women who change from one category in the program to another. For this reason, a full presentation of the formulas will not be included here.

XI-6-2 Optimum Family Size Considering Disutility of Excess and Defect in the Number of Children Within a One Year Planning Horizon

In Section XI-6-1 only to the case where utility is attached to avoiding excess children is considered. However, disutility can also mean having less than the desired number of children. Thus, any deviation from the desired family size brings about disutility.

To consider the simplest case first, it will be assumed that the time horizon of the demographic plan is just one year. In this case, the women can be classified in two groups, those who desire one child more, and those who do not desire any additional children. For the first group, the objective is to avoid an additional child, while for the second group, it is to have an additional child.

To state the objective function just described in mathematical terms, the following notation will be used

α_i normal fertility rates for women in group i

i=1 women who do not want an additional child

i=2 women who want an additional child

β_i fertility rates for women using methods to decrease (i=1) or increase (i=2) their fertility

N_i number of women who should use method (i=1) to decrease and (i=2) to increase fertility.

With these notations it is clear that

$$(\alpha_1 - \beta_1) N_1$$

is the number of children that can be avoided if N_1 women use contraceptive methods

to decrease fertility, and

$$(\beta_2 - \alpha_2)\ N_2$$

is the number of children that can be added, using methods for increasing fertility. Considering the objective to be the maximization of children avoided for women who do not want them, and children added for those who do want them, the object will be to maximize

$$B = (\alpha_1 - \beta_1)\ N_1 + (\beta_2 - \alpha_2)\ N_2 \qquad \text{XI-6-2}$$

A basic assumption implicit in the objective function in XI-6-2 is that the utility of avoiding one child, for women who do not desire them, is equal to the utility of having a child, for women desiring one. This assumption could be modified by attaching weights to the right-hand terms of XI-6-2. For instance, if

$$B = (\alpha_1 - \beta_1)N_1 + .5(\beta_2 - \alpha_2)N_2$$

then the utility of having one additional child is assumed to be half of the utility of avoiding one. As in the case of the weights (j) in XI-6-1, it might be useful to apply the method in Chapter II to the problem of specifying a value for these weights.

This objective in XI-6-2 should be obtained within the constraints

$$0 \leq N_i \leq \overline{N}_i \qquad i=1,2 \qquad \text{XI-6-3}$$

that is, that the number of women N_i should be non-negative, less than or equal to the total number $\overline{N}_i$ of women in the population who do not wish or who do wish more children, and the financial constraint

$$R = c_1N_1 + c_2N_2 \qquad \text{XI-6-4}$$

where R is the amount of resources available and c_i is cost per woman of method i.

To study the solution of the problem in equation XI-6-2 through XI-6-4, it will be assumed that in no case do the resources permit the N_i to become equal to the $\overline{N}_i$, i.e., that the constraint in XI-6-3 is not binding. In this case, N_2 should be increased up to the point where $N_i = c_2/R$ and N_i should be made

equal to zero if

$$c_1/(\alpha_1 - \beta_1) > c_2/(\beta_2 - \alpha_2)$$

i.e., if the cost of having an additional child is less than the cost of avoiding one. This result is the direct consequence of the assumption in XI-6-3 that the utility of avoiding a child, for women who do not desire one, is equal to the utility of having a child for those who do desire one.

The result just presented can be modified in much the same way as in Section XI-6-1 so as to take into consideration the fact that the women who do not desire one additional child might already have 0,1,2,... excess children and also that the women who do desire one additional child might wish to have 0,1,2,... additional children. Only minor modifications are needed in the basic model, and they will not be discussed in detail here.

XI-6-3 Optimum Family Size Considering Disutility of Excess and Defect in Number of Children With a Planning Horizon of Several Years

A serious limitation of the model in Section XI-6-2 is that the planning horizon is only one year, while desired family size refers to the entire fertile period of a woman. This point will be considered in this Section.

To begin the analysis of this problem, it will be assumed that the desired number of children is the same for all women. This assumption will be eliminated later. This uniform number of children desired will be designated τ.

In the analysis it is useful to consider the women classified by number of children on each of the dates to which the problem refers. Let

$\overline{N}_{tj}$ denotes the number of women in the population at date t with j children, and

N_{tj} number of women who should use a method to aid (for j=1 to τ) or prevent (for j=τ+1 to J) conception between t-1 and t among those with j children.

The time horizon of the program will be from t=o to t=T. It will be assumed that births avoided at the beginning of the program do not reduce the number of

the women in the population. This means that $T \leq 15$ years.

The difference between desired and actual family size is at any date t

$$D_t = \sum_{j=1}^{\tau} (\tau - j)\overline{N}_{tj} + \sum_{j=\tau+1}^{J} (j - \tau)\overline{N}_{tj} \qquad \text{XI-6-5}$$

The first term on the right hand side of XI-6-5 is the total of differences for women who have less than the desired number of children. The second term refers to women who have more than the desired number.

Using equation XI-6-5 as a starting point, several objective functions for the problem at hand can be defined. Perhaps the simplest one is to minimize D_T by the appropriate choice of the number N_{tj} of women with j children, i.e., the differences between desired and actual children for t=T. Another possibility is to minimize

$$D = \sum_{t=o}^{T} D_t$$

i.e., the differences over the entire period.

The next question is to determine the relation between the $\overline{N}_{tj}$ and the instrument variable N_{tj}. In general it can be said that $\overline{N}_{tj}$ is equal to the number of women who remained in the group from year t-1 plus those who enter the group between t-1 and t. To find how many left the group, the number of births and deaths among the $\overline{N}_{tj}$ women have to be considered with

α_j birth rate without any method of changing pregnancy rates among women with j children

β_j birth rate using some method to change pregnancy rates among women with j children

σ survival rate per women.

The number of births among the $\overline{N}_{tj}$ women is

$$\alpha_j \overline{N}_{tj} + (\beta_j - \alpha_j)\overline{N}_{tj} \qquad \text{XI-6-6}$$

this means that the number of women who remain in the group with j children is

$$\sigma\ (1 - \alpha_j)\ \overline{N}_{tj} \ - \ \sigma\ (\beta_j - \alpha)\ \overline{N}_{tj} \qquad \text{XI-6-7}$$

In the same way, the number of women added is

$$\sigma\ \alpha_{j-1}\ \overline{N}_{t-1\ j-1} \ + \sigma\ (\beta_{j-1} - \alpha_{j-1})\ \overline{N}_{t-1\ j-1} \qquad \text{XI-6-8}$$

Using equation XI-6-7 and XI-6-8 it is possible to write

$$\begin{aligned} \overline{N}_{t+1,j} &= \sigma\ (1 - \alpha_j)\ \overline{N}_{tj} - \sigma\ (\beta_j - \alpha_j)\ \overline{N}_{tj} \\ &\quad + \sigma\ \ \alpha_{j-1}\ \overline{N}_{t\ j-1} + \sigma\ (\beta_{j-1} - \alpha_{j-1})\overline{N}_{tj-1} \end{aligned} \qquad \text{XI-6-9}$$

Finally, the resources available and the costs of the methods to modify fertility should be considered. To do so, let

c_1 cost per patient to increase fertility

c_2 cost per patient to decrease fertility

R resources available over the whole period

With these elements, the resources constraint becomes

$$R \ \geq \ \sum_{t=o}^{T} \ [\ \sum_{j=1}^{T} c_1\ N_{tj} \ + \ \sum_{j=\tau+1}^{J} c_2\ N_{tj}]$$

These results can be generalized in many ways. Perhaps the two most important are the consideration of different methods of increasing or decreasing fertility, and the fact that a woman's age affects her fertility. All the questions discussed in previous Sections could also be used in a model like the one described. No attempt will be made here to explain these possibilities.

CHAPTER XII

HEALTH PLANNING: SIMULATION MODELS

XII-1 INTRODUCTION

The methods now available for the purpose of forecasting population growth (see Chapter IX) usually take into consideration only mortality and fertility. The vector of the population by age and sex at date t is transformed into the corresponding vector for date t+1 by means of multiplication by a matrix that includes among its components survival and fertility rates.

An important limitation of this approach is that it does not allow a study to be made of the effect of population growth on morbidity, or of the influence of changes in morbidity on population growth. This limitation is particularly important when the models used for population forecasting are to be used for health planning.

XII-2 A MODEL FOR FORECASTING POPULATION GROWTH IN WHICH THE INFLUENCE OF MORBIDITY IS CONSIDERED

As mentioned before, the principal element in the models used to forecast population by sex and age is a matrix that includes as its components survival and fertility rates. In this section the effect on survival rates of numbers of cases by disease, and number of deaths among these cases will be considered. This breakdown will be presented as a series of steps which will be used to compute: (a) the populations used as a term of reference; (b) the number of cases by age, sex and type of disease; (c) the number of deaths by age, sex and type of disease; and, (d) combining all the previous results, the method of forecasting population by sex and age from date t to date t+1.

XII-2-1 The Population to be Used as a Term of Reference

As the starting point for the forecast, it is assumed here that a vector

$$[P]_t = \begin{bmatrix} M \\ F \end{bmatrix}_t$$

is available. The components of this vector are the number of persons in the population classified by sex and age. It will be assumed that the vector has 2 n rows, where n is the greatest age a person can reach. The first n rows have as components the number of males by age group, and are denoted by M; the components of the last n rows are the number of females by age group, and are denoted by F.

To compute the population to be used as a term of reference, the following equation will be used:

$$[P']_t = [R]\,[P]_t$$

where

$[P']_t$ is a vector of 2 (n+1) rows, having as its first component the number of boys born between t and t+1; the following n components are the first n components of vector P, the n+2 component is the number of girls born between t and t+1, and the last n components are the last n components of vector P. From this description it is clear that $[P']_t$ includes all the population susceptible to disease and death between t and t+1.

R is a matrix of 2 (n+1) rows and 2n columns. Instead of fully describing it, an example will be presented assuming that n=2. In this case

$$[P]_t = \begin{bmatrix} M_1 \\ M_2 \\ F_1 \\ F_2 \end{bmatrix}$$

It will also be assumed that women in the age group F_1 are fertile.

With these assumptions the matrix R is

$$[R] = \left[\begin{array}{cc|cc} 0 & 0 & X\beta & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \hline 0 & 0 & (1-X)\beta & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{array}\right] \qquad \text{XII-2-1}$$

Where X denotes the ratio (boys)/(total number of children born) and β is the fertility rate for women in age group F_1 The general form of matrix R can be subdivided into four submatrices of (n+1) rows and n columns R_1 to R_4 as follows

$$R = \begin{bmatrix} R_1 & R_2 \\ R_3 & R_4 \end{bmatrix}$$

R_1 The first row of R_1 is composed only of zeros. The rest is a matrix with ones in the diagonal from the second row, first column to (n+1) th row, nth column;

R_2 The first row of R_2 has the appropriate fertility coefficients multiplied by the ratio (boys)/(total number of births). The rest of the matrix is only zeros;

R_3 Has only zeros as its components;

R_4 Has in the first row the fertility rates multiplied by the ratio (girls)/(total number of births) and the rest of the matrix has ones in the diagonal going from the 2nd row, and 1st column to the (n+1) th row, nth column.

With the matrix in (XII-2-1) and the vector $[P]_t$ with n=2 the vector $[P']_t$ takes the following form:

$$[P']_t = \begin{bmatrix} M_0 \\ M_1 \\ M_2 \\ F_0 \\ F_1 \\ F_2 \end{bmatrix} \qquad \text{XII-2-2}$$

XII-2-2 Number of Cases by Disease, Age and Sex

The method to be presented below is completely general. It permits, in principle, computation of the number of cases by disease, age and sex for all known diseases. However, when we consider that the listing of known diseases fills several volumes, we conclude that such detail is not likely to be useful, that the computational facilities available would not permit the required mathematical operations to be made, and the statistical data available would not be sufficient. For these reasons, the first problem to be solved is that of classifying all these diseases in groups. Below it will be assumed that m disease groups will be considered.

To compute the number of cases of each of the m disease groups in the period between t and t+1, the following procedure will be used:

$$[b_{sij}]_t = [\alpha_{sij}]\,[P']_t \qquad \text{XII-2-3}$$

where

$[b_{sij}]$ is a vector of 2m(n+1) rows and 1 column. The components of this vector are the number of cases of disease i, i=1,...,m among persons of sex s; s=1 male, s=2 female, and age j=0,...,n with j=0 for persons born between t and t+1. Any set of components for i=1,...,m and fixed s and j is the number of cases of the different diseases for persons of sex s and age j.

$[\alpha_{sij}]$ is a matrix of 2m (n+1) rows and 2(n+1) columns.

For the case of s=2, m=2, n=2, the matrix[α] takes the following form:

$$[\alpha_{sij}] = \begin{bmatrix} \alpha_{110} & 0 & 0 & 0 & 0 & 0 \\ \alpha_{120} & 0 & 0 & 0 & 0 & 0 \\ 0 & \alpha_{111} & 0 & 0 & 0 & 0 \\ 0 & \alpha_{121} & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_{112} & 0 & 0 & 0 \\ 0 & 0 & \alpha_{122} & 0 & 0 & 0 \\ 0 & 0 & 0 & \alpha_{210} & 0 & 0 \\ 0 & 0 & 0 & \alpha_{220} & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_{211} & 0 \\ 0 & 0 & 0 & 0 & \alpha_{221} & 0 \\ 0 & 0 & 0 & 0 & 0 & \alpha_{212} \\ 0 & 0 & 0 & 0 & 0 & \alpha_{222} \end{bmatrix} \qquad \text{XII-2-}$$

The components of the matrix α_{sij} are the morbidity rates by sex, disease and age. These components are arranged in 2(n+1) submatrices of m rows and 2 (n+1) columns each. The hth matrix for h=1,...(n+1) has as its hth column the vector of morbidity rates for men of age h; for h=(n+2),...2(n+1) has as its hth column the morbidity rates for women of age h. All other components of these matrices are zero.

From equation XII-2-3 and the definitions above, it is clear that

$$b_{1ij} = \alpha_{1ij} M_j$$
$$b_{2ij} = \alpha_{2ij} F_j \qquad \text{XII-2-5}$$

These equations are important because they can be taken as the definitions of morbidity rates by disease, age and sex. For instance, α_{1ij} is the quotient of the number of cases of disease i between t and t+1 for males age j, divided by total number of males age j at date t.

Starting with the vector $[b_{sij}]$ it is possible to compute the following total numbers of cases:

a) summing over sex, to compute the total by age and disease.

The vector $[b_{..ij}]$ obtained has m(n+1) rows, and is obtained

with the product

$$[b_{.ij}] = [A_s]\,[b_{sij}]$$

The matrix A_s has m(m+1) rows and 2m(n+1) columns. It can be broken down into two matrices of dimensions [m(n+1)] [m(n+1)]. Each of these two matrices is equal to the identity matrix, i.e., its only non-zero components are equal to one and are in its main diagonal.

b) summing over age to compute totals by sex and disease, the vector $[b_{si.}]$ is obtained. It has 2m components. If

$$[b_{si.}] = [A_j]\,[b_{sij}]$$

the matrix $[A_j]$ has 2m rows and 2m(n+1) columns. A typical matrix $[A_j]$ for the case where s=2, m=2, n=2 is

$$[A_j] = \left[\begin{array}{cccccc|cccccc} 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \end{array}\right] \qquad \text{XII-2-6}$$

From (XII-2-6) it is clear that $[A_j]$ and be broken down into four matrices of dimensions (m) [m(n+1)]. The first and fourth of these matrices breaks down into (n+1) unit matrices of dimension m x m.

The third and fourth matrices have all their components equal to zero.

c) summing over conditions to compute number of cases by age and sex, the vector $[b_{s.j}]$ is obtained. It has 2(n+1) components.

The Matrix $[A_i]$, from

$$[b_{s.j}] = [A_i]\,[b_{sij}]$$

has 2(n+1) rows and 2m(n+1) columns. For the case s=n=m=2, this matrix is

$$[A_i] = \left[\begin{array}{cc|cc|cc|cc|cc|cc} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{array}\right] \qquad \text{XII-2-7}$$

The expression in (XII-2-7) shows that $[A_i]$ can be subdivided into 2(n+1) matrices of dimensions [2(n+1)] [m]. The h'th matrix has ones in its h'th row, and zeros everywhere else.

d) summing over sex and age to compute total number of cases by disease, the vector $[b_{.i.}]$ has m rows. It is obtained with the product

$$[b_{.i.}] = [A_{sj}]\,[b_{sij}]$$

The matrix $[A_{sj}]$ of m rows and 2m(n+1) columns is formed by 2(n+1) unit matrices of dimensions m x m.

e) summing over sex and conditions to obtain totals by age, the vector $[b_{..j}]$ has (n+1) rows. If

$$[b_{..j}] = [A_{si}]\;[b_{sij}]$$

then $[A_{si}]$ is a matrix of (n+1) rows and (2m) (n+1) columns. The characteristics of this matrix can be easily derived from those of the matrix $[A_i]$ and the expression in (XII-2-7). The matrix $[A_{si}]$ breaks down into two matrices of (n+1) rows and m(n+1) columns. The first of these matrices is equal to the first matrix in $[A_i]$, and the second to the fourth matrix in $[A_i]$.

f) summing over condition and age to obtain totals by sex, the vector $[b_{s..}]$ has two components. The matrix $[A_{ij}]$ has two rows and 2m (n+1) columns. The first row has ones in the m(n+1) first position and zeros everywhere else, and the second row has zeros in the first m(n+1) position and ones everywhere else.

The mortality rates of persons affected by condition i and specific of age, sex and condition will be used to compute the number of deaths between t and t+1. With the number of deaths, a vector $[d_{sij}]$ of 2m(n+1) rows will be formed. Its components d_{sij} are the number of deaths among persons of sex s, affected by condition i, and of age j. Since

$$d_{sij} = \delta_{sij} \; b_{sij} \qquad \text{XII-2-8}$$

it is clear that the matrix $[\delta_{sij}]$ which transforms the vector $[b_{sij}]$ into the vector $[d_{sij}]$ is a 2m (n+1) diagonal matrix with the mortality rates δ_{sij} in the main diagonal. From equations (XII-2-5) and (XII-2-8) it follows that

$$d_{1ij} = \delta_{1ij} \, \alpha_{1ij} \, M_j$$
$$d_{2ij} = \delta_{2ij} \, \alpha_{2ij} \, F_j$$

From the vector $[d_{sij}]$ it is also possible to obtain the totals of deaths by age and condition, by sex and condition, etc., using methods similar to those used to obtain totals of number of cases. For instance, the total number of deaths by age and sex can be obtained with the matrix product

$$[d_{s.j}] = [A_i] \, [d_{sij}]$$

where

$[A_i]$ is the matrix defined in (XII-2-7)

XII-2-4 A Model for Forecasting Population by Age and Sex

Assuming that the vector $[P]_t$ of population by age and sex at date t is known, the problem is to transform it into the vector $[P]_{t+1}$. To do this, observe that to obtain $[P]_{t+1}$ it is necessary to subtract from $[P']_t$ the number of deaths by age and sex, and to eliminate the components in rows n+1 and 2(n+1). This is obtained with the product

$$[P]_{t+1} = [B] \, \{[P']_t - [d_{sij}]\} \qquad \text{XII-2-9}$$

where [B] is a (2n) [2(n+1)] matrix that has its n+1 and 2(n+1) columns of zeros, while its first (n x n) rows and columns, its rows n+1 to 2n, and its columns n+2 to 2n+1 form identity matrices.

Replacing in equation (XII-2-9) the values of its elements in terms of $[P]_t$ we obtain

$$[P]_{t+1} = [B] \{[I] - [A_i] [\delta_{sij}] [\alpha_{sij}]\} [R] [P]_t \qquad \text{XII-2-10}$$

From equation (XII-1-10) it is clear that the usual recursive relation used to forecast $[P]_t$ to $[P]_{t+h}$ for any h=1,...., assuming constant coefficients, can be obtained.

XII-3 DEMAND FOR MEDICAL SERVICES

One of the advantages of the model in Section XII-2 is that it can be used to obtain estimates of the demand for medical materials and services, consistent with the morbidity, mortality and population forecasts.

Actually, the method for estimating the demand for medical services to be presented below is based on the assumption that the morbidity and mortality rates can be maintained constant only if the rates of medical services (to be defined below) are also maintained constant. In this sense, the estimated demand for medical services is the demand required so that the population forecast is actually realized. If the actual availability of medical services exceeds the estimated demand, the morbidity and mortality rates will be reduced. If the available services fall below the estimated demand, the morbidity and mortality rates will increase. In either case, the actual population will differ from that forecasted.

The methods for estimating the demand for medical services will be explained below with reference to the services of physicians and hospitals. Similar techniques could be applied to the demand for any other type of services of implements say, that of pharmaceutical products. The presentation of a detailed description of the methods used to estimate

the demand for doctors and for hospitals should make it possible for the reader to apply the same techniques to any other type of service or implement.

XII-3-1 Demand for Doctor Services and Number of Doctors Demanded

The demand for doctor services can be subdivided into two main types: (1) the demand for curative services made by the patients counted in the vector $[b_{sij}]$, and (2) the demand for preventive service, i.e., for medical examinations, vaccinations, etc., by healthy persons. These two types of demand will be considered below.

The "visit" will be taken here as the unit element of the demand for doctor services. A method for estimating the number of visits due to the number of cases considered in the vector $[b_{sij}]$ will be presented below as well as one for estimating the number of preventive visits.

XII-3-2 Demand for Curative Services

The number of visits for curative purposes is estimated with the following product:

$$[v_{sij}] = [\pi_{sij}]\,[b_{sij}] \qquad \text{XII-3-1}$$

where

$[v_{sij}]$ is a vector of 2m(n+1) rows with components v_{sij} the number of visits by sex s=1,2, condition i=1,...,m and age j=1,...,n.

$[\pi_{sij}]$ is a 2m(n+1) diagonal matrix. The elements in the main diagonal are the visit rates, defined by the quotient

$$\pi_{sij} = \frac{v_{sij}}{b_{sij}}$$

i.e., the number of visits by sex, condition and age between t and t+1 divided by the number of cases over the same period.

It should be clear that, starting with the vector $[v_{sij}]$, it is possible to compute the number of visits by sex, condition, age, etc.

Several of these estimates can be useful in estimating which specializations will be needed in the doctors. A total to be used below is that of the number of visits by sex and age, i.e.

$$[v_{s.j}] = [A_i]\ [v_{sij}] \qquad \text{XII-3-2}$$

where

$[v_{s.j}]$ is a vector of 2(n+1) rows with components the number of visits by sex and age;

and

$[A_i]$ is the matrix introduced in (XII-2-7)

XII-3-3 Demand for Preventive Services

It is assumed here that the number of visits for preventive services cannot be classified by condition. That is, it is not possible to determine which condition or conditions the persons visiting the doctor are trying to avoid. As a consequence, the number of preventive visits will be classified only by sex and age. Their number is obtained from the product

$$[w_{sj}] = [\theta_{sj}]\,[P']_t \qquad \text{XII-3-3}$$

where

$[w_{sj}]$ is a vector of 2(n+1) rows with components w_{sj} the number of preventive visits by age and sex.

$[\theta_{sj}]$ is a [2(n+1)] [2(n+1)] diagonal matrix. Its components θ_{sj} are the number of preventive visits per person of sex s and age j.

XII-3-4 Total Demand for Doctors' Services and Number of Doctors Needed

The total demand for doctor visits by sex and age is obtained with the sum

$$[k_{sj}] = [v_{s.j}] + [w_{sj}] \qquad \text{XII-3-4}$$

Replacing in XII-3-4 $[v_{s.j}]$ and $[w_{sj}]$ one obtains

$$[k_{sj}] = \{[\Lambda_i]\ [\tau_{sij}]\ [\alpha_{sij}] - [\theta_{sj}]\}\ [R]\ [P_j]$$

The data required to estimate the total number of doctors needed are the number of visits a doctor receives per year. This information could be classified by the sex and age of the patients, or, in the case of curative visits, by type of condition. It will be assumed that the number of visits a doctor receives per year is the same regardless of sex, age or condition of the patient. This number will be denoted by ξ. As a consequence, the number of doctors needed is

$$D = \xi[1]\ [k_{sj}]$$

where

[1] is a row vector of 2(n+1) rows with only one as components

It should be observed that either coefficient ξ or a more refined coefficient, if required, make it possible to forecast the number of doctors needed for preventive and for curative services by type of condition, sex and age of the patients, or number of doctors number classified by the condition in which they should specialize. These forecasts can be used to plan medical education.

XII-4 DEMAND FOR HOSPITAL SERVICES

Using an approach similar to that used to estimate the demand for doctors' services, it is possible to estimate the demand for hospital services. A detailed presentation of this method is made below.

XII-4-1 Number of Hospital Discharges by Sex, Condition and Age

The number of hospital discharges by sex, condition and age is

$$[h_{sij}] = [\gamma_{sij}]\ [b_{sij}] \qquad \text{XII-4-1}$$

where

$[h_{sij}]$ is a vector of 2m(n+1) rows. The number of discharges by sex, condition and age are denoted by h_{sij}.

$[\gamma_{sij}]$ is a diagonal matrix of dimension $[2m\ (n+1)]\ [2m(n+1)]$. the components in its main diagonal are the numbers γ_{sij} of discharges by sex, condition and age by case. These rates are defined by

$$\gamma_{sij} = \frac{h_{sij}}{b_{sij}}$$

Again in the present case, it is possible to obtain total by sex, condition, age, etc.

XII-4-2 Number of Hospital Days Demanded Per Year

In order to estimate the number of hospital days demanded by sex, condition and age of the patients, the following equations will be used:

$$[\ell_{sij}] = \lambda_{sij}]\ [h_{sij}] \qquad \text{XII-4-2}$$

where

$[\ell_{sij}]$ is a vector of $2m(n+1)$ rows, and its components ℓ_{sij} denote the number of days spent in a hospital per patient of sex s, condition i and age j.

$[\lambda_{sij}]$ is a diagonal matrix with components λ_{sij} in the main diagonal defined by

$$\lambda_{sij} = \frac{\ell_{sij}}{h_{sij}}$$

XII-4-3 Number of Hospital Rooms Demanded

The next step is to compute the number of hospital rooms demanded. As in the case of doctors, the method to be presented could be used to estimate rooms classified by sex, condition and age of the patients. Here only the method for estimating total number will be presented. This method is summarized in the following equation:

$$\frac{1}{365}\ [1]\ [\ell_{sij}]$$

where

[1] is a vector of 2m(n+1) columns.

The product [1] $[\ell_{sij}]$ gives the total number of hospital days demanded. This total is divided by 365, the number of days that a hospital room is available.

It should be observed that the previous computation gives only a first approximation of the number of hospitals rooms needed, since seasonal variations in number of cases are not considered. These seasonal variations would increase the demand for hospital rooms during certain periods of the year. In these periods, the number of rooms computed would not be sufficient. However, if the rooms available satisfy the peak demands, some of the rooms would not be used in the remaining periods.

XII-5 INFLUENCE ON POPULATION GROWTH OF CHANGES IN SOCIO-ECONOMIC CONDITIONS IN GENERAL AND IN HEALTH CONDITIONS IN PARTICULAR

The model in equation (XII-2-10) can be used to study the influence of changes in socio-economic conditions in general, and in particular changes in health conditions, on population growth. These changes might or might not be the final result of socio-economic or health planning. However, the method to be presented below can be used to study the impact of planned socio-economic and health changes on population growth.

For this analysis, the coefficients of the matrices $[\delta_{sij}]$ and $[\alpha_{sij}]$ must be expressed as functions of indices of these socio-economic processes. For instance, it can be assumed that δ_{sij} and α_{sij} depend upon per capita income, percentage of the population with access to water supply, number of doctors per person in the population, etc. These relationships can be estimated by regression methods and used to forecast the values of δ_{sij} $_{sij}$. These forecasted values, replaced in equation (XII-2-10), will make it possible to forecast the population, taking into consideration the influence on health of changes in per capita income, etc.

CHAPTER XIII

HEALTH PLANNING: OPTIMIZATION MODELS

XIII-1 INTRODUCTION

In optimization models for health planning, as in any other type of optimization models, the problem is to choose among several alternative means to optimize an objective function. In Section XIII-2 the specification of the objective function will be studied. Several optimization models will be discussed in later sections. The technical planner would have to adapt general models to the specific situation he confronts, constructing in this process new models.

XIII-2 THE OBJECTIVE FUNCTION FOR HEALTH PLANNING

Several objective functions for evaluating the efficiency of health services have been proposed in references (1 to 5). Comments on these approaches will be presented below.

The minimization of the number of deaths can be considered a first approximation to the objective of health services. The number of deaths as a decreasing index of the efficiency of health services has several advantages and disadvantages.

The main advantage -- in addition to its clear intuitive meaning and appeal -- is the ready availability of some of the statistical data needed.

One of the disadvantages is that not all deaths are equally important. For instance, the death of the father of a family represents a larger social loss than the death of an infant. However, this type of limitation can be avoided with an appropriate system of weights. Another limitation is that such an index excludes the losses due to morbidity alone. It appears difficult to find a system of weights that would introduce the

effects of morbidity in an index based on the number of deaths.

All that has been said with respect to an index based on the number of deaths also applies to indexes closely related to that number, such as death rate, life expectancy, etc.

An index that would include losses due to both mortality and morbidity is the number of days of health. The construction of such an index is not too difficult if only one disease is considered, but it might become extremely complex if we consider the increase in number of days of health brought about by prevention or cure of several diseases. This index would also fail to take into consideration the differences in the losses brought about by diseases, depending upon whether they are suffered by adults or by children.

Finally, the objective of health services is to minimize the economic losses brought about by disease and death. In a direct approach, the losses caused by one disease are evaluated, using its incidence on people of several different ages. As in the case of the number of days of health, this approach might become quite complex if several diseases are considered simultaneously. Another approach is to evaluate the increases in the productivity of the labor force brought about by improvements in health. The techniques employed to disaggregate the residual factor of economic growth are used in this case. A limitation of these two methods is that the economic losses brought about by disease or death depend also on the level of employment. As a consequence, it would be meaningful to introduce such an index only when planning of health and employment are integrated. In addition, it is intuitively clear that the value given to health is independent of any of its economic consequences.

Despite the observations above, we will use number of deaths as the index of the efficiency of health services. The mathematical models to be introduced below would need some modifications if we attempted to use

them with some other type of index, but the basic ideas could be applied without alteration.

XIII-3 PREVENTION VERSUS CURE FOR ONE DISEASE, ONE PERIOD MODEL

XIII-3-1 Content of this Section

At the risk of some repetition, three forms of the problem to be studied in this section will be considered below. In section XIII-3-2, the basic approach will be introduced. Some of the simplifications used in this approach are removed in sections XIII-3-3 and XIII-3-4, but linear relationships are maintained, and a numerical example is presented. Finally, in section XIII-3-6, the assumption of linearity is removed. With this step it is possible to see more clearly the principles of economic theory that are being applied. No consideration will be given in any of these cases to the problems caused by the passage of time. A dynamic model is studied in section XIII-4.

XIII-3-2 The Basic Model

The problem to be studied in this section is the influence on number of deaths caused by a given disease of expenditures on preventive and curative measures.

The basic model to be introduced in this section demonstrates the relationships among the main variables in a rather simple way. Although this model has no practical application, its modification in the following section can be used in actual planning.

The following notations will be used:

P = population susceptible (Datum).

S = total number of people affected by the disease, i.e., who become sick.

D = total number of deaths.

E_1 = total expenditure on preventive measures.

E_2 = total expenditure on treatment of sick people.

R = total resources available (Datum).

$$R = E_1 + E_2 \qquad \text{XIII-3-1}$$

It will be assumed that the total number of people who become sick is a decreasing function of the total expenditures on prevention.

$$S = P - \alpha_1 E_1 \qquad \text{XIII-3-2}$$

where α_1 is a parameter that can be designated as the number of cases that can be avoided with an expenditure of one dollar. In section XIII-3-3 the method to evaluate α_1, starting with actual data, will be presented, and the assumption in equation XIII-3-2 that every person in the population who has not been protected with a preventive measure will become sick will be removed.

Next we will assume that the number of deaths is the following linear function of the number of people sick and the expenditures on treatment:

$$D = S - \alpha_2 E_2 \qquad \text{XIII-3-3}$$

where α_2 is a parameter that denotes the number of deaths that can be avoided with the expenditure of one dollar. In section XIII-3-3 a more detailed analysis of this equation is made along lines similar to those explained with respect to equation XIII-3-2.

With equations XIII-3-1, XIII-3-2, and XIII-3-3, the problem of minimizing the number of deaths takes the following form:

Minimize

$$D = P - \alpha_1 E_1 - \alpha_2 E_2 \qquad \text{XIII-3-4}$$

Subject to

$$R = E_1 + E_2 \qquad \text{XIII-3-5}$$

and

$$D \geq 0$$

Since in practice the amount of resources available will not usually be enough to make $D \geq 0$, we will ignore this condition in the analysis below.

From XIII-3-4 and XIII-3-5 it follows that

$$D = P - (\alpha_1 - \alpha_2)E_1 - \alpha_2 R \qquad \text{XIII-3-6}$$

and

$$0 \leq E_1 \leq R$$

Hence D will be a minimum if

$$\begin{aligned} E_1 &= R \text{ when } \alpha_1 \geq \alpha_2 \\ E_2 &= R \text{ when } \alpha_1 < \alpha_2 \end{aligned} \qquad \text{XIII-3-7}$$

The result obtained, i.e., spend everything on the measures giving higher returns per dollar spent, makes perfect intuitive sense.

XIII-3-3 <u>A More Realistic Approach -- Model and Numerical Example</u>

The main limitation of the model in section XIII-3-2 is that it does not include any indication of the method that should be used to evaluate the parameters α_1 and α_2 using statistical data. This limitation is removed in the present section. The following notations and equations will be used for this purpose.

P = susceptible population (Datum).

N_1 = number of people that should be protected with preventive measures such as vaccinations, in order to minimize deaths.

N_2 = number of people that should not be protected.

$$P = N_1 + N_2 \qquad \text{XIII-3-8}$$

τ_1 = morbidity rate among the people protected (Datum).

τ_2 = morbidity rate among the people not protected (Datum).

S = total number of cases, i.e., of people affected by the disease.

$$S = \tau_1 N_1 + \tau_2 N_2 \qquad \text{XIII-3-9}$$

M_1 = number of sick people that should be treated with curative techniques in order to minimize deaths.

M_2 = number of sick people that should not be treated with curative techniques.

$$S = M_1 + M_2 \qquad \text{XIII-3-10}$$

δ_1 = mortality rate among people treated (Datum).

δ_2 = mortality rate among people not treated (Datum).

D = total number of deaths.

$$D = \delta_1 M_1 + \delta_2 M_2 \qquad \text{XIII-3-11}$$

c_1 = cost of protecting one person (Datum).

c_2 = cost of treating one person (Datum).

E_1 = amount that should be spent on prevention in order to minimize deaths.

E_2 = amount that should be spent on treatment.

R = total resources available (Datum).

$$R = E_1 + E_2 \qquad \text{XIII-3-12}$$

$$E_1 = c_1 N_1 \qquad \text{XIII-3-13}$$

$$E_2 = c_2 M_1 \qquad \text{XIII-3-14}$$

The problem is to determine E_1 and E_2 in such a way as to minimize D. A comparison of the problems in sections XIII-3-2 and XIII-3-3 shows that they are essentially identical. However, the numbers of variables and parameters needed in section XIII-3-3 makes it difficult to understand

the basic principles introduced in Section XII-3-2.

In order to reduce the problem in this section to the one in section XIII-3-2, the following transformations are required:

From XIII-3-10 and XIII-3-11

$$D = (\delta_1 - \delta_2)M_1 + \delta_2 S \qquad \text{XIII-3-15}$$

From XIII-3-8 and XIII-3-9

$$S = (\tau_1 - \tau_2)N_1 + \tau_2 P \qquad \text{XIII-3-16}$$

From XIII-3-15 and XIII-3-16

$$D = \delta_2\tau_2 P + \delta_2(\tau_1 - \tau_2)N_1 + (\delta_1 - \delta_2)M_1 \qquad \text{XIII-3-17}$$

And from XIII-3-13, XIII-3-14 and XIII-3-17

$$D = \delta_2\ \tau_2 P + \delta_2(\ \tau_1 - \tau_2)\frac{E_1}{c_1} + (\delta_1 - \delta_2)\frac{E_2}{c_2} \qquad \text{XIII-3-18}$$

The problem reduces to that of minimizing D in XIII-3-18 subject to condition XIII-3-12. The problem is equivalent to the one in equations XIII-3-5 and XIII-3-6, with

$$\begin{aligned} -\ \alpha_1 &= \frac{\delta_2(\tau_1 - \tau_2)}{c_1} \\ -\ \alpha_2 &= \frac{(\delta_1 - \delta_2)}{c_2} \end{aligned} \qquad \text{XIII-3-19}$$

With XIII-3-19, the solution in XIII-3-7, can be applied to this case.

From equation XIII-3-18 it should be clear that α_2, as defined in XIII-3-19, is the number of deaths that can be avoided with the expenditure of one dollar on treatment, while α_1 is the number of deaths that can be avoided with the expenditure of one dollar on prevention of the disease, but without treating those who fall sick. It is possible to verify directly the meanings just given to α_1 and α_2 with the following approach.

First, let us observe that from XIII-3-11 we have

$$\Delta D = \delta_1 \Delta M_1 + \delta_2 \Delta M_2 \qquad \text{XIII-3-20}$$

and from XIII-3-9, since S is assumed to remain constant, we have

$$0 = \Delta M_1 + \Delta M_2 \qquad \text{XIII-3-21}$$

Hence, from XIII-3-10 and XIII-3-21

$$\Delta D = (\delta_1 - \delta_2) \Delta M_1 \qquad \text{XIII-3-22}$$

From XIII-3-22 with $\Delta D = 1$, we obtain that

$$- \Delta M_1 = - \frac{1}{\delta_1 - \delta_2}$$

is the number of people to be treated to avoid one death. Since c_2 is the cost per person treated, the cost of avoiding one death with treatment is

$$\frac{c_2}{\delta_1 - \delta_2}$$

and its inverse, i.e., α_2 is the number of deaths that can be avoided with the expenditure of one unit. A similar analysis is valid for the case of α_1.

To complete this section, a numerical example will be presented below.

The basic statistical data needed is presented in Table XIII-3-1 These data, referring to whooping cough in Northern Santiago, Chile, in 1963, are taken from reference (1).

Table XIII-3-1

Basic data needed to apply the model in this section, referring to whooping cough in Northern Santiago, Chile, 1963

Symbol	Definition	Value
τ_1	Morbidity rate in protected population	0.45
τ_2	Morbidity rate in non-protected population	0.60
δ_1	Mortality rate with treatment	0.01
δ_2	Mortality rate without treatment	0.03
c_1	Cost of protecting one person	0.30
c_2	Cost of treating one person	28.86
R	Total resources available (Escudos)	31,317.00

Source: Reference (1)

With the data in Table XIII-3-1, formula XIII-3-18 becomes

$$D = 0.018P - 0.015E_1 = 0.00069E_2$$

with $\alpha_1 = 0.015$ and $\alpha_2 = 0.00069$

Since $\alpha_1 > \alpha_2$, the maximum reduction of deaths will be obtained with $E_1 = R = 31{,}317$ and $E_2 = 0$. In this case, the total number of deaths that could be avoided is $\alpha_1 R = 470$.

It is worthwhile to observe that, according to the information in reference (1), the distribution of resources was $E_1 = 7{,}158$, E_2 24,159, and the number of deaths prevented was 124. That is, with a planning approach, a total of 346 deaths could have been avoided.

XIII-3-4 Minimization of the Number of Deaths When Several Diseases are Considered*

In the model in XIII-3-3 only one disease is considered. An immediate generalization is to consider several diseases.

The main difference between the case of one disease and that of several or all diseases is that in the latter the interdependences of the diseases must be considered. The main forms of interdependence are as follows.

The first form refers to the assumption made in the case of one disease that the amount of resources available might not be enough to reduce to zero or less than zero the minimum number of deaths brought about by the disease. When dealing with all the resources available for the health services, it might happen that the minimum number of deaths, as determined by this model, will be negative. Since in actual practice this minimum cannot be less than zero, the result obtained with the model would simply mean that some resources are wasted. For this reason, in the actual computations, one should include the condition that the number of deaths brought about by any disease should be larger than or equal to zero.

The second interdependence appears because of the fact that one person might be susceptible to several diseases. For this reason, it is impossible to define the population susceptible to one disease without knowing the measures taken against all the other diseases. For instance, if malaria is not controlled, the number of persons who become sick and die from, say, cancer might be substantially reduced. Fortunately, when the plan refers to short time periods this interdependence is not likely to be important. As a first approximation, this interdependence of susceptible population will be ignored below.

---

*This section is a summary of: H. Correa and W. A. Hassouna, Planning for Health of Infants and Children in Egypt. UNICEF Document 1972.

Finally, there is an interdependence of preventive measures, i.e., some preventive measures (to be called "general" here) that reduce the incidence of several diseases at the same time. The most common example of such measures is a hygienic water supply. Education and nutrition could also be considered among the preventive measures that reduce the incidence of several diseases. This fact forces us to consider in the model both general and specific preventive measures for each disease, and to modify the model in section XIII-3-3 accordingly. To understand this modification it is necessary to remember the role of equation XIII-3-9 in the model in section XIII-3-3. In this equation the total number of sick people is the sum of those who became sick after having enjoyed preventive measures, and those who became sick but had not enjoyed preventive measures. In this case it is necessary to define the total number of people who became sick, taking into consideration that the preventive measures could be both the general and specific. It appears that the only way to do this is to consider the four alternatives combining general and specific measures, i.e., total number of sick persons should be equal to number of sick persons among those who enjoyed both types of preventive measures, plus those who enjoyed general but not specific measures, plus those who enjoyed specific but not general measures, plus those who did not enjoy any measures at all. It is necessary to have information with similar detail about morbidity rates, costs per person, different types of expenditures, etc. Only specific prevention measures will be considered below.

In addition, despite that the model is completely general, it will refer here only to children, and only to three diseases, to be designated 1, 2, and 3.

It will also be assumed that there are a total of three specific prevention methods, i.e., methods that reduce morbidity almost exclusively in one disease.

The first decision that a planner has to make is to determine the number of children that should receive:

a) No protection (N_o);

b) Only specific protection against disease 1 (N_1);

c) Only specific protection against disease 2 (N_2);

d) Only specific protection against disease 3 (N_3);

e) Specific protection against 1 and 2 (N_4);

f) Specific protection against 1 and 3 (N_5);

g) Specific protection against 2 and 3 (N_6);

h) Specific protection against 1, 2, and 3 (N_7)

It is clear that:

$$N = \sum_{i=o}^{7} N_i \qquad \text{XIII-3-23}$$

The number of cases of disease 1 will be equal to the number of cases in each of the eight groups defined above, i.e.:

$$B_1 = \sum_{i=o}^{7} \alpha_{1i} \; N_i \qquad \text{XIII-3-24}$$

where

B_1 = number of cases of disease 1

α_{1i} = proportion of persons with protection i that becomes sick with disease 1.

In the same way, for disease 2 the number of cases is:

$$B_2 = \sum_{i=o}^{7} \alpha_{2i} \; N_i \qquad \text{XIII-3-25}$$

Finally, the number of persons affected by disease 3 will be:

$$B_3 = \sum_{i=o}^{7} \alpha_{3i} \; N_i \qquad \text{XIII-3-26}$$

A second decision that the planner has to make is to specify the number of cases in each of the three possibilities above that should be treated. This means that he has to divide the patients of each of the

three diseases above into two sub-groups: those that should be treated, and those that should not be treated. In formulas, this can be stated as follows:

$$B_i = T_{oi} + T_{1i} \quad i = 1,\ldots,3 \qquad \text{XIII-3-27}$$

where

B_i number of cases with disease i

T_{oi} number of patients of disease i who do not receive treatment

T_{1i} number of patients who receive treatment.

It should be observed that several methods of treatment could be considered, if desired.

The total number of deaths will be

$$D = \sum_{i=1}^{3} (\delta_{oi} T_{oi} + \delta_{1i} T_{1i}) \qquad \text{XIII-3-28}$$

where

D Total number of deaths

δ_{oi} mortality rate among untreated patients of disease $i = 1,\ldots,3$

δ_{1i} mortality rate among treated patients of disease $i = 1,\ldots,3$

In recapitulation, it can be said that the problem of the planner is to specify the numbers N_i $i = 1,\ldots,7$, T_{oi} and T_{1i} $i = 1,\ldots,3$ in such a way as to minimize D. In this minization, the fact that human, physical and financial resources are limited has to be considered. To do so, let H be the total number of doctor hours available for the period under consideration--say one year. It will be assumed here that the usefulness of the specific methods of prevention does not change when its application is somewhat postponed. This means that a child is equally protected whether he is vaccinated at the beginning or at the end of the year. This highly artificial assumption simplifies the estimation of the parameters and reduces the impact of the limited number

of doctors. More specifically, in the case of an epidemic it might be required to consider that the doctor's time available is--say--only one month, because after that period the epidemic has already affected all susceptible children. In this case, the doctor constraint is stronger.

The time needed to apply prevention of type i will be denoted with τ_{oi}. This means that the total time used in prevention--to be denoted with P_o- is:

$$P_o = \sum_{i=1}^{3} \tau_{oi} N_i + (\tau_{o1} + \tau_{o2})N_4 + (\tau_{o1} + \tau_{o3})N_5 + (\tau_{o2} + \tau_{o3})N_6 + (\tau_{o1} + \tau_{o2} + \tau_{o3})N_7 \qquad \text{XIII-3-29}$$

The time needed for treatment -- to be denoted with P_1 - is:

$$P_1 = \sum_{i=1}^{3} \tau_{1i} T_{1i} \qquad \text{XIII3-30}$$

The total time used must satisfy the constraint

$$H \geq P_o + P_1 \qquad \text{XIII-3-31}$$

The time of nurses and other personnel required for prevention and/or treatment is analysed using relationships similar to those in XIII-3-29 to XIII-3-31. The details will not be presented here. In the application to be presented below, the constraints imposed by doctors and nurses are considered.

Another constraint that must be considered is that imposed by the financial resources available. To study this constraint, let c_{oi} be cost per child of prevention method i = 1,...,3. This cost should cover doctors' and nurses' time, and implements used. With this, the total cost of prevention is:

$$C_o = \sum_{i=1}^{3} c_{oi}N_i + (c_{o1} + c_{o2})N_4 + (c_{o1} + c_{o3})N_5 + (c_{o2} + c_{o3})N_6 + (c_{o1} + c_{o2} + c_{o3})N_7 \qquad \text{XIII-3-32}$$

The cost of treatment of condition i = 1,3 will be denoted with $c_{1\,i}$. As a consequence, the total cost of treatment is

$$C_1 = \sum_{i=1}^{3} c_{1i}\, T_{1i} \qquad \text{XIII-3-33}$$

The total cost must be less than or equal to the resources available, i.e.

$$R \geq C_o + C_1 \qquad \text{XIII-3-34}$$

This completes the statement of the problem faced by a planner. It is to minimize the number of deaths through protecting specified numbers of children by means of prevention methods, and also by curing specific numbers of those who become sick. In the application of both prevention and treatment methods, the constraints imposed by doctors' and nurses' time, implements, and financial resources available must be taken into consideration.

The problem has been put as a linear programming problem. This means that once the values of the parameters α, γ, δ, τ, and c, and of the constraints N, H, and R are available, the determination of the optimum allocation of resources is a routine exercise in computation.

The model below will be applied to the minimization of the number of deaths of infants and children in the United Arab Republic. The diseases to be considered are Bronchitis, all forms of Diarrhea and Measles.

The first problem is that the three diseases mentioned present an infinite number of variations. As medical doctors say, there are no diseases, there are only patients. Each patient is a different problem. Despite this, it was assumed that each of the three diseases can be treated as an entity. The estimated proportion of minor and major, or light and serious cases was used to evaluate total number of cases, costs, etc.

It was assumed that there is one prevention and one treatment method for each disease. The main reason for this assumption is that there are no data for a more detailed study. The prevention method for Bronchitis is better housing and clothing; for Diarrhea, more hygienic water supply, and for Measles, vaccination. The mortality rate for populations age 0-4, protected and not protected, were estimated using data from different countries, and from different govenorates of the UAR. The costs of using the three methods were obtained from different departments of the UAR.

Two types of treatment were assumed for each of the three diseases: one for the light and one for the serious cases. The main difference between them is the assumption that the light cases can be treated at home, while the serious ones require hospitalization. The cost in doctors nurses and hospital time and in financial resources was estimated for each type of treatment, using the medical records in the UAR and experts' opinions. As observed above, for the final analysis weighted averages per disease were computed for three types of resources: doctors, nurses, and financial, the weights being the proportions of light and serious cases. The data used are presented in Table XIII-3-2.

The results of the application of the model appear in Table XIII-3-3 and Figure XIII-3-1. The table shows that with up to 5,000 Egyptian Pounds, the optimum allocation is in vaccination against Measles and in treatment of Diarrhea. With resources of 10,000 Egyptian Pounds, optimum allocation shifts mainly to prevention of Diarrhea and Measles, and treatment of all three diseases. Further increments of resources should be used in simultaneous prevention of Bronchitis, Diarrhea, and Measles.

TABLE XIII-3-2

Data Used to Determine the Allocation of Resources that minimize Infants and Children Deaths

Description			Value
Morbidity	Disease 1	Persons Not Protected	5.1
"	" 2	Persons Not Protected	85.0
"	" 3	Persons Not Protected	70.0
Morbidity	Disease 1	Persons Protected from 1	1.7
"	" 2	Persons Protected from 1	75.0
"	" 3	Persons Protected from 1	65.0
Morbidity	Disease 1	Persons Protected from 2	4.5
"	" 2	Persons Protected from 2	40.0
"	" 3	Persons Protected from 2	68.0
Morbidity	Disease 1	Persons Protected from 3	5.1
"	" 2	Persons Protected from 3	85.0
"	" 3	Persons Protected from 3	9.0
Morbidity	Disease 1	Persons Protected from 1 and 2	1.5
"	" 2	Persons Protected from 1 and 2	40.0
"	" 3	Persons Protected from 1 and 2	63.0
Morbidity	Disease 1	Persons Protected from 1 and 3	1.7
"	" 2	Persons Protected from 1 and 3	75.0
"	" 3	Persons Protected from 1 and 3	8.5
Morbidity	Disease 1	Persons Protected from 2 and 3	4.5
"	" 2	Persons Protected from 2 and 3	40. 0
"	" 3	Persons Protected from 2 and 3	9.0
Morbidity	Disease 1	Persons Protected from 1, 2, and 3	1.5
"	" 2	Persons Protected from 1, 2, and 3	35.0
"	" 3	Persons Protected from 1, 2, and 3	8.5
Mortality	Disease 1	Not Treated Patients	40.0
"	" 2	Not Treated Patients	9.59
"	" 3	Not Treated Patients	.34
Mortality	Disease 1	Treated Patients	20.0
"	" 2	Treated Patients	.8
"	" 3	Treated Patients	.22
Doctor's Time Used (Minutes per Patient)			
	Prevention	Disease 3	2.0
	Treatment	" 1	25.0
	"	" 2	10.0
	"	" 3	20.0
	All Other		0

TABLE XIII-3-2 (Continuation)

Description	Value
Nurses Time Used (Minutes per Patient)	
Prevention Disease 1	3.0
" " 2	3.0
" " 3	2.0
" " 1 and 2	5.0
" " 1 and 3	5.0
" " 2 and 3	5.0
" " 1, 2, and 3	7.0
Treatment Disease 1	32.5
" " 2	13.0
" " 3	31.0
Financial Cost (Egyptian Pounds per Child)	
Prevention Disease 1	7.15
" " 2	1.0
" " 3	0.18
" " 1 and 2	8.15
Treatment Disease 1	6.15
" " 2	1.13
" " 3	.99
Total Number of Children	5000
Doctors' Time Available per Year (Minutes)	504000
Nurses' Time Available per Year (Minutes)	504000
Financial Resources Available (Egyptian Pounds)	
Case I	2000
" II	5000
" III	10000
" IV	15000
" V	20000
" VI	25000

Disease 1 Bronchitis
Disease 2 Gastritis, Duodenitis, Enteritis and Colitis, except Diarrahoea of the New Born
Disease 3 Measles

Source: Explained in Text

TABLE XIII-3-3

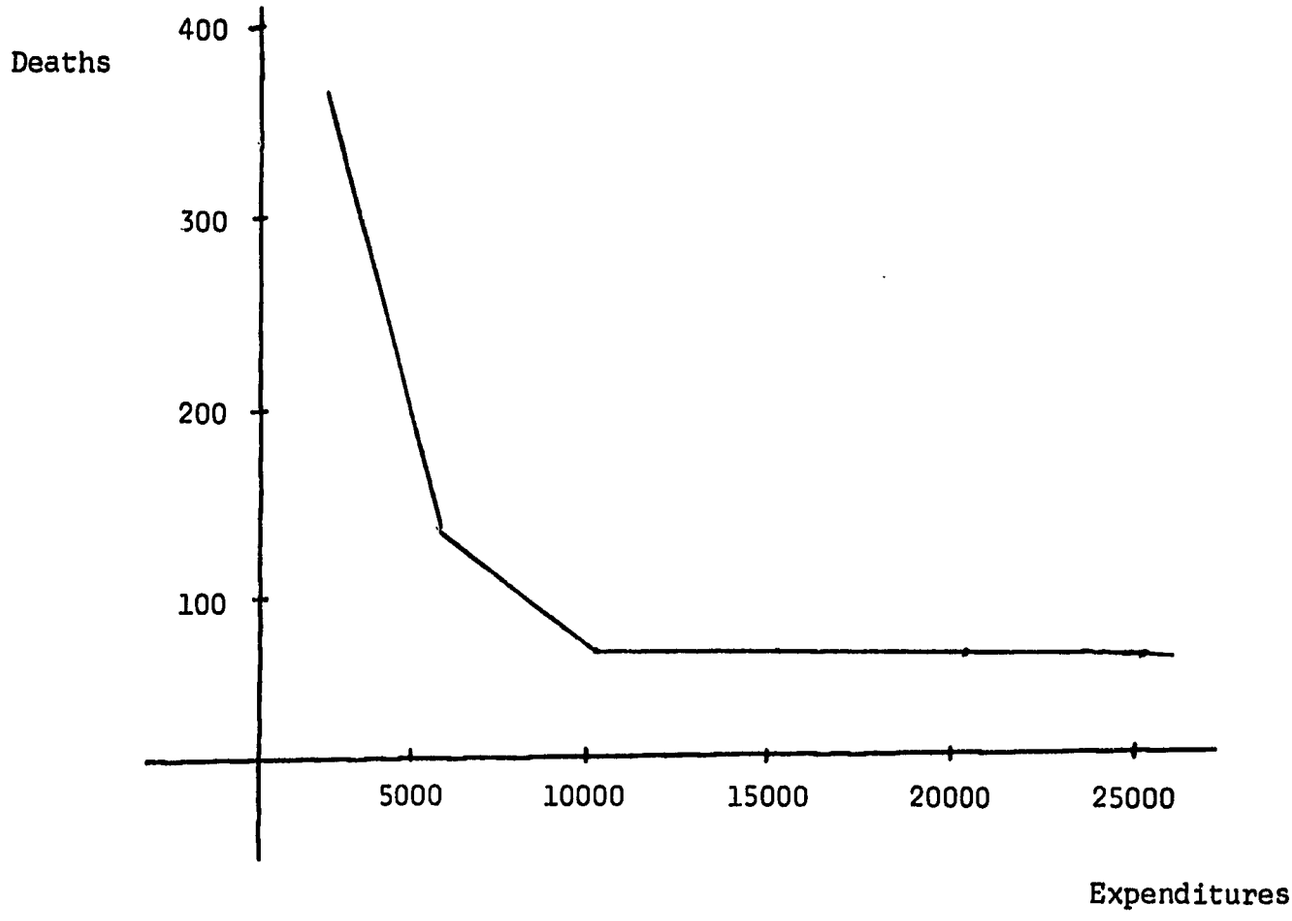
Number of Children that Should Receive Preventive Measures and Number of Patients that Should Be Treated to Minimize Children Death.

	Case I	Case II	Case III	Case IV	Case V	Case VI
Children in the Population	5000	5000	5000	5000	5000	5000
Financial Resources Available (Egyptian Pounds)	2000	5000	10000	15000	20000	25000
Minimum Number of Deaths	362	134	61	57	52	47
Number Should Receive No Protection	0	0	0	0	0	0
" " " Protection from 1	0	0	0	0	0	0
" " " " " 2	0	0	0	0	0	0
" " " " " 3	5000	5000	0	0	0	0
" " " " " 1 and 2	0	0	0	0	0	0
" " " " " 1 and 3	0	0	0	0	0	0
" " " " " 2 and 3	0	0	4880	4156	3432	2708
" " " " " 1, 2, and 3	0	0	120	844	1568	2292
Patients of 1 that should not be Treated	255	237	0	0	0	0
" " 2 " " " "	2559	0	0	0	0	0
" " 3 " " " "	450	450	0	0	0	0
Patients of 1 that Should Be Treated	0	18	221	199	178	156
" " 2 " " " "	1691	4250	1994	1958	1922	1885
" " 3 " " " "	0	0	449	446	442	439

Source Explained in Text

Figure XIII-3-1

Minimum Number of Deaths As
Function of Expenditures



XIII-3-5 Further Refinements of the Linear Model

The model presented in Section XIII-3-2 and refined in Sections XIII-3-3 and XIII-3-4, like any scientific model, can be improved ad infinitum. Several possible refinements will be mentioned below.

First, a more detailed classification of the mortality rates, taking into consideration the influence of preventive measures could be made. Four mortality rates would then have to be considered instead of two: two for the population protected, and two for the population not-protected by preventive measures.

Another improvement would be to make a more detailed classification of costs. For instance, a sub-division of the costs of treatment could be made, based on whether the patients did or did not receive any protective measures.

XIII-3-6 A Non-Linear Model

Non-linear elaborations of the model in XIII-3-3 would be useful for the purpose of pointing out some of the limitations of the linear case, and also because they make it possible to explore more easily some of its characteristics. In this section, the problem in equations XIII-3-4 and XIII-3-5, or its equivalent in equations XIII-3-12 and XIII-3-18 will be replaced by the following:

Minimize:

$$D = P - f(E_1) - g(E_2) \qquad \text{XIII-3-35}$$

subject to

$$R = E_1 + E_2 \qquad \text{XIII-3-36}$$

In formula XIII-3-35, f and g are increasing functions of their arguments, i.e.

$$f'(E_1) > 0; \; g'(E_2) > 0$$

in addition, we will assume that

$$f''(E_1) < 0 \quad \text{and} \quad g''(E_2) < 0$$

It is easy to verify that for minimum the following conditions must be satisfied:

$$f'(E_1) = g'(R - E_1) \qquad \text{XIII-3-37}$$
$$- f''(E_1) - g''(R - E_2) > 0$$

Condition XIII-3-37 is a well-known condition for optimum use of resources. This condition, when expressed in terms appropriate to our problem, states that for a minimum number of deaths, the marginal returns of money used in the prevention of a disease must be equal to the marginal returns of money used in its treatment.

XIII-4 AN INTEGRATED MODEL OF HEALTH PLANNING AND POPULATION GROWTH

An important limitation of the models in section XIII-3 is that they refer to only one time period. This limitation will be removed below.

The principal consequence of considering several time periods is that health programs in one period influence the size of the population in the next period. This is particularly true when all the diseases that could affect a population are considered in a model.

It will be assumed below that the time horizon extends from $t = 0$ to $t = T$, and that the number of diseases is I.

The objective function in the present case takes the following form:

Minimize

$$D = \sum_{i=1}^{I} \sum_{t=0}^{T} D_{it} \qquad \text{XIII-4-1}$$

as before, D equals total number of deaths

where

D_{it} Number of deaths by disease i between dates t and t + 1

The number of deaths caused by one disease during one period is

$$D_{it} = \delta_{1i}M_{1it} + \delta_{2i}M_{2it} \qquad \text{XIII-4-2}$$

where

δ_{hi} Mortality rate of disease i among people treated h = 1, and not treated h = 2

M_{hit} Number of cases of disease i that h = 1 should be treated and h = 2 should not be treated in the period between t and t + 1

Equations XIII-4-1 and XIII-4-2 are the counterpart of equations XIII-3-1 in the one period, one disease model.

Two equations dealing with population are also needed. The first one gives the growth of population in time.

$$P_{t+1} = (1 + \beta)P_t - D_t \qquad \text{XIII-4-3}$$

In this equation use is made of the assumption that all causes of death are identified among the I considered. The second is the counterpart of XIII-3-8:

$$P_t = N_{1it} + N_{2it} \qquad \text{XIII-4-4}$$

where:

N_{hit} number of persons who should receive preventive measures h = 1, and should not receive preventive measures h = 2, for disease h at date t.

In equation XIII-4-4 use is made of the assumption of independent effect of the different diseases, and, as in section XIII-3, it is assumed that the preventive measures have, at most, a one-period effect.

The total number of cases of disease i between t and t + 1 is given by

$$S_{it} = \tau_{1i} N_{1it} + \tau_{2i}N_{2it} \qquad \text{XIII-4-5}$$

where the meaning of the new subscripted symbols should be clear. This equation is equivalent to XIII-3-9.

The constraint of the number of cases that should be treated and should not be treated in equation XIII-3-10 takes the form

$$S_{it} = M_{1it} + M_{2it} \qquad \text{XIII-4-6}$$

Finally, the resources constraint is

$$R \geq \sum_{i=1}^{I} \sum_{t=0}^{T} (c_{1i}N_{1it} + c_{2i}M_{1it}) \qquad \text{XIII-4-7}$$

The problem now is to minimize the objective function in XIII-4-1 subject to constraints XIII-4-2 to XIII-4-7.

To apply the standard techniques of Linear Programming to this problem, all the variables should be expressed in terms of the M_{hit} and N_{hit} control variables. The steps needed are closely parallel to those used in XIII-3.

For a simplified example, it will be assumed that I = 2 and that T = 2. The coefficients used appear in Table XIII-4-1; the matrix of constraints in terms of the M_{hit} and N_{hit} in Table XIII-4-2, and the results in Table XIII-4-3.* Perhaps the only aspect of these tables that needs explanation is the value of some of the coefficients in XIII-4-1. In this Table some of the morbidity rates are larger than one, meaning that some persons become sick more than once a year. Similar values of the coefficients are likely to appear in highly aggregated models.

---

*The computations for this example were made by Mr. D. Cummings, former student of the author.

TABLE XIII-4-1

HYPOTHETICAL DATA USED FOR NUMERICAL EXAMPLE OF MODEL IN SECTION XIII-4, I=2, T=2

Symbol	Definition	Value
δ_{11}	mortality rate disease 1 with treatment	.040
δ_{12}	mortality rate disease 1 without treatment	.050
δ_{21}	mortality rate disease 2 with treatment	.045
δ_{22}	mortality rate disease 2 without treatment	.055
β	birth rate	.016
τ_{11}	morbidity with disease 1 with prevention	.5
τ_{12}	morbidity rate disease 1 without prevention	1.0
τ_{21}	morbidity rate disease 2 with prevention	.6
τ_{22}	morbidity rate disease 2 without prevention	1.1
c_{11}	cost of protecting one person disease 1	$ .31
c_{12}	cost of protecting one person disease 2	$ .50
c_{21}	cost of treating one person disease 1	$ 20.00
c_{22}	cost of treating one person disease 2	$ 100.00
P_o	total initial population	100,000
R	total resources available	$2,000,000

TABLE XIII-4-2

OBJECTIVE AND CONSTRAINTS OF MODEL IN SECTION XIII-4

EXPRESSED IN TERMS OF M_{hit} AND N_{hit}

M110	M120	M111	M121	M112	M122	N110	N120	N111	N121	N112	N122	M210	M220	M211	M221	M212	M222	N210	N220	N211	N221	N212	N222	-1	Constant
-.012	-.014	-.009	-.009	-.005	-.005	-.0045	-.0055	-.0045	-.0055	-.0045	-.0055	-.008	-.002	-.004	-.005										-25,871
						1.												1.							100,000
							1.												1.						100,000
.04	.05							1.				.045	.055							1.					101,600
.04	.05								1.			.045	.055								1.				101,600
.041	.051	.04	.05							1.		.046	.056	.045	.055							1.			103,225
.041	.055	.04	.05								1.	.046	.056	.045	.055									1.	103,225
1.						.1						1.													50,000
.024	.03	1.						.1				.027	.033	1.											50,950
.025	.031	.024	.03	1.						.1		.028	.034	.027	.033	1.									51,935
	1.						.1						1.												110,000
.044	.055		1.						.1			.05	.061		1.										111,750
.044	.055	.044	.055		1.						.1	.051	.062	.05	.061		1.								113,548
20.	100.	20.	100.	20.	100.	.31	.5	.31	.5	.31	.5													1.	2,000,000

TABLE XIII-4-3

Number of persons that should participate in the program to minimize the number of deaths*

Year	Disease 1		Disease 2	
	Treated	Protected	Treated	Protected
0	0	100,000	0	100,000
1	44,341	93,850	0	99,350
2	44,094	88,308	0	88,308

*Minimum number of deaths = 19,168

REFERENCES

(1) Ahumada, J., (et. al.),
Health Planning: Problems of Concept and Method
Pan American Health Organization, Washington, D.C., 1965

(2) Correa, H.,
The Economics of Human Resources
North Holland Publishing Co., (2nd Printing), Amsterdam, 1967

(3) Correa, H.,
"Health Planning",
Kyklos
Vol. XX, 1967, Fasc. 4, pp. 909-923

(4) Feldstein, M.S.
"Health Sector Planning in Developing Countries,"
Economica
Vol. 37, 1970, pp. 139-163

(5) Klarman , H.E.,
The Economics of Health
Columbia University Press, New York, 1965

(6) Weisbrod, B.A.,
Economics of Public Health
University of Pennsylvania Press, Philadelphia, 1961

CHAPTER XIV

INTEGRATION OF POPULATION AND HEALTH PLANNING

XIV-1 INTRODUCTION

The starting point for the integration of population and health planning is the delimitation of the two areas. As mentioned before, population planning is identified here with the control of births or fertility, whether the intention is to increase or decrease them. Health planning, using one of the possible alternatives available, was identified in Chapters XII and XIII with the planning of the medical control of disease oriented toward the postponement of death. The only points that should be added to these delimitations are, first, that any delimitation is arbitrary and restrictive, and second, there is no reason why the definitions adopted could not be modified if desired.

The question of the integration of population and health planning can be seen from several points of view. The first one is that of the interaction between morbidity and mortality control with population growth. A model dealing with this problem is presented in Section XIII-4 and will not be repeated here. Another problem deals with the influence of fertility control on mortality, i.e., it can be assumed that the final objective of fertility control is to reduce mortality. In the present chapter, attention will be paid to the control of fertility in order to reduce the mortality of infants and mothers. Since the direct affect of fertility control on deaths produced by other causes is rather remote, this aspect will not be studied here. Second is the influence of the control of mortality on fertility. For this, a cause-effect relationship between the two aspects is needed. One that could be used is that a child living up to the age of two increases the motivation to avoid having other children. In the same line of reasoning, if, say, 80% of all children live to be 40 years of age, then parents do not need to have many children in order to be sure that some of them will live to help them in their old age.

XIV-2 MINIMIZATION OF INFANT DEATHS

The basic ideas of the model to be presented is that infant deaths can be avoided by either one or two approaches, or a combination of them. The first approach is limiting the number of children born, and the second, providing care to those born. Either of these two methods uses the limited resources available for the program. The question is how to use them in such a way as to minimize the number of deaths.

To simplify the analysis, a time horizon of one year will be adopted, and the only medical care considered will be that related to pre- and post- natal care for mothers and children.

The number of children born is, as explained before,

$$B = \alpha F + (\beta - \alpha)N \qquad \text{XIV-2-1}$$

where

B = number of births

F = number of women in the population

α = fertility rate without contraception

β fertility rate with contraception

N = number of women that should receive contraception advice and service

These children can be divided into two groups

$$B = M_1 + M_2 \qquad \text{XIV-2-2}$$

where

M_i = number of children that should receive care for i=1, and should not receive care for i=2.

The total number of deaths among the children born is

$$D = \delta_1 M_1 + \delta_2 M_2 \qquad \text{XIV-2-3}$$

where

D = number of deaths

δ_i = mortality rate among children in group i.

Finally, the costs of the program are

$$R = c_1 N + c_2 M_1 \qquad \text{XIV-2-4}$$

where

c_i = for i=1 is cost of providing contraceptive advise and services to one woman, and for i=2 is cost of child care.

The problem of minimizing deaths is that of minimizing XIV-2-3 subject to XIV-2-1, XIV-2-2, XIV-2-4 and

$$\begin{aligned} 0 &\leq N \leq F \\ 0 &\leq M_i \leq B \end{aligned} \qquad \text{XIV-2-5}$$

To study the solution of this problem it will be assumed that the resources available are not sufficient to provide contraceptive advice and service to all the F women in the population, nor to provide care to all the B children born. This means that N and M_1 can be as large as the resources available permit without violating conditions XIV-2-5.

From equations XIV-2-1 to XIV-2-4 it is possible to obtain

$$D = \delta_2 \alpha F + \frac{\delta_1 - \delta_2}{c_2} R + [\delta_2 (\beta - \alpha) - \frac{\delta_1 - \delta_2}{c_2} c_1]N \qquad \text{XIV-2-6}$$

Equation XIV-2-6 means that D will increase with N if the coefficient of N is positive, and will decrease if that coefficient is negative. That is, N should increase if

$$\frac{c_2}{\delta_2 - \delta_1} > \frac{c_1}{\delta_2 (\alpha - \beta)} \qquad \text{XIV-2-7}$$

i.e., if the cost of reducing one death with health care is larger than the cost of reducing one death by avoiding one birth. This interpretation will be explained in detail below, since it might not be evident. Observe that, from XIV-2-2 and XIV-2-3, it is possible to write

$$D = \delta_2 B + (\delta_1 - \delta_2) M_1$$

As a consequence, it follows that

$$-1 = (\delta_1 - \delta_2) \Delta M_1$$

i.e.

$$\frac{c_2}{\delta_2 - \delta_1} = c_2 \Delta M_1$$

is the cost of avoiding one death by treating ΔM_1 children. A similar analysis can be made with respect to the right hand side of XIV-2-7.

XIV-3 MINIMIZATION OF MOTHERS' AND INFANTS' DEATHS

An immediate extension of the model in Section XIV-2 is to consider as an objective function the minimization of not only infant deaths, but of the total of infant plus mothers' deaths.

The simplest way to consider this objective function is to assume that there is one child per mother. In this case, the number of mothers can be written

$$B = T_1 + T_2 \qquad \text{XIV-3-1}$$

where

T_i is number of mothers who should receive care for $i=1$, and who should not receive care for $i=2$.

The total number of deaths becomes

$$D = \delta_1 M_1 + \delta_2 M_2 + \gamma_1 T_1 + \gamma_2 T_2 \qquad \text{XIV-3-2}$$

where

γ_i mortality rate among mothers in group i.

The costs of the program becomes

$$R = c_1 N + c_2 M_1 + c_3 T_1$$

where

c_3 cost of providing care to one woman.

The algebraic solution of this problem can be obtained by the method used in XIV-2. It will not be presented here.

Several modifications could be mentioned. Perhaps a more realistic assumption than the one discussed in the text is that mother and child receive simultaneous care. The modifications needed to consider this case need no explanation.

XIV-4 ANALYSIS OF THE INFLUENCE OF NUMBER OF CHILDREN SURVIVING ON ACCEPTANCE OF CONTRACEPTION

In the previous section, no attention was given to the fact that the number of infant deaths, or more specifically, the provision of post partum care for children, might be one of the determinants of the acceptance of contraceptives.

A first possibility is to assume that the number of women in a contraception program is completely determined by the number of children that receive post partum care. Then the equation

$$N = e + f M_1 \qquad \text{XIV-4-1}$$

where e and f are known parameters should be added to the model.

In this case, all the variables in the model, including number of deaths, have a unique value.

A more reasonable possibility is to assume that only part of the women using contraceptives do so because their children receive post natal care, while number of women not doing so can be determined in order to minimize deaths. This means that instead of equation XIV-4-1, the following should be used:

$$N = N_1 + fM_1 \qquad \text{XIV-4-2}$$

where

N = as before, total number of women using contraceptives

N_1 = number of women who should use contraceptive, but do not do so as a consequence of the post natal care given to children;

M_1 = number of children receiving post natal care.

With the use of equation XIV-4-2, the problem becomes that of minimizing deaths in equation XIV-2-3, subject to equations XIV-2-1, XIV-2-2, XIV-2-4 and XIV-4-3.

With a process similar to the one used in Section XIV-2, it can be shown that N_1 should be made as large as possible, i.e.,

$$N_1 = \frac{R}{c_1}$$

and $M_1 = 0$ if

$$\frac{c_1 f + c_2}{\delta_2 (\alpha - \beta) f + (\delta_2 - \delta_1)} > \frac{c_1}{\delta_2 (\alpha - \beta)} \qquad \text{XIV-4-3}$$

Comparing formulas XIV-2-7 with XIV-4-3, it follows that the left hand side of XIV-4-3 is the cost of avoiding one death with health care. It has two components: the cost of avoiding death with medical post natal care, and the cost of avoiding deaths because post natal care induces women to use contraceptives.

From additional comparisons of equations XIV-2-1 and XIV-4-3 it can be concluded that the influence of post natal care on the number of women accepting contraceptive use is irrelevant in the sense that if $N_1 = R/c_1$ according to the model in Section XIV-4, then $N=R/c_1$ in the model in Section XIV-2 and vice versa. This means that if the model in Section XIV-2 is used, and according to it--without explicit consideration of the influence of M_1 on N--it is prescribed that $N=R/c_1$ and $M_1=0$, then also according to the model in Section XIV-4 one would reach the conclusion that $M_1=0$. To verify this point observe that if $N_1=R/c_1$, i.e., if formula XIV-4-3 holds, then

$$(c_1 f + c_2)\, \delta_2 (\alpha - \beta) > c_1 [\delta_2 (\alpha - \beta) f + (\delta_2 - \delta_1)] \qquad \text{XIV-4-4}$$

and this equation implies XIV-2-7, i.e., that $N=R/c_1$. On the other hand starting with $N=R/c_1$ with algebraic transformations it is possible to reach XIV-4-4, and from it XIV-4-3, i.e., the conclusion that $N_1=R/c_1$.

XIV-5 EXTENSIONS

The models presented in Sections XIV-2 and XIV-4 are greatly simplified in order to bring out the main issues. They need several extensions to become more realistic, and, as a consequence, more useful in practice.

All the problems associated with time have been eliminated with the assumption that the time horizon of the plan is one year. Although a first impression is that the consideration of several years will not bring about any major modifications in the models, this topic should be studied.

Another very useful simplifying assumption is that all the medical services

considered are those associated with pre- and post natal care for mothers and children. All other possible medical services could also be considered. To do so, the medical services provided for control of each of the possible diseases should be considered by itself, and not aggregated in one entry.

In the same line of approach, there is no reason why only one method of contraception should be considered. The same is valid for all the different models of prevention and treatment of disease that could be included in the model.

Finally, a more detailed description of the resources needed in a demographic and health program could be included in the model. In this case, the availability of doctors, nurses, hospitals, etc. could be considered. This step is useful in cases where it is not possible to purchase the services of personnel, physical resources, etc., even if the financial resources are available.

CHAPTER XV

AN OPTIMIZATION MODEL FOR NUTRITIONAL PLANNING

XV-1 REVIEW OF EXISTING STUDIES

In this Section the work already done in two areas closely related to optimization models in nutritional planning will be considered. First, reference will be made to the use of mathematical models in diet and menu planning, and second, the work done on conceptual and on simulation models for nutritional planning will be briefly mentioned.

XV-1-1 Mathematical Models in Diet and Menu Planning

Diet planning has a special place in the history of Linear Programming. A problem of diet planning was proposed and partially solved in reference (3) even before the first formal method of solution of linear programming problems was developed (1). At present, the application of linear programming to diet or menu planning is a standard example in textbooks of operations research. The object of these examples is to specify the menu that minimizes costs while satisfying nutritional requirements. A major limitation of these elementary uses of linear programming techniques is that they do not take into consideration the preferences of the consumers, and, as a consequence, the diets recommended are limited to a few foods without any variety. These same foods must be repeated day after day, whether the persons consuming them like it or not. In more advanced applications, for example, in diet or menu planning for hospitals, schools, army camps, etc., sufficient constraints can be included in the linear programming problem (2), or disutility indices can be introduced in a quadratic programming problem (4), to ensure day-to-day variations, and even, when appropriate, daily choices from among a limited number of alternatives.

However, even the most sophisticated applications of menu and diet planning would not produce acceptable results if used for nutritional planning. The reason for this is that in nutritional planning the population for whom the plan

is made does not reside in the type of institutions for which the methods for diet and menu planning were devised. The most important consequence of this fact is that the population for whom a nutritional plan is made cannot be presented day after day with a limited set of food choices, combined and cooked in such a way as to satisfy nutritional requirements. In addition, it is not possible to control the health conditions of this population so that the nutrients taken with the foods are actually used by the organism. In summary, the basic problem of a nutritional plan is the simultaneous determination of the foods a population should buy, the way they should be cooked, the health conditions that the population should enjoy, and the methods that should be used to induce the population to actually buy the required foods, cook them in the appropriate way, and maintain appropriate health conditions. A model that includes all these elements and has as its objective the minimization of costs is presented in Section XV-2. As frequently is the case when initial steps are taken, no data are available to estimate the parameters needed to apply such a model. However, as is also frequently the case, the major limitation does not seem to be the cost or difficulty of obtaining the required data. Extensive nutritional surveys are frequently conducted, such as those made by the U.S. Interdepartmental Committee on Nutrition for National Defense in 11 countries. However, most of the data required for policy-making on nutrition are not collected in these or similar surveys, because such data have not been clearly specified.

XV-1-2 Conceptual Models in Nutritional Planning

The studies in references (1) to (5) specify the main elements that should be considered in nutritional planning. They will be mentioned briefly in this Section.

Nutritionists and economists have pointed out that nutritional planning covers all the medical, educational, technical and economic aspects associated with the production, distribution, demand, and utilization of foods and nutrients. In the conceptual models of nutritional planning that are available, all these

elements are interrelated.

In Section XV-1-3, brief mention will be made of the use of the conceptual models in the simulation models for nutritional planning. In Section XV-2, an optimization model that takes into consideration the health, education and demand aspects of the conceptual models will be presented.

XV-1-3 Simulation Models in Nutritional Planning

The simulation models for nutritional planning are direct extensions of models for agricultural planning. The main thrust of the latter type of model is to estimate the future demand for agricultural products, the supply needed to satisfy that demand, and the investment and labor force needed to produce that supply. This estimation process is usually made by successive approximations. The successive steps are needed to achieve coherence between the forecasts for demand and supply. These successive approximations also make it possible for the planner to take into consideration constraints not included in the initial forecasts, such as, the impact on employment of the agricultural plan.

Obviously, a great deal of attention is given to demand and supply of food in agricultural plans. As a consequence, only minor extensions are needed in order to include a nutritional component in an agricultural plan. The basic element in this case is a transformation that makes it possible to estimate demand and supply of nutrients on the basis of demand and supply of foods. Once this is done, the process of successive approximations can be used to produce forecasts of supply and demand of agricultural products that also satisfy nutritional constraints.

Perhaps the best example of this method is found in reference (1).

XV-2 A MATHEMATICAL MODEL FOR NUTRITIONAL PLANNING

XV-2-1 The Model

As a first step in the presentation of the model, a formal characterization of the nutritional constraints will be made. To a large extent, this follows the

approach used in diet and menu planning models. Let $\hat{q}_j$ $j=1,\ldots,J$ denote the quality of good or service j that a consumer uses. These J goods and services are not limited to foods, for the reason that a consumer uses his income not only for food, but for all the other goods and services he uses, as well. This means that his decisions about food are made taking into consideration the total of goods and services he can purchase. As a consequence, when planning nutrition, all the goods and services competing for the consumer's income must be considered. In the analysis below the subindex $j=1,\ldots,h-1$ will denote foods, the subindex $j=h$ will denote health services, $j=h+1=e$ educational services, and subindices $j=h+2,\ldots,J$ will denote other non-food goods and services.

The amount of nutrients in the foods available to a consumer will be

$$[n_{ij}]\,[\hat{q}_j] = [n_i] \qquad \begin{array}{l} i=1,\ldots,I \\ j=1,\ldots,h-1 \end{array} \qquad \text{XV-2-1}$$

where

n_{ij} is the quality of nutrient i per unit good or service j used by the consumer. It will be assumed that there are I nutrients, i.e., $i=1,\ldots,I$.

n_i total amount of nutrient i in the combination of foods $[\hat{q}_j]$ $j=1,\ldots,h-1$.

A point that must be considered in nutritional planning is that the quantities n_{ij} of nutrient i contained in food j are not fixed. Actually, the values of n_{ij} vary according to the different processes of industrialization, but in particular with the "fortification" of foods. The simplest way to take this into consideration is to treat the fortified and non-fortified types of the same good as different foods. For example, non-fortified rice can be given subindex 3, while fortified rice has subindex 4. This subdivision can proceed without limits.

Another problem is the possibility that the nutrients contained in certain foods might not be fully utilized by a consumer because they are partially destroyed in storage at his home or during preparation. Denoting with $g(\hat{q}_e)$--where $0 \leq g \leq 1$--

the proportion of nutrients available in the food that remains after home storage and cooking, the total intake of nutrient i eaten is $n_i g(\hat{q}_e)$. The index $g(\hat{q}_e)$ above is assumed to depend on the educational status $\hat{q}_e$ achieved by the consumer.

Since the educational characteristics of a consumer play an important role in what follows, it is useful to digress here in order to examine this aspect with some attention. Educational characteristics are assumed here to be determined by at least three elements. The first is formal general education, frequently including some education with regard to what constitutes good nutrition. The second is specific nutritional education, such as that obtained in mother and child centers. Finally, there is education through advertising and mass media. All these forms of education can be considered in principle in a nutritional plan. In practice, some of them could be excluded if the time horizon of the plan is not long enough. For instance, a nutritional plan for 2 or 3 years cannot use formal education to change the behavior of the consumers.

Next, the nutritional planner has to take into consideration the fact that the utilization of the nutrients ingested by an individual depends upon his health conditions. These conditions in turn depend upon the health services available to him. An index of the health conditions that influence the use of the nutrients taken in a person's food will be denoted with $h(\hat{q}_h)$. This index also ranges from 0 to 1. The amount of nutrients a person would be able to use becomes $n_i gh$. This quantity must satisfy the constraint

$$n_i gh \geq \bar{n}_i \qquad i=1,\ldots,I \qquad \text{XV-2-2}$$

where $\bar{n}_i$ denotes required intake of nutrient i.

The form of constraint XV-2-2 shows an important difference between diet and menu planning and nutritional planning. In the former, the components g and h of the constraints XV-2-2 are not considered, perhaps with the exception of the health index in menu planning for hospitals. On the other hand, these two elements play an important role in nutritional planning.

So far, the nutritional and health aspects of nutritional planning have been considered. It is also necessary to consider the determinants of the quantities

$\hat{q}_j$, j=1,...,J of goods and services a consumer uses, in order to study the possibility of inducing him to satisfy his nutritional requirements in XV-2-2. For this it is useful to distinguish between the goods and services a consumer buys and those he receives gratis. For this purpose, it will be assumed that

$$\hat{q}_j = q_j + k_j$$

where

q_j amount of good j purchased by the consumer

k_j amount of good j received gratis by the consumer

The distinction between q_j and k_j makes it possible to consider special feeding health or educational programs that can be used in a nutritional plan without direct costs to the consumer. It will be assumed that all the goods received gratis by a consumer are used by him.

To study the possibility of inducing a consumer to buy the appropriate quantities of foods, the economic theory of consumer behavior will be used. According to this theory, the consumer determines the quantities q_j of the goods and services he uses in such a way as to maximize his utility function subject to the constraints imposed by his income and the market prices. This suggests that there are three avenues open to the nutritional planner. The first is to modify through education the preferences of the consumer; the second is to modify his income; and the third is to modify the market prices. These three possibilities will be considered below.

It will be assumed that the preferences of a consumer are described by the frequently used Klein-Rubin utility function (1), (2), (3). The parameters of this function will be assumed to depend on the educational characteristics of the consumer, as determined in the nutritional plan. With this, the utility function takes the form:

$$u = \sum_{j=1}^{J} \mu_j(e)\log\,[q_j - \alpha_j(e)] \qquad \text{XV-2-3}$$

where

u utility index

$\mu_j(e)$, $\alpha_j(e)$ parameters that characterize the utility function. It is assumed that these parameters are functions of the education of the consumer. These parameters must satisfy the conditions $\mu_j > 0$ and $q_j > \alpha_j \geq 0$.

The income constraint that restricts the expenditures of the consumer to the level of his income makes it impossible for him to increase his utility without bounds. In economic theory two elements of this constraint are considered fixed, namely, the income of the consumer and the prices of the goods he buys. However, in a nutritional plan, these two elements can be modified to satisfy the constraints in XV-2-2. As a consequence, the income constraint takes the form

$$(m + \beta_o) = \sum_{j=1}^{J} (p_j - \beta_j)q_j \qquad \text{XV-2-4}$$

where

m consumer's income in the absence of a nutritional plan;

β_o income supplement as specified by the nutritional plan;

p_j prices of goods $j=1,\ldots,J$ in the absence of a nutritional plan;

β_j supplement to price j, $j=1,\ldots,J$ as determined for the nutritional plan.

The following demand functions are obtained from the maximization of the utility function in XV-2-3 subject to the income constraint in XV-2-4:

$$(p_j - \beta_j)q_j = (p_j - \beta_j)\alpha_j(e) + \mu_j(e)\left[(m + \beta_o) - \sum_{k=1}^{J} (p_k - \beta_k)\alpha_k(e)\right] \qquad j=1,\ldots,J \qquad \text{XV-2-5}$$

In the derivation of the demand function in XV-2-5 it has been assumed that the parameters μ_j and α_j of the utility function are independent of the quantities q_j purchased. For this it is necessary to assume that the educational characteristics

of the consumers depend on k_e but not on q_e. Without this assumption, the demand functions would not be those in XV-2-5. In spite of this, it will be assumed below that e is a function of $\hat{q}_e$ and not only of k_e. This deviation from the theoretical result has some advantages in terms of computational convenience.

The costs of a program like the one described above would be the following: First, the cost of the income supplements per consumer, i.e., β_o; second, the cost of the price subsidies, i.e., $\beta_j q_j$; and finally, the cost of the goods and services provided gratis, i.e., $p_j k_j$. The total cost will be

$$C = \beta_o + \sum_{j=1}^{J} (\beta_j q_j + p_j k_j) \qquad \text{XV-2-6}$$

This model can be used for nutritional planning, assuming that the objective of the plan is to minimize the cost C in XV-2-6. The minimization should be performed under the nutritional constraints in XV-2-1 and XV-2-2, the income constraint in XV-2-4, the demand functions constraint in XV-2-5, the constraints determined by the functions $g(\hat{q}_e)$, $h(\hat{q}_h)$, $\mu_j(\hat{q}_e)$, $\alpha_j(\hat{q}_e)$ and the appropriate constraints requiring non-negativity of some variables. In practical applications this should be interpreted as minimizing the average cost to be paid in order to induce a typical consumer in a homogeneous population to buy, store and cook the required foods, while maintaining the health conditions needed to utilize the nutrients ingested.

XV-2-2 Computational Aspects of the Model

The computational aspects of the model appear to be rather formidable. Even with the assumption that the functions for g, h, μ_j, and α_j are linear, the problem is to minimize a quadratic function subject to up to cubic constraints. The only possibilities open are the Kuhn-Tucker method and numerical approximations.

Additional difficulties are a result of the dimensions of the problem. The number of variables is at least 5J + 3, and that of constraints is 3J + I + 7.

A substantial simplification of both the structure and the size of the problem is obtained if it is assumed that the practices that determine storage

and preparation of food at home (g), the health conditions of the consumer (h), and his preferences (μ's and α's) are fixed. The problem then becomes one of minimizing a quadratic function subject to quadratic constraints. However, even in this simplified form, the computational problems are rather difficult.

On the other hand, it does not seem feasible to eliminate the quadratic constraints of the model, as would be necessary in order to put it in the standard quadratic programming form. This is because the quadratic constraints reflect the interaction between price subsidies and quantities purchased, and this is the basic modification needed in a diet or menu-planning model in order to construct one for nutritional planning.

From these brief comments it appears that the only solution might be to experiment with simple examples while work is done on the development of algorithms specifically adapted to the characteristics of the model. The analysis of simple examples is important because it might suggest simplifications of the model. In particular, it might show that some of the variables appearing in the objective function or constraints can be treated as constants. This would reduce nonlinearities in the model.

XV-2-3 Extensions of the Model

As observed, the objective of the model in Section XV-2-1 is to minimize the average expenditure needed to induce an average consumer in a homogenous population to satisfy his nutritional requirements.

For practical applications, it is useful to extend the model in order to consider several groups of consumers, for instance, groups defined by income intervals, by level of education, by age, etc. In principle there is no problem in doing this. To write such a generalized model, only changes in notation have to be introduced in the model in Section XV-2-1. Of course, the computational problems become much more difficult.

It is useful to observe that with the inclusion in the model of several population groups, the distinction between q_j and k_j, i.e., between purchased

goods and services and those received gratis, becomes particularly relevant. With only one group, q_j would be zero if $p_j < \beta_j$, and in this case all good of type j should be provided gratis. However, with several groups, it might be convenient to raise the price of one good, i.e., to make $\beta_j < 0$, while distributing it free to some specific groups of the population.

The model can also be extended in order to make it dynamic. Again in principle, it is likely that only notational changes are needed in order to extend the model to consider several time periods. However, there is little advantage in doing so, if the computational problems are not solved.

Perhaps the most important, and by no means simple, extension of the model in Section XV-2-1 is the inclusion of the processes of production and distribution of foods. In the model as it now stands, attention is paid only to the demand for goods and services. It includes the implicit assumption that, whatever the demand, the goods and services required will be supplied at constant prices. However, this is clearly not the case. Substantial modifications of demand are likely to bring about changes in prices and supply conditions. To avoid them if undesirable, or to foment them if useful, it is necessary to plan the production and distribution of goods and services.

No attempt will be made here to proceed along these lines. However, it should be observed that it is advisable to develop such models, despite that at present their main contribution will be to clarity of the definition of the problems involved. Computational problems are likely to limit the practical utilization of these models when developed.

REFERENCES

Section XV-1-1

(1) Arnoff, E.L. and S.S. Sengupta
"Mathematical Programming"
in Ackoff, R.L. (ed.)
Progress in Operations Research, Vol. I
New York: John Wiley, 1961

(2) Smith, V.E.
Electronic Computation of Human Diets
Bureau of Business and Economic Research
Michigan State University Studies, East Lansing, 1963

(3) Stigler, G.J.
"The Cost of Subsistence"
Journal of Farm Economics
Vol. 27, pp. 303-314 (1945)

(4) Wolfe, P.
"The Simplex Method for Quadratic Programming"
Econometrica
Vol. 27, pp. 382-398 (1959)

Section XV-1-2

(1) Bengoa, J.M. and R. Rueda-Williamson
"Planificacion y Organizacion de Programas Nacionales de Nutricion"
Boletin de la Oficina Sanitaria Panamericana
Vol. 73, No. 5, November, 1972

(2) Berg, A. and R. Muscat
"An Approach to Nutrition Planning"
American Journal of Clinical Nutrition
Vol. 25, pp. 939-954, 1972

(3) Johnston, B.F. and J.P. Greaves
Manual on Food and Nutrition Policy
FAO Nutritional Studies No. 22, 1969, Rome

(4) Proyecto Interagencial de Promocion de Politicas Nacionales de Alimentacion y Nutricion
Guia para la Planificacion de una Politica Nacional Integrada de Alimentacion y Nutricion
Diciembre, 1972 (Mimeo)

(5) Recalde, F.
Politica Alimentaria y Nutricional
Fondo de Cultura Economica, 1970, Mexico

Section XV-1-3

(1) FAO
Provisional Indicative World Plan for Agricultural Development
Vol. I, II and Summary and Conclusion
FAO, 1970, Rome

Section XV-2-1

(1) Klein, L.R. and H. Rubin
"A Constant Utility Index of the Cost of Living"
The Review of Economic Studies
Vol. 15, pp. 84-87, 1947-1948

(2) Stone, R.
"Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand"
The Economic Journal
Vol. 64, pp. 511-527, 1954

(3) Thiel, H.
Introduction to Demand and Index Number Theory
Center for Mathematical Studies in Business and Economics
University of Chicago
Report 7126, 1971 (Mimeo)

Chapter XVI

THE INTEGRATION OF POPULATION AND EDUCATIONAL PLANNING

XVI-1 SIMULATION MODELS

Two questions must be considered in constructing simulation models for the integration of population and educational planning: a) the influence of population growth on the size of the educational system, and b) the influence of educational achievement on the rate of growth of the population. To do this, only minor modifications of the simulation models for population planning presented in Chapter IX are needed. These extended models are described in detail in reference (1), and will not be presented here.

XVI-2 OPTIMIZATION MODELS

In this Section a conceptually interesting question of population and educational planning will be studied: the specification of the best method to reduce the number of children without education.

The problem presents different characteristics, depending on whether the analysis is made for children not yet born, and whose birth could be avoided with population control measures, or children already living, or, finally, to both. These three cases will be considered below.

XVI-2-1 Optimum choice between educational and birth control expenditures to minimize number of children without education

The first step in the solution of the problem of choosing between expenditures on education or on birth control in order to minimize the number of children without education is to specify clearly the periods of time and the educational levels involved. It will be assumed here that the decision with respect to the use of resources has to be made at date t. This decision will affect births between t and t+1. If the

resources are not used at date t they can be saved with interest r between t and t+e. At date t+e all the children surviving from those born between t and t+1 begin school and all the costs of their schooling are paid.

As in chapters X to XI the number of births between t and t+1 is $B = \alpha F + (\beta - \alpha)N$

where

B number of births

F total number of women

N number of women that should use contraceptive methods

α fertility rate without contraceptives

β fertility rate with contraceptives

The number of children surviving at age e will be denoted by

$$\sigma B$$

where σ is the survival rate over, say, six years.

The total cost of the population control program is

$$c_1 N$$

where c_1 is the cost per woman per year of advise and services.

The number of children that can enter the educational system at age e will be denoted with S. If the cost of one student at date t+e is c_2' the equivalent cost at date t will be the discounted value of c_2', i.e.

$$c_2 = \frac{c_2'}{(1+r)^e}$$

As a consequence, the total cost of S students entering the educational system at date t+e is, on date t, equal to $c_2 S$.

With the concepts introduced, the problem discussed above is that of minimizing the difference

$$D = \sigma B - S \qquad \text{XVI-2-1}$$

$$0 \leq S \leq \sigma B \qquad \text{XVI-2-2}$$

$$B = \alpha F + (\beta - \alpha)N \qquad \text{XVI-3-2}$$

$$R = c_1 N + c_2 S \qquad \text{XVI-2-4}$$

To simplify the solution of this problem, it will be assumed that constraint XVI-2-2 is not binding, i.e., that not enough resources are available to give education to all the children born. With this assumption, and the use of constraints XVI-2-3 and XVI-2-4 in the objective function XVI-2-1, one obtains

$$D = \sigma\alpha F + \frac{\sigma(\beta - \alpha)}{c_1} R - [1 - \frac{\sigma(\alpha - \beta)c_2}{c_1}] \quad S$$

This means that S should be increased if its coefficients are positive, and decreased otherwise. The coefficient of S is positive if

$$\frac{c_1}{\sigma(\alpha - \beta)} \qquad c_2$$

i.e., if the cost of reducing by one the number of children surviving to age e is larger than the cost of the education of one child.

XVI-2-2 <u>Minimum investment required in order to open schools for all the school-age population</u>

One problem that developing countries face is the lack of adequate school facilities. The problem takes many forms. One of these is the existence of a large group of persons of school age who have never enrolled in the educational system. Another form is the half-time schools created in order to permit twice as many children to use the same school facilities.

A country in which these conditions exist must provide schools not only for children reaching the minimum school age, but also for the backlog of persons who are still of school age but who have never enrolled, and for half the children in schools with double enrollment.

In this section, the method for minimizing the investment necessary to achieve this goal, presented in reference (1) is summarized. In the

example included, it will be seen that this method can result in a substantial reduction of expenses.

The basic idea of the method is that if a country in any one year manages to open schools that will take care of all the backlog of school-age population not previously enrolled, or all the part-time students, it will be wasting its resources. The school facilities made available for the backlog of non-enrolled and part-time students will be under-utilized when, in the following years, only those reaching six years of age enroll in the educational system. If the enrollment of the backlog of non-enrolled and part-time students is spread over several years, it is possible to reduce the wastage of some resources.

Below, the question of the minimum amount of investment needed to enroll the backlog of non-enrolled, plus population reaching six years of age, is put in the form of a linear programming problem.

Let us suppose that in the year t=0 a country has a backlog of non-enrolled persons of

$$\sum_{j=0}^{H} P_j^0 \qquad \text{XVI-2-5}$$

where p_j^t is the number of non-enrolled persons of age j in year t, and H is the maximum age at which a person can begin his schooling. Let us suppose that the country wants to open schools for the entire backlog in the period between t=0 and t=T.

If the problem is not the existence of a backlog of non-enrolled persons, but rather that of part-time students, p_j^t should equal half the number of half-time students having age j in year t. The definitions of p_j^t can be modified if the country has both a backlog of non-enrolled persons and part-time students. Since the formal treatment does not

change the meaning of the p_j^t, for the sake of simplicity we will refer only to the backlog of non-enrolled persons.

Let n_h^t denote the number of new entrants in the school system in year t having age h. It is assumed that schools must be open for all the backlog of non-enrolled persons before they reach age H+1, and during the period between t=0 and t=T; i.e., the total number of new entrants must satisfy

$$p_h^0 = \sum_{j=1}^{J} n_{h+j}^j \quad h=0,\ldots,H \qquad \text{XVI-2-6}$$

with $$J = \begin{cases} T \text{ if } T < H - h \\ H - h \text{ otherwise} \end{cases}$$

In addition, schools must be available for all persons reaching school age betwen t=1 and t=T. However, it will be assumed here that these persons might not begin their education at the minimum school age, but rather at some time before they reach the maximum permissible age. Let P_h^t denote the total number of persons reaching age h at year t. According to the observations above, the number of new entrants must satisfy the following conditions:

$$P_0^t = \sum_{j=0}^{J} n_j^{t+j}; \quad t=1,\ldots,T \qquad \text{XVI-2-7}$$

with $$J = \begin{cases} H \text{ if } T-t \geq H \\ T-t \text{ otherwise} \end{cases}$$

Equations XVI-2-6 and XVI-2-7 refer to all the backlog and all the persons reaching school age during the periods. However, if required, they can be modified to include only a known part of either or both of these quantities.

At any time t the total of new entrants in the educational system will be

$$N_1^t = \sum_{j=0}^{H} n_j^t \quad t=1,\ldots\ldots T. \qquad \text{XVI-2-8}$$

The school facilities should make possible the attendance not only of the new entrants in the educational system, but also of all the students already in it. For this let us assume that there are G grades in the system, and denote with N_g^t the number of students in grade g, year t. The values of N_g^o for g=1,...,G will be assumed to be known. The same is true for W_g, the probability of passing from grade g to g+1 and remaining in the educational system. It is assumed that a student cannot remain in the same grade for more than one year; i.e., the possibility of repeating a grade is excluded. From the previous observations, the following equation may be written:

$$N_g^t = W_{g-1} N_{g-1}^{t-1} \qquad \text{XVI-2-9}$$

for g=2,...,G. For g=1, N_1^t is given by equation XVI-2-8.

Finally, the total number of students in the educational system in year t is

$$N^t = \sum_{g=1}^{G} N_g^t \quad t=0,\ldots,T \qquad \text{XVI-2-10}$$

The investment required to provide schools for the N^t students is

$$K^o + \sum_{j=1}^{t} I_j = v\, N^t \quad t=1,\ldots,T \qquad \text{XVI-2-11}$$

where

K^o = capital available in year 0

I_j = investment in year j

v = capital/student ratio

The problem here is to minimize the investment required to enroll the backlog in equation XVI-2-5 plus all those reaching school age, i.e., P_0^t t=1,...,T. This means that

$$I = \sum_{j=1}^{T} I_j \qquad \text{XVI-2-12}$$

From equations XVI-2-8, XVI-2-9 and XVI-2-10, and column 4 in Table XVI-2-1 we have

$$N_1^t = \sum_{j=0}^{2} n_j^t$$

$$N_2^t = .90 \; N_1^{t-1} \qquad \text{XVI-2-14}$$

$$N_3^t = .95 \; N_2^{t-1}$$

$$N^t = \sum_{g=1}^{3} N_g^t$$

Whe next step is to eliminate constraints XVI-2-8, XVI-2-9 and XVI-2-10 in which N_g^t and N^t appear as variables. For this, the N variables are expressed as functions of the n and the values assumed to be known. For instance, with the data in Table XVI-2-1 and equations XVI-2-14, it is possible to write

$$N_1^2 = \sum_{j=0}^{2} n_j^2$$

$$N_2^2 = .90 \sum_{j=0}^{2} n_j^1 \qquad \text{XVI-2-15}$$

$$N_3^2 = 195{,}316$$

$$N^2 = \sum_{j=0}^{2} n_j^2 + .90 \sum_{j=0}^{2} n_j^1 + 195{,}316$$

Once the N's are replaced by their values in terms of the n's, equations XVI-2-11, divided by 1,000 and with the n as defined in equation XVI-2-13, take the following form:

$$371.3 = 2.837 \sum_{j=0}^{2} n_j^1 - I_1$$

$$722.2 = 2.553 \sum_{j=0}^{2} n_j^1 + 2.837 \sum_{j=0}^{2} n_j^2 - I_1 - I_2 \qquad \text{XVI-2-16}$$

$$1{,}276.3 = \left(2.425 \sum_{j=0}^{2} n_j^1 + 2.553 \sum_{j=0}^{2} n_j^2 + 2.837 \sum_{j=0}^{2} n_j^3\right) - I_1 - I_2 - I_3$$

and the problem is to minimize

$$I = I_1 + I_2 + I_3 \qquad \text{XVI-2-17}$$

subject to conditions XVI-2-13 and XVI-2-16.

The characteristics of the computer programs available forced us to take another detour and to maximize the expression in parenthesis in equations XVI-2-16, instead of minimizing XVI-2-17, and to obtain the values of I_j $j = 1,\ldots,3$ as slack variables.

In Table XVI-2-2, the pattern of enrollment as well as the investment required, as determined by the method described above, are compared with the conditions that would exist if the backlog problem were solved completely in year 1 and if, from then on, all school-age children were admitted to the educational system.

The pattern of enrollment in Column 2 of Table XVI-2-2 is completely different from that of Column XVI-2-3. In Column 2, the persons close to the maximum age for enrollment are those admitted to the educational system. The contrary is true in Column 3. The implications for investment of these two policies appear in the last row of Table XVI-2-2. The negative signs for investment I_2 and I_3 in Column 3 denote over-capacity. It can be observed that the minimum total investment in the period -- Column 2 -- is only 60% of that needed to implement the policy in Column 3. This shows that the method developed in this paper has very important practical implications.

In conclusion, another problem should be mentioned: the optimization of the length T of the period in which the backlog problem should be solved. This problem appears because it is clear that the optimum investment determined by the method described above is a decreasing function of T. However, to increase T also means to postpone the education of a part of the population. This postponement has a social and economic

TABLE XVI-2-2

ENROLLMENT AND INVESTMENT UNDER OPTIMUM CONDITIONS AND WHEN THE BACKLOG PROBLEM IS SOLVED IN YEAR 1

	Optimum Conditions	Backlog problem solved in year 1
$10^3 \times n_1^1$	78.699	81.133
$10^3 \times n_2^2$	2.434	0.0
$10^3 \times n_2^1$	52.229	52.229
$10^3 \times n_0^1$	0.0	141.900
$10^3 \times n_1^2$	0.0	0.0
$10^3 \times n_2^3$	141.900	0.0
$10^3 \times n_0^2$	134.309	145.170
$10^3 \times n_1^3$	10.861	0.0
$10^3 \times n_0^3$	148.400	148.400
$10^6 \times I_1$	0.0	409.475
$10^6 \times I_2$	0.0	17.081
$10^6 \times I_3$	244.690	- 182.831
$10^6 \times I$	244.690	409.475

cost. The economic cost, at least, can be roughly estimated. The value of T will be optimum when the marginal gain in investment is equal to the marginal cost.

XVI-2-3 Integration of the models in sections XVI-2-1 and XVI-2-2

In order to link the models in the two previous section, it is only necessary to relate the number of persons reaching age 0 at date t, i.e., P_0^t, to the number of births e years previously. This is done by means of the formula

$$P_0^t = \sigma B_{t-e}$$

Number of births in formula XVI-2-3 does not change, and expenditures on birth control become

$$C_t = c_1 N_t$$

Finally, the objective to be minimized obtained by introducing the expenditures on birth control in XVI-2-12 is

$$I = \sum_{j=1}^{T} (I_j + C_j).$$

REFERENCES

Section XVI-1

(1) Correa, H.
Models for Forecasting Flows of Students and the Human and Physical Resources Required With and Without Technologically Assisted Education
in Correa, H. (ed.)
Analytical Models in Educational Planning and Administration
To be published by David McKay Co., 1973

Section XVI-2-2

(1) Correa, H.
An Optimum Enrollment Policy for Developing Countries
in R.H.P. Kraft
Education and Economic Growth
Educational Systems Development Center
University of Florida, 1968, Tallahassee

CHAPTER XVII

INTEGRATED PLANNING OF POPULATION GROWTH, HEALTH, NUTRITION, EDUCATION AND ECONOMIC DEVELOPMENT

XVII-1 INTRODUCTION

Two types of planning models are presented in this Chapter. In Section XVII-2, a large simulation model integrating population growth, health, nutrition, education and economic development is presented. This model is a direct extension of those first suggested in references (1), (2) and (4) and discussed from a theoretical point of view in Chapter VII. In Section XVII-3, a mathematical analysis is made of the problem of optimum investment in population control programs. This Section incorporates the ideas first introduced by Enke (3) in the neo-classic model of economic growth discussed in Chapter VII.

XVII-2 A SIMULATION MODEL FOR PLANNING POPULATION GROWTH, HEALTH, NUTRITION, EDUCATION AND ECONOMIC DEVELOPMENT

XVII-2-1 General Statement of the Model

As a first step, a summary of the complete model will be presented. In Sections XVII-2-2 and XVII-2-3 each of the main components of the model will be studied in detail, and in Section XVII-2-4, the results of the application of the model to Mexico will be discussed.

In the actual model, a society with three classes and an open economy is considered. However, since these refinements would only complicate the presentation of the main ideas, the summary to be presented below will refer to a one-class society in a closed economy.

The model is basically a system of first-order difference equations. This means that the values of the variables on date t-1 determine the values for date t.

In some particularly simple cases, it is possible to solve a system of different equations, i.e., to express all the variables as functions only of t.

This method is not used in the model to be presented below. The general solution of the model is not presented here. It is only used sequentially, i.e., assuming that the values of the variables for t-1 are known, those for t are obtained with the aid of a computer. Once the values for t are known it is possible to compute t+1, and so on.

The information for year t-1 needed is:

a1) Population classified by age, educational structure, and participation in the labor force;

b1) Distribution of public and private income on consumption expenditures, and on investment. Consumption expenditures are subdivided into expenditures on food, health, population control, education and others.

c1) Total capital and its distribution between the public and private sectors.

This information is used in the following way:

a2) To specify for year t the fertility and mortality of the population and its capacity for educational achievement and work as determined by health and nutritional conditions;

b2) The variables specified in (a2) together with the information in (a1) are used to determine for year t size and age structure of the population, number of students in the different levels of the educational system, educational achievement of the population outside the system, and size and quality of the labor force;

c2) The size and quality of the labor force specified in (b2) and the quantity and quality of capital as specified with the information in (c1) are used to determine total production in year t and its distribution, whether public or private. Next, the estimated public and private income is distributed among different types of consumption expenditures and investment. The values obtained for investment are used to update the information on capital.

With the results in (a2), (b2), and (c2) it is possible to reinitiate the process, i.e., to estimate the values of the variables for year t+1, using those for year t.

From the summary it follows that the model can be subdivided into two main parts, the first dealing with population, education and labor force; and the second with production. Both parts will be studied below.

XVII-2-2 Part of the Model Dealing with Population, Education and Labor Force

In the model being presented, population size and growth and the size of the educational system are integrated, while the analysis of the labor force is treated apart. These subdivisions are maintained in the presentation below.

Population and Education

Three main determinants of population size and educational or class structure are considered in the model: fertility, mortality and the entrance, transition, drop-out and graduation rates for the educational system. The way that these elements are included in the model and the procedures used to modify them will be explained below.

The population is assumed to be divided into three social classes, based entirely on educational achievement. Six subdivisions of each class are considered. As a consequence, a vector A of dimension (18,1) and components A_j is formed. The components of this vector are:

(a) children 0-6 and 7-12 who have not entered school (2 subdivisions)

j=1, to 2, class 1

j=3, to 4, class 2

j=5, to 6, class 3

(b) students in the elementary school, high school and college (three subdivisions)

j=7 to 9, class 1

j=10 to 12, class 2

j=13 to 15, class 3

(c) population 6 years and older who have completed their education

j=16, class 1

j=17, class 2

j=18, class 3.

The vector A for year t-1, to be denoted with A_{t-1} is transformed into the vector for year t by means of the equation

$$A_t = [\alpha]A_{t-1} \qquad \text{XVII-2-1}$$

where

A_t = vector of dimension (18, t) that has as components the population by class and subdivisions of class date t;

$[\alpha]$ = (18 x 18) transition matrix presented in Table XVII-2-1.

It should be observed that the sum of the components of columns 1 to 15 is equal to the survival rate of the population group to which the column refers. In symbols, this statement is

$$\Sigma_i \alpha_{ij} = \sigma_j \qquad j=1,\ldots,15 \qquad \text{XVII-2-2}$$

where

σ_j = survival rate in population group j.

In columns 16 to 18, the components $\alpha_{1,16}$, $\alpha_{3,17}$, $\alpha_{5,18}$ represent the birth rates of the population in classes 1 to 3. As a consequence, they should not be included in the sum of the elements of a column that has as total σ_j, j=16,...,18. From the observations on matrix $[\alpha]$, it follows that

$$\alpha_{j,j} = \sigma_j \qquad j=16,\ldots,18 \qquad \text{XVII-2-3}$$

It follows from the observation above that the matrix $[\alpha]$ determines changes in the structure of the population. In the model, the values of the α's are changed from year to year to reflect the influence of public and private expenditures on food, health, family planning, education and other.

The coefficients $\alpha_{1,16}$, $\alpha_{3,17}$, $\alpha_{5,18}$, reflecting birth rates, are modified using the formula:

$$\log \alpha = \text{const} + \chi_1 \log \text{CAL} + \chi_2 \log \text{PROT} + \sum_{i=3}^{6} \chi_i \log \text{PCMU}_{i-1} + \chi_7 \log \text{DDY} \qquad \text{XVII-2-4}$$

where

CAL = intake of calories per person

PROT = intake of proteins per person

PCMU_i = per consumer expenditures in
i=2 health

TABLE XVII-2-1

Transition Matrix [α]

row \ column	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	$\alpha_{1,1}$															$\alpha_{1,16}$		
2	$\alpha_{2,1}$	$\alpha_{2,2}$																
3			$\alpha_{3,3}$														$\alpha_{3,17}$	
4			$\alpha_{4,3}$	$\alpha_{4,4}$														
5					$\alpha_{5,5}$													$\alpha_{5,18}$
6					$\alpha_{6,5}$	$\alpha_{6,6}$												
7	$\alpha_{7,1}$	$\alpha_{7,2}$					$\alpha_{7,7}$											
8							$\alpha_{8,7}$	$\alpha_{8,8}$										
9								$\alpha_{9,8}$	$\alpha_{9,9}$									
10			$\alpha_{10,3}$	$\alpha_{10,4}$						$\alpha_{10,10}$								
11										$\alpha_{11,10}$	$\alpha_{11,11}$							
12											$\alpha_{12,11}$	$\alpha_{12,12}$						
13					$\alpha_{13,5}$	$\alpha_{13,6}$							$\alpha_{13,13}$					
14													$\alpha_{14,13}$	$\alpha_{14,14}$				
15														$\alpha_{15,14}$	$\alpha_{15,15}$			
16		$\alpha_{16,2}$		$\alpha_{16,4}$		$\alpha_{16,6}$	$\alpha_{16,7}$			$\alpha_{16,10}$			$\alpha_{16,13}$			$\alpha_{16,16}$		
17								$\alpha_{17,8}$			$\alpha_{17,11}$			$\alpha_{17,14}$			$\alpha_{17,17}$	
18									$\alpha_{18,9}$			$\alpha_{18,12}$			$\alpha_{18,15}$			$\alpha_{18,}$

In this Table only the $\alpha_{ij} \neq 0$ are written.

i=3 population control

i=4 education

i=5 other

DDY = per consumer income

X_i i=1,...,7 coefficients

To simplify the notation in formula XVII-2-4, the subscripts of the variables and coefficients referring to the specific α being modified and to social class have been eliminated. For the actual computation, the equivalent of formula XVII-2-4 relating $d\alpha/\alpha$ to the growth rates of the explanatory variables is used. It is assumed that $dz/z = 0$ whenever $z=0$.

The expenditures on health, nutrition, education, etc., are assumed to affect the reamining α's in two ways: first, through the modification of the survival rates; and second, through the reduction of the α's representing late entrance in the school system, repetition or dropping out. Since the total of the α's in each column is equal to a σ, the reductions just mentioned mean that the α's representing entrance in the educational system at the correct age, promotion and graduation are increased.

The actual formulas used to modify the survival rates--are basically identical with XVII-2-4, and will not be presented here. The changes in the survival rates obtained with those formulas are assumed to modify the corresponding α's in proportion to their initial values, i.e., according to the formula

$$\alpha_t = \alpha_{t-1}\ \sigma_t/\Sigma\ \alpha_{t-1} \qquad \text{XVII-2-5}$$

where the subscripts denoting row and column have been eliminated. The sum of the α's refers to all the α's in the column corresponding to the σ.

The α's (2,1), (16,7), (16,10), (16,13), (17,8), (17,11), (17,14), (18,9), (18,12) and (18,15) represent the proportions of students not entering school at the proper age or dropping out before graduation. The equation to modify these α's again has the same form and arguments as XVII-2-4. The α's in columns 1 to 15 not enumerated above represent the proportions of students remaining in the system, whether at the same level if appropriate or in the next higher one. The

values of these increasing α's are computed with a formula similar to XVII-2-5, in which the difference σ minus the decreased α's is distributed among the α's to be increased.

Size and Quality of the Labor Force

The number of workers by social class at date t is estimated with the equation

$$L_{i,t} = \beta_{i,t} * A_{15+i,t} \qquad i=1,\ldots,3 \qquad \text{XVII-2-6}$$

where

$L_{i,t}$ = number of workers in class i, year t

$\beta_{i,t}$ = labor force participation ratio class i, year t

$A_{15+i,t}$ = number of persons who have completed their education, class i, year t.

It should be observed that a slight modification of the definition of the vectors A and of the matrix [α] would make it possible to compute the L using equation XVII-2-1.

The next step is to estimate the size of the labor force in number of full workers quality equivalents. The number of full workers quality equivalents class i, year j is denoted with N_{ij}. It is assumed that

$$N_{ij} \leq L_{ij}$$

with the difference being explained by the nutrition and health conditions of the workers. The relationship used is

$$N_{ij} = \xi_{i,3,j} * L_{ij} \qquad i=1,\ldots,3 \qquad \text{XVII-2-7}$$

where

$\xi_{i,3,j}$ = index of quality of the labor force class i, year j.

The index of quality is evaluated with

$$\xi_{i,3,j} = \xi_{i,1,j} * \xi_{i,2,j} \qquad \text{XVII-2-8}$$

where the subindex 1 means quality as determined by nutritional conditions, and subindex 2 as determined by health conditions. The values of $\xi_{i,j,k}$ i=1,3, j=1,2 are computed with formulas similar to XVII-2-4. Once this is done, formula

(6) is applied to compute the N_{ij}.

XVII-2-3 Parts of the Model Dealing with Economic Aspects

Total Production

To estimate total production, including imported raw materials, the following production function is used:

$$\log TY = Const + rt + \delta_1 n_1 + \delta_2 n_2 + \delta_3 n_3 + \delta_4 k_{1t-1} + \delta_5 k_{2t-1} \qquad \text{XVII-2-9}$$

where

TY = total production, including imported raw materials

Const = constant

r = rate of growth of labor and capital augmenting technological change

n_i = logarithm of the number of full quality equivalent workers in social class i, i=1,...,3

k_i = logarithm of value of capital measured in productivity units i=1 national, i=2 imported

δ_i = i=1,...,5 variable elasticity of TY with respect to the corresponding factor of production

To change the coefficients δ_i it is assumed that the total $\delta_4 + \delta_5$, i.e., the sum of the elasticities of TY with respect to capital, is a decreasing function of capital per worker. The changes in the total are distributed between δ_4 and δ_5 in proportion to the initial values of these variables. The change of $1 - \delta_4 - \delta_5$ is distributed proportionally to the initial values of δ_i i=1,...,3.

To estimate value added, or Gross National Product, two steps are needed. First, the value of imported raw materials is estimated as a constant proportion of TY, plus a factor that reflects the influence of the conditions of the foreign trade balance. Next, value added is computed by subtracting imported raw materials from TY.

Equation XVII-2-9 is also used as starting point to estimate the contribution of health, nutrition, education, size of the labor force, and capital to the

growth of GNP. The method used is presented in Chapter VI, in particular in formula VI-4-3, and will not be repeated here.

Distribution of Income Among the Social Classes

It is assumed that the income of each social class in year t, to be denoted with Y_{it}, is the total of labor income, income obtained through capital owned by members of the class, and part of the income produced by publicly-owned capital, i.e., capital formed by government investments depreciated in the accounts to a zero value, and used free by the public. (An example of this type of capital can be found in toll-free highways.)

The computation of income by class is made using the homogeneity properties of the production function in XVII-2-9. Special care is taken in the computer program that the sum of income by class plus the income produced by government-owned capital, is equal to total value added.

Private Disposable Income

Disposable income by class is estimated by subtracting from total income by class Y_i $i=1,\ldots,3$ that part received by the government through taxes. Tax rates are assumed to be constant by class. Per capita disposable income is obtained from figures of disposable income by class and population by class.

Government Income

Government income is equal to that part of the income produced by government-owned capital that is retained by the government, plus tax income.

To simplify, it is assumed that budget equilibrium always exists. This means that government expenditures are always equal to government income.

Allocation of Income Among Different Uses: the Frame of Reference

To explain the distribution of income among consumption, investment, imports and exports, two steps will be used. First, the distribution will be explained using a simplified model where no distinction among social classes

or time periods is included. Then the modifications needed to consider social classes and government will be discussed. The modifications needed to consider time periods are quite obvious and will be left to the reader.

The accounting identities and variables used in the simplified model are:

$$TY = Y + AMP(3) \qquad \text{XVII-2-10}$$

$$TY = CN + AIN + X \qquad \text{XVII-2-11}$$

$$Y = C + AI + X - AMP(4) \qquad \text{XVII-2-12}$$

$$C = CN + AMP(1) \qquad \text{XVII-2-13}$$

$$AI = AIN + AMP(2) \qquad \text{XVII-2-14}$$

$$AMP(4) = \sum_{I=1}^{3} AMP(I) \qquad \text{XVII-2-15}$$

$$AMP(3) = f(TY) \qquad \text{XVII-2-16}$$

$$C = f(Y) \qquad \text{XVII-2-17}$$

$$AI = f(Y) \qquad \text{XVII-2-18}$$

$$X_t = rax*X_{t-1} \qquad \text{XVII-2-19}$$

$$AMP(1) = f(C) \qquad \text{XVII-2-20}$$

The meanings of the symbols are as follows:

TY = total production, including imported raw materials

Y = value added

AMP(I) = imports of I=1 consumer goods

I=2 investment goods

I=3 raw materials

I=4 total imports

C = consumption goods

CN = consumption of national goods

AI = investment goods

AIN = investment of national goods

X = exports.

There is a total of 11 variables. Of these, TY will be considered exogenous, i.e., determined outside the system, of equations XVII-2-10 to XVII-2-20, in this case, by equation XVII-2-9. The number of equations in the system is 11. However, equation XVII-2-11 can be obtained from equations XVII-2-10 and XVII-2-11 to XVII-2-15.

This means that equations XVII-2-10 to XVII-2-20 can be used to specify the values of Y, AMP(I), I=1,...,4, C, CN, AI, AIN and X.

Allocation of Private and Government Income Among Expenditures on Food, Health, Population Control, Education, Other and Investment

As observed before, equations XVII-2-10 to XVII-2-20 outline the method used in the simulation model being described, but they are not actually used in it. In the simulation model a detailed analysis of consumption and investment replaces equations XVII-2-17 and XVII-2-18.

In this analysis, total private and government income is subdivided between expenditures on food, health, population control, education, other and investment.

With respect to the allocation of government income, it is also taken into consideration that only a part of the expenditures actually reaches the public, while the rest appear only as administrative expenditures. Administrative expenditures are included in the class of "other" expenditures. It is assumed that the government income allocated to food, health, population control and education, and that actually reaches the public, is added to the private expenditures for these items. Finally, it is assumed that all government income used in investment increases publicly-owned capital.

The actual estimations are obtained assuming that a known proportion of total government income is allocated to the different uses. The values of these proportions are exogenously determined by the "decision makers". In the model they can be changed at will to study through simulation the impact of several government policies.

Next, the government expenditures on consumption are distributed among the three social classes into which the population is divided. The distribution of consumption expenditures among the social classes is made, again assuming that a known proportion of the total goes to each class. These known proportions are also policy instruments. The parts of the expenditure per class covered with government income are estimated by means of the method just described.

Private per capita investment and consumption expenditures--classified in the five groups being considered--are estimated on the assumption that they are functions of per capita disposable income. Controls are introduced to avoid the sum of the values assigned to the different uses of income becoming larger than disposable income per capita in each class.

Total per capita expenditures in each of the five alternative consumption uses are obtained by adding private and government supported private expenditures. Per capita expenditures on food are used to estimate calorie and protein intake.

Total expenditures per class on each of the five alternative uses are computed by multiplying per capita values by the population per class.

Total expenditures on consumption by class are obtained by adding consumption per class of each of the five items considered above. Total expenditures on consumption is obtained by adding the totals by class. Since government expenditures are assumed to be distributed among the members of each class, the totals described above are the total consumption C in equation XVII-2-17.

The computation of investment, first by class and then the total for the country, follows closely the explanation above. With this, AI in equation XVII-2-18 is obtained.

Estimation of Value and Composition of Imports

The computation of total imports is made with formula XVII-2-12. Since the method used does not guarantee that the value obtained for AMP(4) will be

positive, a control appears in the model to modify it, if needed, to an acceptable one, and if this modification is performed, to also change total consumption, total investment, and all the quantities that were used to obtain these totals.

For the purpose of the model, there is no need to subdivide the expenditures on food, health, population control, education, and other between national and imported goods. However, it is useful to do so with total consumption by class. This is done using formula XVII-2-20 for each social class, i.e., assuming that imports of consumer goods are a function of total expenditures on consumption. Imports of consumption goods by class are used to compute total imports of consumption goods. Using formula XVII-2-13 by class, consumption of national goods by class is evaluated. These results are used to compute total consumption of national goods.

The last step is to use formula XVII-2-15 to estimate imports of investment goods. This total is then subdivided by class. The object is to compute investment by class in national and imported goods. These figures are used to estimate national capital and imported capital owned by class. The distinction is maintained because it is assumed that the productivity of national and imported capital grow at different rates. After a detailed verification that the different types of investment estimated have reasonable--i.e., non-negative--values, the values of capital by class and total investment and capital are computed.

Reinitiation of the Sequence

With the estimated allocation of income among the different uses, the computation of the values of all the variables for year t is completed, and it is possible to reinitiate the sequence, i.e., to begin computing the values for year t+1

XVII-2-4 Application of the Model

General Observations on the Data Needed

Before presenting a list of the data needed, it should be observed that only the data that seem to be easier to obtain, or that more directly satisfy

the requirements of the model, will be mentioned below. This list does not imply that the lack of some of the data mentioned will make it impossible to apply the model. Actually, the opposite is the case. It is not expected that all the data to be mentioned will be immediately available. The information that is not available could be replaced with other data bearing on the same point, since a large degree of substitutability exists. Finally, if everything else fails, some data could be obtained by pooling information from well-informed persons in the country to be studied (Delphi surveys), and using international comparisons.

Another point that should be considered is that, in addition to national totals on some recent date, it is useful to obtain information for as many years as possible, and for as many subnational subdivisions, such as urban and rural regions, provinces and states, etc., as possible. When these data are available, many of the parameters of the model may be estimated using standard statistical techniques.

Data Needed

(a) Population classified by age, sex, and educational achievement. The classification by educational achievement is used to define social classes.

(b) Fertility and mortality rates for the population classified by age, sex, and educational achievement (i.e., social class).

(c) Transition rates in the educational system for students classified by the social class of their parents.

(d) Intake of calories and proteins per person in each of the social classes.

(e) Number of school and work days lost due to disease per person in each of the social classes.

(f) Number of workers in the labor force, classified by social class.

(g) National and imported capital owned by the government and by persons in each of the social classes. Also, value of national and imported

public capital. (Public capital is that used by the public at no cost, such as, say, capital in highways, ports, etc.)

(h) Depreciation rates for capital.

(i) Total GNP (or similar information on total production), labor and capital income received by each social class, income produced by government owned capital, and by public capital.

(j) Part of income paid as direct and indirect taxes per person in each social class.

(k) Distribution of government and per capita income in each social class among expenditures in food, health, population control, education, other, and investment.

(l) Part of the government expenditures that directly benefit persons in each social class, for instance, the part of government expenditures on health that benefits persons in classes 1,2, and 3.

Once the data described above are available, they can be used to estimate the parameters of the equations appearing in the model.

Data Used in the Computation to be Presented Below

For the application of the model described in Sections XVII-2-2 and XVIII-2-3, readily available information for Mexico was used. However, it cannot be said that the application below actually forecasts Mexican conditions, or suggests policy alternatives for that country. The reason for this is that when actual data were not immediately available, figures were obtained by comparison with other countries, by guesswork, or finally, after running the model, by modifying the parameters so as to eliminate inconsistencies in the results. As a consequence, the results below show that the model can provide useful insights for policy making, but they must be considered hypothetical.

Results Obtained with the Model

No attempt will be made here to present all the results obtained with the model. The computer output for a forecast for 20 years consists of

approximately 150 tables showing the yearly values of all the variables and their rates of growth. In addition, the simplest policy alternative, that of reducing one type of government expenditures and increasing another, is considered. With this, the total output comes out to be roughly 6,000 pages of computer print-out. Only summaries dealing with per capita income and total population at the end of a 20-year period will be presented below.

For analysis, it is convenient to use as a term of reference the forecast of past conditions. According to these conditions, government income was allocated only to health, education, other and investment. In this case, the results in Table XVII-2-2 are obtained.

Table XVII-2-3 shows the results obtained by reducing, say, expenditures on health, while increasing expenditures on each of the other alternatives, i.e., food, population control, education, other and investment. The results obtained show that the highest return is obtained using resources on population control. With this, income per capita could be substantially higher than with any other allocation of government resources. These results are confirmed in Table XVII-2-4 that shows GNP/Pop and Total Population under the assumption that population control programs are as effective as those in supervised programs. An example of this type of program is the Louisiana Family Planning Program.(1)

XVII-3 OPTIMUM POPULATION CONTROL PROGRAMS

XVII-3-1 Introduction

In Section VII-2-2 the interaction between the growth of the population and of the economy was studied, within the framework of the neo-classic model of economic growth. In this analysis it was assumed that the rate of population growth is a function of per capita income. The model was closed, and its time path could not be changed once the initial values of the variables and the parameters were chosen.

Population planning attempts to modify the rate of population growth by

TABLE XVII-2-2

Results for Year 20 Obtained with Simulation Model When Past Trends are Forecasted

Percentage of Government Income Used In	
Food	0.0
Health	21.25
Population Control	0.0
Education	12.28
Other	28.32
Investment	38.14
GNP/Population (Pesos)	13.131
Population (10^3)	94.336

TABLE XVII-2-3

GNP/Pop and Total Population for Year 20 Estimated With Simulation Model Assuming that Governments Expenditures are Relocated

(Results as Percentages of Estimates with Past Trends)

INCREASED EXPENDITURES	REDUCED EXPENDITURES							
	Health to 13%		Education to 7.5%		Other to 17.5%		Investment to 23.5%	
	GNP/Pop	Pop	GNP/Pop	Pop	GNP/Pop	Pop	GNP/Pop	Pop
Food	99.35	99.87	99.92	99.87	100.50	100.11	93.72	99.95
Health	--	--	100.10	99.93	100.40	100.23	93.99	100.11
Population Control	104.82	93.41	105.65	93.45	105.89	93.57	98.32	93.44
Education	99.69	100.05	--	--	100.25	100.34	93.72	100.23
Other	98.64	99.79	99.50	99.82	--	--	92.54	100.00
Investment	102.83	99.90	101.90	99.89	104.80	100.14	--	--

TABLE XVII-2-4

GNP/POP and Total Population for Year 20 Estimated With Simulation Model Assuming that Government Expenditures in Population Control are Increased, and that Programs are Very Effective

(Results as Percentage of Estimate With Past Trends)

EXPENDITURES REDUCED	EXPENDITURES AS % OF TOTAL	GNP/POP	POPULATION
Health	13.0	128.15	75.63
Education	7.5	128.51	75.62
Other	17.5	128.74	75.68
Investment	23.5	120.06	75.74

destroying the relationship between it and per capita income. However, there is a cost attached to changing the rate of population growth from its normal value.

The explicit consideration of the possibility of influencing--at a cost--the rate of population growth separates the analysis below from that made in Section VII-2-2 in the neo-classic model of economic growth, and also from studies of optimum population (2), (8), or of optimum population growth (1), in which the cost of bringing population to the desired levels is not considered.

The dynamic optimization models to be presented are an extension of Enke's work (3). He showed that under the conditions existing in most developing countries, it is financially advisable to "invest" in population control, rather than in more traditional types of physical or human capital. In more recent studies (4) Enke has used a simulation model to show that his results are also valid when dynamic factors are taken into consideration. The observations of Leibenstein (6), perhaps the most serious challenge to the theoretical basis of Enke's work, will also be considered here. Leibenstein concludes that it is not possible to calculate a meaningful cost-benefit ratio until a satisfactory set of social welfare criteria for birth prevention is available. Enke (5) does not give a satisfactory answer to this objection. In the present section it is shown that, under reasonable assumptions, Enke's model gives the same decision rule as a dynamic model of welfare optimization.

XVII-3-2 The Cost Function of a Population Control Program*

The rate of growth, n, achieved with a population control program is expressed in terms of the achieved birth rate, β, by

$$n = \beta - \mu(y) \qquad \text{XVII-3-1}$$

The cost per capita of achieving this birth rate involves the cost of

---

*The notation introduced in Section VII-2 will be used below.

contraceptives, health personnel, facilities, and equipment expenditures, as well as any educational programs aimed at encouraging a segment of the population to subscribe voluntarily to birth control techniques. Clearly this cost is culture-dependent, since it is influenced by religious beliefs, social attitudes, and the value systems of the individuals composing the population. Thus, the characteristics of the cost function will probably differ from one country to another even for the same per capita incomes. However, certain general statements can be made concerning the cost function of any given country.

The cost per capita of a population control program is assumed to depend upon the difference

$$\beta - \alpha(y) \qquad \text{XVII-3-2}$$

as well as on y directly, and can be written $g(\beta-\alpha(y), y)$. It will be assumed that it has the property that

$$g\ (0,y) = 0 \qquad \text{XVII-3-3}$$

for all y so that the cost of a population program in which $\beta=\alpha(y)$ is zero. The cost of achieving a zero birth rate or the maximum birth rate α_m biologically possible is infinite, i.e.,

$$\lim_{\beta\to o} g(\beta-\alpha(y),y) = \infty \qquad \text{XVII-3-4}$$

$$\lim_{\beta\to\alpha_m} g(\beta-\alpha(y),y) = \infty \qquad \text{XVII-3-5}$$

In addition the cost function has the properties:

$$\frac{\partial g}{\partial \beta}\begin{cases} <0 & \text{if } \beta < \alpha\ (y) \\ =0 & \text{if } \beta = \alpha\ (y) \\ 0 & \text{if } \beta > \alpha\ (y) \end{cases} \qquad \text{XVII-3-6}$$

$$\lim_{\beta\to o} \frac{\partial g}{\partial \beta} = -\infty, \lim_{\beta\to\alpha_m} \frac{\partial g}{\partial \beta} = \infty \qquad \text{XVII-3-7}$$

$$\frac{\partial^2 g}{\partial \beta^2} > 0 \qquad \text{XVII-3-8}$$

The behavior of the cost function respect to per capita income is characterized by the following assumptions--consistent with VII-3-3 and VII-3-8:

$$\lim_{y \to 0} g(\beta - \alpha(y), y) = 0 \qquad \text{for } 0 \leq \beta \leq \alpha(y) \qquad \text{XVII-3-9}$$

and

$$\lim_{y \to \infty} g(A - \alpha(y), y) = 0 \qquad \text{XVII-3-10}$$

It will be also assumed that

$$\lim_{y \to \infty} \frac{\partial}{\partial \beta} g(\beta - \alpha(y), y) = -\infty \qquad \text{for } 0 \leq \beta < \alpha(y) \qquad \text{XVII-3-11}$$

Note that

$$\frac{\partial g}{\partial y} = \frac{\partial g}{\partial \alpha} \frac{\partial \alpha}{\partial y} + \frac{\partial \tilde{g}}{\partial y} \qquad \text{XVII-3-12}$$

where $\partial \tilde{g}/\partial y$ is the derivative of g with respect to y holding α constant. From XVII-3-6 it follows that

$$\frac{\partial g}{\partial \alpha} > 0 \qquad \text{for } \beta \leq \alpha(y) \qquad \text{XVII-3-13}$$

and it is assumed that

$$\frac{\partial \tilde{g}}{\partial y} > 0 \qquad \text{for all } \beta \qquad \text{XVII-3-14}$$

Thus from VII-3-6 to VII-3-8 and XVII-3-13 and XVII-3-14 it follows that for $\beta \leq \alpha(y)$

$$\frac{\partial g}{\partial y} \begin{cases} > 0 & \text{for small } y \\ \text{undetermined in sign for intermediate } y \\ > 0 & \text{for large } y \text{ (as } y \to \infty) \end{cases} \qquad \text{XVII-3-15}$$

The last statement in XVII-3-15 follows from VII-3-8 which implies that

$$\lim_{y \to \infty} \frac{\partial \alpha}{\partial y} = 0$$

Finally it is assumed that

$$\begin{aligned} \lim_{k \to 0} \frac{\partial^2 g}{\partial y \partial \beta} \frac{\partial y}{\partial k} &= -\infty \qquad \text{for } \beta < \alpha(y) \\ \lim_{k \to \infty} \frac{\partial^2 g}{\partial y \partial \beta} \frac{\partial y}{\partial k} &= 0 \qquad \text{for } \beta < \alpha(y) \end{aligned} \qquad \text{XVII-3-16}$$

In the analysis of the following sections, the marginal cost $\partial g/\partial \beta$ plays an important role. It will be shown that this marginal cost for the population as a whole is equal to the marginal cost of part of that population.

The population is divided into two groups P_i, i=1, 2 with $P = P_1 + P_2$, and normal birth rates $\alpha_i(y_i)$, and cost functions $g_i\ (\beta_i, y_i)$ for achieving birth rate β_i. The birth rate for P when P_2 grows at rate β_2 is:

$$\beta = (\alpha_1(y_1)P_1 + \beta_2 P_2)/P \qquad \text{XVII-3-17}$$

The cost per person for the population as a whole when the population control program is directed at P_2 is:

$$g(\beta,y) = P_2 g_2(\beta_2, y_2)/P \qquad \text{XVII-3-18}$$

From XVII-3-17 and XVII-3-18 it follows that:

$$\frac{\partial}{\partial\beta}\ g(\beta,y) = \frac{\partial}{\partial\beta_2}\ g_2(\beta_2, y_2) \qquad \text{XVII-3-19}$$

Thus any statement in the following sections establishing conditions for the marginal cost of the population as a whole is valid for some subgroup having a cost function with the general properties given above.

With $g(\beta,y)$ expenditures per capita it is possible to divert the rate of population growth from its normal path so that β can be considered a control variable. Then equation XVII-3-1 becomes:

$$\dot{P} = [\ \beta - \mu(y)\ ]\ P \qquad \text{XVII-3-20}$$

and equations VII-3-11 and VII-3-13 with the inclusion of $g(\beta,y)$ become:

$$\dot{k} = y - c - g(\beta,y) - [\beta - \mu(y)] * k \qquad \text{XVII-3-21}$$

and

$$\frac{\dot{y}}{y} = \frac{f'_k}{y}(y - c - g(\beta,y) - [\beta - \mu(y)] * k) \qquad \text{XVII-3-22}$$

The objective of a central authority is to achieve maximum benefits. This maximization must be feasible in the sense that:

$$\beta(t) \geq 0 \qquad \text{XVII-3-23}$$

and

$$y(t) \geq c(t) + g(t) \qquad \text{XVII-3-24}$$

An additional constraint for the optimization of VII-3-22 follows from the observation that at an equilibrium point:

$$(46) \qquad y = c + g(\beta,y) + [\beta - \mu(y)] * k \qquad \text{XVII-3-25}$$

In this equation the coefficient of k could be negative so that $y<c + g$, meaning that capital is being spent for population control. This use of capital does not affect K because the population is also decreasing. Clearly, such an equilibrium point, even if mathematically stable, cannot be accepted. To avoid this problem, XVII-3-23 should be replaced with

$$\beta(t) \geq \mu(y) \qquad \text{XVII-3-26}$$

XVII-3-3 Maximization of the Rate of Growth of Per Capita Income

As stated by Enke (3), a first objective function that can be considered for the determination of β is the rate of growth of per capita income.

From equation XVII-3-22 it is clear that an optimal policy for β is one that minimizes $g(\beta,y) + k\beta$ subject to constraint XVII-3-26. When an interior solution exists, the use of calculus yields the necessary condition:

$$-\frac{\partial}{\partial\beta} g(\tilde{\beta},y) = k \qquad \text{XVII-3-27}$$

where $\tilde{\beta}(k)$ is the value of β satisfying XVII-3-27; from the assumptions with respect to g it follows that $\tilde{\beta}(k)$ is a single-valued function of k.

The sufficient condition for the optimization of XVII-3-22 is also satisfied, since

$$\frac{\partial^2}{\partial\beta^2} \frac{\dot{y}}{y} = -\frac{f'_k}{y} \frac{\partial^2}{\partial\beta^2} g(\beta,y) < 0 \qquad \text{XVII-3-28}$$

from VII-2-3 and XVII-3-8.

The function $\tilde{\beta}(k)$ satisfies the following properties:

$$0 \leq \tilde{\beta}(k) \leq \alpha(k) \qquad \text{XVII-3-29}$$

This property follows from XVII-3-6 and XVII-3-27. As a consequence of XVII-3-29 it follows that

$$\lim_{k\to 0} \tilde{\beta}(k) = \lim_{k\to 0} \alpha(k) = 0 \qquad \text{XVII-3-30}$$

and from XVII-3-7 that

$$\lim_{k\to\infty} \tilde{\beta}(k) = 0 \qquad \text{XVII-3-31}$$

Differentiating both sides of XVII-3-27 with respect to k, and after some manipulation, it follows that

$$\frac{\partial\beta}{\partial k} = -\left(1 + \frac{\partial y}{\partial k}\ \frac{\partial}{\partial y}\ \frac{\partial g}{\partial \beta}\right) / \frac{\partial^2 g}{\partial \beta^2} \qquad \text{XVII-3-32}$$

This result and the assumptions in XVII-3-8 and XVII-3-16 yield

$$\frac{\partial\beta}{\partial k} \begin{cases} > 0 & \text{for small } k \\ < 0 & \text{for large } k \end{cases} \qquad \text{XVII-3-33}$$

The graphs of $\tilde{\beta}(k)$ and $\alpha(k)$ are compared in Figure XVII-3-1.

With (k) determined from equation XVII-3-27, equation XVII-3-20 determines P, equation XVII-3-21, k and XVII-3-22, y.

Using (k) in XVII-3-21, it is possible to study the equilibrium points of the system. From XVII-3-3 and XVII-3-30

$$\lim_{k\to 0} g(\tilde{\beta}(k), k) = 0 \qquad \text{XVII-3-34}$$

and from XVII-3-11

$$\lim_{k\to\infty} \frac{\partial}{\partial\beta}\ g(\tilde{\beta}(k), k) = -\infty \qquad \text{XVII-3-35}$$

From VII-2-3, XVII-3-6, XVII-3-15, XVII-3-33 and XVII-3-35 it follows that

$$\frac{\partial g}{\partial k} = \frac{\partial g}{\partial \beta}\ \frac{\partial \beta}{\partial k} + \frac{\partial g}{\partial y}\ \frac{\partial y}{\partial k} \qquad \text{XVII-3-36}$$

is positive for large k but undetermined for small and intermediate k.

From VII-3-17 and XVII-3-31 it follows that

$$\lim_{k\to\infty} [\tilde{\beta}(k) - \mu(k)] * k \to -D * k \qquad \text{XVII-3-37}$$

It cannot be concluded from the characteristics of y-c and $g + (\beta - \mu) * k$ that an equilibrium point for equation XVII-3-21 exists, or, if it does exist, whether it is stable. If an equilibrium point does not exist, k will approach zero or infinity with the consequences from VII-3-3 and XVII-3-30 that

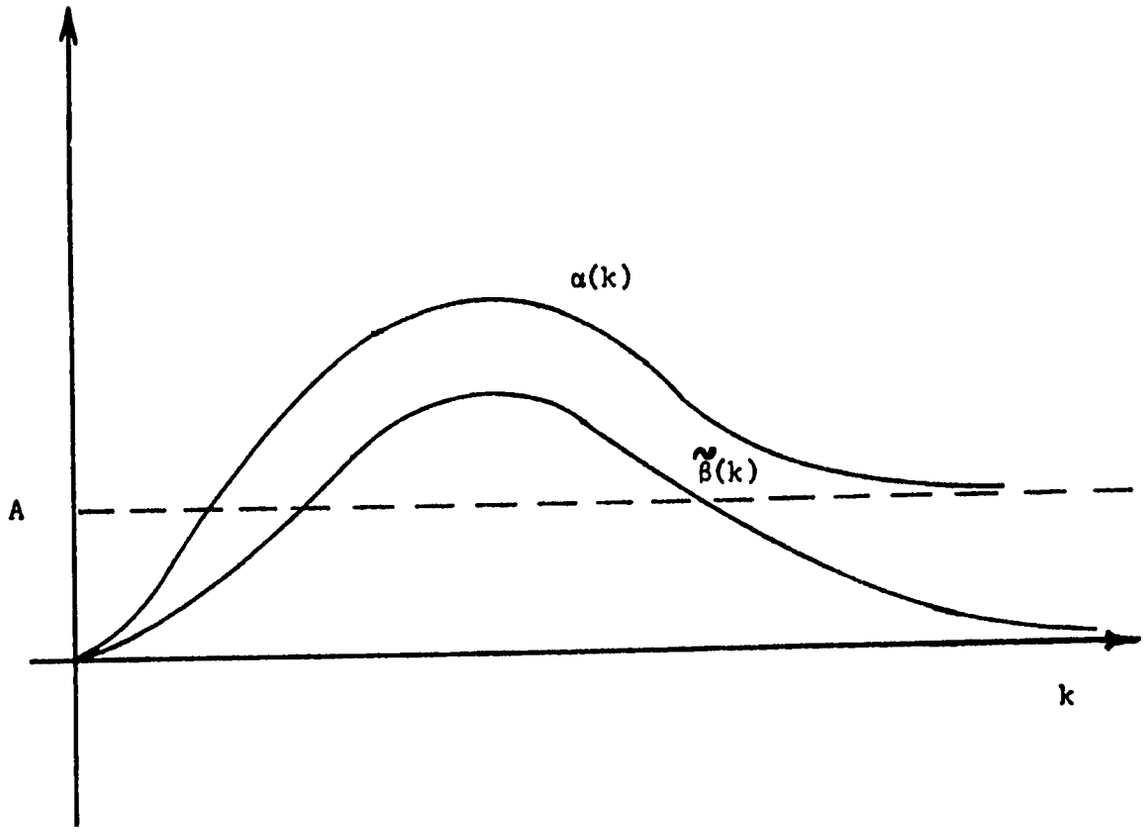
$$\lim_{k\to 0} (\tilde{\beta} - \mu) = -\infty \qquad \text{XVII-3-38}$$

and from VII-3-7 and XVII-3-31 that

$$\lim_{k\to\infty} (\beta - \mu) = -D \qquad \text{XVII-3-39}$$

FIGURE XVII-3-1

Comparison of $\alpha(k)$ and $\tilde{\beta}(k)$ vs k



Thus the constraint XVII-3-26 becomes binding, and it follows that the analysis of the stability of XVII-3-21 reduces to an analysis at the points where XVII-3-26 is binding.

From the properties of $\tilde{\beta}(k)$ and $\mu(k)$, if $\tilde{\beta} \geq \mu$ for some k, then there exist k_L and k_H such that

$$\tilde{\beta}(k) \geq \mu(k) \text{ for } k_L \leq k \leq k_H \qquad \text{XVII-3-40}$$

The case when $k < k_L$ may be that of an underdeveloped country. The low value of capital available implies that β and $\alpha(y)$ are close to zero while $\mu(y)$ has a large value. Making $\beta = \mu(y)$ is likely to imply that $\beta > \alpha(y)$, i.e., that the population program should be directed to increase the birth rate.

Only highly developed countries are likely to have $k > k_H$. For such large k, the decision rule in XVII-3-27 calls for large expenditures on population control, that forces $\tilde{\beta}$ to values below $\mu(y)$. However, the constraint XVII-3-26 forces $\tilde{\beta} = \mu(y)$ and XVII-3-21 becomes

$$\dot{k} = y - c - g\,[\mu(y), y] \qquad \text{XVII-3-41}$$

If

$$\lim_{y \to \infty} \frac{d}{dy} \; g(\mu(y), y) = \infty \qquad \text{XVII-3-42}$$

then equation XVII-3-41 will have at least one stable equilibrium point.

Finally, it is possible to derive the condition for the golden path of accumulation. The necessary condition, a straightforward generalization of VII-3-15, is

$$f'_k = g'_k + (\tilde{\beta}'_k - \mu'_k) * k + (\beta_k - \mu_k) \qquad \text{XVII-3-43}$$

XVII-3-4 Maximization of Per Capita Income Over an Infinite Time Horizon

Leibenstein's (6) criticism of the model in Section XVII-3-3 is that its objective function, i.e., the rate of growth of per capita income, is not appropriate. This criticism is partly answered in this section, where the objective function adopted is not the rate of growth of per capita income, but per capita income itself over an infinite time horizon. More specifically, the

objective assumed for a population program is to maximize

$$\int_0^\infty dt\ y(t)\ e^{-\varepsilon t} \qquad \text{XVII-3-44}$$

where $e^{-\varepsilon t}$ is the discount function at an instantaneous rate $\varepsilon > 0$.

To maximize XVII-3-44, the conditions assumed before are retained; in particular, the maximization is done under the constraints in VII-2-3, VII-3-12, XVII-3-20, XVII-3-21 and XVII-3-26.

It is shown below that the existence of a maximum attainable capital per worker is enough to ensure the convergence of the integral in XVII-3-44.

Applying the Pontryagin principle, the necessary conditions for the maximization of XVII-3-43 subject to the constraints mentioned above are:

$$e^{-\varepsilon t} \max_{\beta} [-g\ (\beta, y) - \beta * k] \qquad \text{XVII-3-45}$$

$$\frac{d}{dt}(e^{-\varepsilon t}\ \lambda_2) = e^{-\varepsilon t} f_k'$$

$$-\lambda_2 e^{-\varepsilon t}\ [(1 - c_y' - g_y')f_k' - (\beta - \mu)] \qquad \text{XVII-3-46}$$

If $\lambda_2 \neq 0$, and XVII-3-45 has an interior solution, then it is equivalent to condition XVII-3-27 obtained in Section XVII-3-3.

To obtain the functional forms of P, k, and y that will maximize XVII-3-44, equations XVII-3-20, XVII-3-21 and XVII-3-22 must be solved. This shows that the necessary conditions for the maximization of XVII-3-44 are the same as for the maximization of $\dot{y}/y$ in XVII-3-22.

At this point the assumption that λ_2 is not equal to zero is explored; λ_2 can be interpreted as the shadow price of capital, and, as a consequence, it can be considered different from zero. Also, $\lambda_2 = \dot{\lambda}_2 = 0$ in equation XVII-3-46 would imply that $f_k' = 0$, a result that is not acceptable.

Finally, the observations made with respect to the stability of the differential equation XVII-3-21--as already observed when dealing with the convergence of XVII-3-44--and the golden rule in Section XVII-3-3 also apply to the case discussed in this section and will not be repeated.

XVII-3-5 Maximization of Well-being Over an Infinite Time Horizon

The objective function XVII-3-44 is still not the one suggested by Leibenstein. On intuitive grounds, it is more acceptable to maximize the discounted value of utility over the planning horizon, i.e., the objective should be to maximize

$$\int_0^\infty U(c)\, e^{-\varepsilon t} dt \qquad \text{XVII-3-47}$$

where U(c) is the utility derived from consumption c.

It is assumed that U(c) is continous and

$$U(c) > 0 \text{ for } c > \underline{c}$$

where $\underline{c}$ is the consumption at a subsistence level; also

$$U'(c) > 0$$

$$U''(c) < 0$$

$$\lim_{c \to 0} U'(c) = \infty$$

$$\lim_{c \to \infty} U'(c) = 0$$

Again in the present case, the existence of a maximum attainable capital per worker, observed in Section XVII-3-3, is enough to ensure the convergence of integral XVII-3-46.

The functional XVII-3-47 is maximized subject to the constraints in equations VII-2-3, VII-3-12, XVII-3-20, XVII-3-21 and XVII-3-26. Constraint equation XVII-3-12 requires some explanation; in the Ramsey problem (7), per capita consumption c is taken as a control variable to be determined in such a way as to optimize the discounted value of total utility. This assumption is basic to the purpose that Ramsey had in mind, that of the optimum distribution of resources between consumption and savings. However, for the objective of this chapter, which is the specification of the optimum distribution of resources between investment in physical capital and in population control, Ramsey's assumption is not essential. Nevertheless, in Section XVII-3-6 the Ramsey problem is considered.

Applying the Pontryagin principle, the following necessary conditions for the maximization of XVII-3-47 are obtained:

$$\lambda_2 e^{-\varepsilon t} \max_{\beta} (-g(\beta,y) - \beta k) \qquad \text{XVII-3-48}$$

$$\frac{d}{dt}(\lambda_2 e^{-\varepsilon t}) = U'_c c'_y f'_k \, e^{-\varepsilon t} \qquad \text{XVII-3-49}$$

$$-\lambda_2 e^{-\varepsilon t}[(1 - c'_y - g'_y) f'_k - (\beta - \mu)]$$

Where λ_2 is the costate variable required for the problem. When $\lambda_2 \neq 0$ and an interior solution exist, equation XVII-3-48 reduces to equation XVII-3-27. Once the optimizing function $\beta(k)$ is obtained, P, k, and y are found from equations XVII-3-20 to XVII-3-22 respectively. Thus the necessary conditions for the optimization of XVII-3-47 are the same as those for the optimizations of XVII-3-22 and XVII-3-44. This fact is particularly useful because the empirical evidence on U(c) is at best questionable.

The observations made before with respect to the positivity of λ_2, the stability conditions, and the golden rule are valid in this case.

XVII-3-6 Maximization of Well-being When Both Levels of Consumption and of Expenditures on Population Control are Control Variables

In this Section, the Ramsey problem (7) is extended with the assumption that utility is maximized by the appropriate choice of the time pattern for per capita consumption; thus the total resources for investment are determined, and these resources are distributed optimally between investment in physical capital and population control.

In more precise terms, the problem is the optimization of XVII-3-47 under the constraints in Section XVII-3-5 except for the consumption function constraint VII-3-12. Thus β and c are the control variables.

Assuming an interior solution, the necessary conditions for optimization are:

$$U'_c = -\lambda_2 e^{-\varepsilon t}$$

$$U'_c \left(\frac{\partial g}{\partial \beta} + k\right) = 0$$

and

$$\frac{1}{U_c} \quad \frac{dU_c'}{dt} = [(1 - \frac{\partial g}{\partial y})f_k' - (\beta - \mu)]$$

This last equation is the well-known Ramsey condition for the case when the population grows at rate $\beta - \mu$ with expenditures of $g(\beta,y)$.

Again in this case, it can be shown that XVII-3-27 must be satisfied. However, equations XVII-3-21 and XVII-3-27 are not sufficient to determine the time path of k; the Ramsey condition must also be considered. As a consequence, the time path in this section will be different from the time paths described in the previous sections.

XVII-3-7 Conclusions

The basic conclusions of the Section are:

(a) The decision rule for the allocation of resources to a population control program only is not affected by any of the objective functions chosen in this chapter.

(b) The decision rule for choosing the optimal rate of savings and for allocating investment between physical capital and population control is affected by the type of objective function adopted.

REFERENCES

Section XVII-1

(1) Barlow, R.
"The Economic Aspects of Malaria Education"
American Economic Review
Papers and Proceedings, Vol. LVII, May, 1967, No. 2

(2) Coale, A.J. and E.M. Hoover
Population Growth and Economic Development in Low Income Countries
Princeton University Press, 1958.

(3) Enke, S.
"The Economic Aspects of Slowing Population Growth"
The Economic Journal
Vol. 76, 1966

(4) Hoover, E.M. and M. Perlman
"Measuring the Effects of Population Control on Economic Development: A Case Study of Pakistan,"
The Pakistan Development Review
Vol. VI, Winter, 1966, No. 4, pp. 545-566

Section XVII-2

(1) Beasley, J.D. and V.W. Parrish
"Family Planning and the Reduction of Fertility and Illegitimacy"
Social Biology
Vol. 16, No. 3, September, 1969

Section XVII-3

(1) Dasgupta, P.S.
"On the Concept of Optimum Population"
Review of Economic Studies
1969

(2) David, A.S. and C.J. Huang
"Population Theory and the Concept of Optimum Population"
Socio-Economic Planning Sciences
Vol. 3, 1969

(3) Enke, S.
"The Economic Aspects of Slowing Population Growth"
The Economic Journal
Vol. 76, 1966

(4) Enke, S.
"Birth Control for Economic Development"
Science
Vol. 164, 1969

(5) Enke, S.
"Leibenstein on the Benefits and Costs of Birth Control Programmes"
Population Studies
Vol. 24, 1970

(6) Leibenstein, H.
"Pitfalls in Benefit/Cost Analysis of Birth Prevention"
Population Studies
Vol. XXIII, 1969

(7) Ramsey, F.
"A Mathematical Theory of Saving"
Economic Journal
Vol. 38, 1928

(8) Votey, H.L.
"The Optimum Population and Growth: A New Look"
Journal of Economic Theory
Vol. 1, 1969.

INDEX

AGRICULTURE

Nutritional Planning, 346

BIRTH RATE

I.Q., 45
Participation of Women in Labor Force, 30
Population, 371

CAPITAL

Health, 137

CONTRACEPTIVES

Participation of Women in Labor Force, 43
Population Planning, 238, 245, 250, 271, 274, 285, 357

COST

Education, 373, 378
Health, 130, 373, 378
Health Planning, 312, 324, 338
Nutrition, 373, 378
Nutrition Planning, 345
Population Planning, 238, 245, 250, 252, 271, 274, 282, 387

CRIME

Education, 211
Employment, 216, 226
Family Size, 202
Health, 201, 207
Income, 216
Index, 201
Interpersonal Relations, 201
Model, 216
Nutrition, 201, 211
Population, 201

DEVELOPMENT

Definition, 1
Health, 1, 15
Nutrition, 1, 15
Population, 1, 15

DOCTORS REQUIRED

Health, 303
Population Planning, 238, 245, 283

ECONOMIC GROWTH

Employment, 151
Model, 151, 178, 185, 189, 368
Population, 178, 185, 189, 368
(See Production)

EDUCATION

Costs, 373, 378
Crime, 211
Health, 106, 371
Health Planning, 319
Income, 157
Mental Health, 109, 42
Model, 368
Morbidity, 53
Nutrition, 111, 117, 142, 371
Nutrition Planning, 345
Participation of Women in Labor Force, 35
Physical Capacities, 107
Population, 99, 102, 356, 370
Population Planning, 270, 271
Production, 142, 145, 149, 166
Technological Change, 151, 162
Well-being, 15, 17

EDUCATIONAL PLANNING

Population Planning, 356

EFFORT, 123

EMPLOYMENT

Crime, 216, 226
Economic Growth, 151
Effort, 123
Family Size, 36
Health, 123
Model, 123
Nutrition, 123
Population Planning, 271
Production, 151
Wages, 127

FAMILY SIZE

Crime, 202
Population Planning, 270, 288

GROUP VIOLENCE, 201, 227

HEALTH

Capital Formation, 137
Costs, 130, 373, 378
Crime, 201, 207
Development, 15
Doctors Requirements, 303
Economic Consequences, 130
Education, 106, 109, 371
Effort, 123
Employment, 123
Group Violence, 201, 227
Hospitals Requirements, 306
Index, 8, 47, 134, 309
I.Q., 47

Mental Capacities, 29, 46, 61
Nutrition Planning, 345
Physical Capacities, 29, 46
Population, 308
Production, 130, 145, 149, 151, 162, 166, 369
Simulation Model, 295
Technological Change, 151, 162
Wages, 127
Well-being, 1, 15, 25
Working Capacity, 153, 374

HEALTH PLANNING

Costs, 312, 324, 338
Education, 319
Index, 310
Model, 309
Mortality, 309
Nutrition, 319
Population, 330, 337
Water Supply, 319

HOSPITALS REQUIRED

Health, 306

HOUSING

Technological Change, 162

INCOME

Crime, 216
Education, 157
(See also Production)

INDEX

Crime, 201
Health, 8, 10, 47, 134, 309
Health Planning, 310
Interpersonal Relations, 201
Group Violence, 201
Mental Capacities, 29
Mortality, 47
Nutrition, 9
Physical Capacities, 29
Working Capacity, 124, 374

INTERPERSONAL RELATIONS, 201

I.Q.

Birth Rate, 45
Health, 47
Mental Capacities, 29

LIFE EXPECTANCY
(See Mortality)

LIFE TABLE
(See Mortality)

MENTAL CAPACITIES

Education, 109, 142
Health, 29, 46, 61
Index, 29
I.Q., 29
Nutrition, 29, 62, 69, 80, 138, 142
Population, 29
Production, 138, 142

MODEL

Crime, 216
Development, 1
Economic Growth, 151, 178, 185, 189, 368
Education, 368
Employment, 123
Employment and Family Size, 36
Health, 295, 369
Health Planning, 309
Morbidity, 295
Neo-Classic (Economic), 151, 178, 185, 189
Nutrition Planning, 344, 368
Participation of Women in Labor Force, 31
Population, 235, 368
Population Planning, 235, 239, 252
Well-being, 1, 17

MORBIDITY

Education, 53
Model, 295
Nutrition, 67
Working Capacity, 53

MORTALITY

Health Planning, 209
Index, 47
Labor Force, 131
Income, 134
Nutrition, 67
Physical Capacities, 47
Working Capacity, 131

NUTRITION

Costs, 373, 378
Crime, 201, 211
Development, 15
Education, 111, 117, 142, 371
Effort, 123
Employment, 123
Group Violence, 201, 227
Index, 9
Mental Capacities, 29, 62, 69, 80, 138, 142
Model, 368
Morbidity, 67
Mortality, 67
Physical Capacities, 29, 62

Production, 137, 142, 145, 149, 162, 166
Technological Change, 151, 162
Wages, 127
Well-being, 1, 15, 17, 25
Working Capacity, 83, 138, 154, 374

NUTRITION PLANNING

Agriculture, 346
Costs, 345
Education, 345
Health Planning, 319, 345
Model, 344
Production, 345

PARTICIPATION OF WOMEN IN THE LABOR FORCE, 30

PHYSICAL CAPACITIES

Education, 107
Health, 29, 46
Index, 29
Labor Force, 29
Life Expectancy, 29
Mortality, 47
Nutrition, 29, 62
Population, 29
Working Capacity, 47

POPULATION

Crime, 201
Development, 15
Economic Growth, 178, 185, 189
Education, 99, 102
Group Violence, 201
Health, 308
Labor Force, 29
Mental Capacity, 29, 43
Participation of Women in the Labor Force, 30
Physical Capacities, 29
Production, 145, 149
Savings, 178, 183, 189
Target, 250, 267, 285
Well-being, 15, 17

POPULATION PLANNING

Contraceptives, 238, 245, 250, 271, 274
Costs, 238, 245, 250, 252, 271, 274, 282, 387
Doctors' Requirement, 228, 245, 283
Education, 270, 370
Education Planning, 356
Employment, 271
Family Size, 270, 288
Health Planning, 330, 337
Optimization Models, 250
Simulation Models, 235, 239, 368
Target, 250, 267, 285

PRODUCTION

Education, 142, 145, 149, 166, 369
Health, 130, 145, 149, 151, 162, 166, 369
Mental Capacities, 138, 142
Nutrition, 137, 142, 145, 149, 162, 166
Nutrition Planning, 345
Population, 145, 149

QUALITY OF LIFE
(See Well-being)

SOCIAL GOALS, 13

STANDARD OF LIVING
(See Well-being)

TECHNOLOGICAL CHANGE, 151, 162

WAGES, 124

WELFARE
(See Well-being)

WELL-BEING, 1

WORKING CAPACITY

Health, 157, 374
Index, 124, 374
Morbidity, 53
Mortality, 131
Nutrition, 83, 138, 154, 374
Physical Capacities, 47
Wages, 124

INDEX OF AUTHORS

Ackoff, R.L., 354
Adelman, I., 90, 198
Ahumada, J., 336
Alix, E.N., 230
Almond, G.A., 16
Anderson, T.W., 28
Areskog, N.H., 97
Arnoff, E.L., 354
Arrow, J.K., 16
Ascoli, W., 94
Athamnssates, D., 172

Bagot, J.H., 231, 232
Barlow, R., 171, 172, 198, 399
Baster, N., 175
Baumert, G., 90
Baumol, W.J., 198
Beasley, J., 91, 399
Becker, G., 90, 199, 233
Belli, P., 95, 174
Bengoa, J.M., 94, 354
Berg, A.D., 97, 354
Birch, H.G., 94
Blake, J., 199
Blumenthal, I.S., 172
Bolte, M., 90
Boyd, A.M., 121
Braine, M.D.S., 93
Bruno, M., 175

Cabak, V., 95
Calhoun, P.B., 230
Campbell, A.A., 91
Carnoy, M., 175
Carvioto, J., 94, 95
Chau, T.N., 120
Churchill, J.A., 9
Clark, R., 231
Coale, A.J., 198, 399
Cohne, C., 232
Coleman, J., 16
Cooper, R.S., 170
Correa, H., 92, 94, 95, 97, 98, 120, 121, 174, 175, 176, 200, 236, 367
Cummins, G., 97, 98

Dasgupta, P.S., 399
David, A.S., 398
Dayal, R., 176
Demeny, P., 198
Denison, E.F., 176
Dirkson, C., 198
Drakatos, C.G., 90
Dublin, L.I., 170, 173
Duesenberry, S., 233
Duncan, C.G., 90

Elliott, D.S., 233
Enderica, R.V., 94
Enke, S., 170, 399
Evanco, W., 200
Ezekiel, H., 129

Fawog, M., 173
Feim, R., 172
Feldstein, M.S., 336
Festingler, L., 233
Fleisher, B.M., 233
Flores, M., 94
Food and Agriculture Organization, 98, 354
Foster, R., 173
Francis, J.O., 172
Freedman, A.M., 93
Freedman, R., 90
Friedlander, S., 90, 199
Friedman, D., 199
Frish, R.E., 95

Galenson, W., 176
Gates, A.I., 94
Gatteff, C., 173
Gendell, M., 90
Getzels, J.W., 121
Giok, L.T., 96
Glueck, R., 231
Glueck, S., 231
Goldberger, A.S., 90
Gomaa, R.A., 93
Gordon, J.E., 94, 95, 96
Grams, P., 232
Greaves, J.P., 354
Gussov, J.D., 94
Guzman, H.A., 95
Guzman, H.A., 94
Gyorgy, P., 96

Harrell, R.F., 94, 97, 122
Harter, C.L., 91
Hassouna, W.A., 94, 121, 318
Heimer, C.B., 93
Hie, T.T., 96
Hirschi, T., 232
Hoffman, L.W., 91
Hoover, E.M., 198, 399
Huang, C.J., 399

Jackson, R., 95, 121
Jan, D.H., 96
Jelliffe, D.B., 94, 96
Jensen, A.R., 96
Johnston, B.F., 354
Johnston, J., 96
Johnston, N., 230, 232, 233

Kaplan, J., 91
Kaser, M.C., 172
Kawi, A.A., 121
Kelly, H., 95
Kendall, M.G., 28
Keyfitz, N., 92
Klarman, H.E., 93, 170, 171, 172, 173, 336
Klein, L.R., 90, 355
Klinger, A., 90
Knoblock, H., 94
Kraft, R.H.P., 120, 367
Kuglemass, N.I., 96
Kyllomen, R.L., 230

Labasquiere, R., 173
Lamarinier, G., 173
Lauw, T.G., 96
Lees, J.P., 230
Leff, N.H., 198
Lehman, G., 98
Leibenstein, H., 90, 98, 129, 176, 199, 400
Liang, P.H., 96
Livades, G., 172
Lotka, A.J., 170
Lowry, G.H., 97
Lunden, W.A., 232, 233, 234

Macleod, 120
Malenbaum, W., 175
Massell, B.F., 176
Maxwell, D.E., 91, 199
Mazumdar, D., 129
McClelland, D.C., 176
McCord, W., 230, 231, 232
McGranaham, D.V., 175
McKay, H.G., 231
Meredith, H.V., 96
Merton, R.V., 234
Metzger, C.B., 171
Mincer, J., 90
Mishan, E.J., 170, 174
Mishler, E.G., 91
Mitchell, G.E., 171
Morrison, D.F., 28
Muller, E., 98
Muscat, R., 354
Mushkin, S.J., 92, 174

Najdanvic, R., 95
Nakamura, M., 90
National Academy of Sciences, 94, 96
National Bureau of Economic Research, 90
National Institute of Mental Health Center for Studies of Crime and Delinquency, 231
Nebout, H., 173
Netherlands Productivity Center, 93
Newson, L.J., 230

Nurkse, R., 234
Nye, F.I., 91

Ohlin, G., 199
Ortiz, J.R., 172
Oshima, H.T., 129

Parrish, V.W., 91, 399
Pasamanick, B., 94, 121
Patterson, J.E., 91
Peacock, A.T., 199
Perez, C., 94
Perlman, M., 170, 198, 399
Pettenkofer, M.V., 170
Phillips, L., 91, 199
Polk, U., 233
Potter, R.G., 91
Poull, L.E., 96
Proyecto Interagencial de Promocion de Politicas Nacionales de Alimentacion y Nutricion, 354
Pyatt, G., 176

Ramsey, F., 400
Recalde, F., 354
Rice, D.P., 92, 170, 173
Richard-Proust, C., 175
Riker, W.H., 16
Robles, B., 95
Rodman, H., 232
Rose, C., 96
Rosen, L., 232
Rosenthal, G.D., 172
Rosso, P., 97
Rubin, H., 355
Rueda-Williamson, R., 354
Russet, B., 234

Sagi, P.C., 91
Samuel, E.L., 96
Savitz, L., 230, 232, 233
Schaffer, W.E., 233
Schultz, T.P., 91, 199
Schwab, P.M., 171
Scott, W., 175
Scrimshaw, N.S., 94, 95, 96
Secretaria de Industria y Comercio de Mexico, 176
Selinus, R., 97
Sellin, T., 232, 234
Selowsky, M., 96, 174
Sengupta, S.S., 354
Shaw, C.R., 231
Siddiqui, F., 120
Silver, M., 90, 93, 199
Smart, K.F., 122
Smith, P.H., 233
Smith, V.E., 354
Smythe, P.M., 96
Solow, R.M., 176
Sovani, N.V., 175
Spengler, J.J., 92

Spitzer, H., 98
Stafford, F.P., 91
Stanfield, R.E., 232
Stigler, G.J., 354
Stoch, M.B., 96
Stocks, M., 93
Stone, R., 355
Stycos, J.M., 91
Subrananian, M., 175

Teele, J.E., 232, 233
Thiel, H., 355
Thompson, A.M., 96
Tinbergen, J., 177
Turner, S., 234

Union Panamaericana, 177
United Nations, 91, 93, 97, 98, 175, 176, 234
U.S. Department of Commerce, 97, 174
U.S. Department of Health, Education and Welfare, 92, 93, 171

Vahlquist, B., 97
Votey, H., 91, 199, 400
Vyas, M.D., 120

Walsh, B.T., 198
Waterlow, 95
Watson, E.H., 97
Watts, R.E., 230
Weintraub, R., 91, 199
Weisbrod, B.A., 171, 172, 173, 336
West, D.J., 231
Westoff, C.F., 91
Whelpton, P.K., 91
Whitney, J., 173
Willerman, L., 94
Wills, V.G., 95
Winick, M., 97
Winslow, E.A., 170
Wolfe, P., 354
Wolfgang, M.E., 230, 232, 233, 234
Woods, E.A., 171
Woodyard, E., 94
Wootton, B., 230, 231, 232, 233, 234
Worlis, H., 93

Xydis, G.A., 121

Yotopoulas, P.A., 129

Zaharchuk, T.M., 120