PB-225 959

INSTITUTIONAL DETERMINANTS OF TECHNICAL CHANGE AND ARGICULTURAL PRODUCTIVITY GROWTH: DENMARK, FRANCE, AND GREAT BRITAIN, 1870-1965

William Windsor Wade

Minnesota University

Prepared for:

Agency for International Development

August 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

BIBLIOGRAPHIC DATA SHEET	1. Report No. EUR-338.1-W121	2.	PB 225 959

4. Title and Subtitle
"Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France, and Great Britain, 1870-1965"

5. Report Date
Aug. 1973

6.

7. Author(s)
William Windsor Wade

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
University of Minnesota
Department of Agric. Economics
St. Paul, Minn. 55101

10. Project/Task/Work Unit No.
92.1-11-1-4-122

11. Contract/Grant No.
AID /csd-2815-211(d)

12. Sponsoring Organization Name and Address
Department of State
Agency for International Development
Washington, D.C. 20523

13. Type of Report & Period Covered
Economic Thesis

14.

15. Supplementary Notes

16. Abstracts
This dissertation pursues the hypothesis that there are institutional determinants of technical innovation and productivity growth in agricultural development. These institutional determinants can be isolated and their effect on the inducement mechanism identified. The degree of flexibility of these institutional determinants establishes the optimal direction for input substitution. The stated objectives of this dissertation are three:
(1) To test the factor price induced innovation hypothesis with data from the agricultural sectors of Denmark, Great Britain and France.
(2) To determine to what extent the differential productivity acceleration periods and growth patterns of the three countries were determined by interacting institutional and economic forces.
(3) To analyze the formation of French institutional forces in the early 19th century to see what effect these forces had on French agricultural productivity growth after 1870.

17. ~~[illegible]~~

17b. Identifiers/Open-Ended Terms

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group 3-58

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 365 p
	20. Security Class (This Page) UNCLASSIFIED	22. Price 20.25/1.45

3390 47

INSTITUTIONAL DETERMINANTS OF TECHNICAL CHANGE AND AGRICULTURAL PRODUCTIVITY GROWTH: DENMARK, FRANCE, AND GREAT BRITAIN, 1870-1965

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

By

William Windsor Wade

In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

August 1973

i a

ACKNOWLEDGEMENTS

The author expresses a deep feeling of gratitude to Professor Yujiro Hayami who was a visiting professor in the Department of Agriculture and Applied Economics from 1968 to 1970. Professor Hayami taught me the meaning of empirical research with his counselling: "Remember, paper is your least expensive resource."

Much appreciation is also expressed to my advisor, Professor Vernon W. Ruttan, for continued guidance during the study and throughout my graduate program. Dr. Mathew Shane offered valuable comments on the entire manuscript and Dr. Hans Binswanger offered valuable comments that improved the econometric analysis. I am grateful to them for their critical remarks.

My wife, Artye, in her patience, love and understanding during the course of my Ph.D. program made the whole thing worthwhile.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ii

LIST OF TABLES vi

LIST OF FIGURES ix

Chapter

I INTRODUCTION 1

Statement of Problem and Hypothesis . . 1
Definition 5
Theory: Induced Innovation Hypothesis and Institutional Forces 8
Research Objectives 14
Research Procedure 19

II PATTERNS OF AGRICULTURAL DEVELOPMENT . . . 22

Introduction 22
Resource Endowments, Prices, Production and Productivity 23
Major Influences of Productivity Trends 40
Denmark 40
United Kingdom 57
France 73
Institutional Forces, Technological Change and Productivity Growth 86

III ESTIMATING THE PARAMETERS OF NON-NEUTRAL INDUCED INNOVATION 91

Introduction 91
Estimating Non-Neutral Technical Change in a CES Production Function 93
The Model 96
Estimable Equations 100
Statistical Model 105
Estimating the Effect of Institutional Effects on the Inducement Mechanism . 108
Statistical Model 110

(cont.)

Chapter | Page

Estimating Non-Neutral Technical Change in the Hayami-Ruttan Framework 114
Estimated Equations 115
Econometric Problems of Estimation 116
Empirical Findings 123
Denmark 125
France 130
United Kingdom 142
Implications of the Empirical Findings for Institutional Interaction 156

IV THE RETARDATIVE EFFECT OF FRENCH POLYCULTURE ON TECHNICAL INNOVATION AND PRODUCTIVITY GROWTH 166

Introduction 166
Overview and Hypothesis 168
Polyculture and the Demand for Labor . . . 172
Rail Transportation and Regional Integration 177
Labor Market Imperfections and the Lag in Horse Mechanization 182
The Effect of Labor Market Imperfections on the Induced Innovation Hypothesis . . 193
Productivity Under Dualism in Agriculture 205
Government Policy and Productivity 223
Through 1940 224
After World War II 239
Summary and Implications for the Induced Innovation Hypothesis 243

APPENDIX A: A SIMPLIFIED MODEL OF THE POLYCULTURE SECTOR 248

V SUMMARY: IMPLICATIONS FOR POLICY AND CONTINUED RESEARCH 257

Introduction 257
Summary: Estimation Procedures 259
Summary: Empirical Findings 264
Policy Implications and Directions for Needed Research 272

(cont.)

APPENDICES

Page

B British Data 278

D Danish Data 301

F French Data 324

BIBLIOGRAPHY 342

LIST OF TABLES

Table		Page
1-1	Factor Endowments and Productivity Measures Contrasted	15
2-1	An Overview of Factor Endowments and Growth Rates	24
2-2	Hypothesized Relationships Between Relative Factor Prices and Induced Changes in Factor Use	26
2-3	United Kingdom: Factor Endowments and Productivity, Selected Years	28
2-4	Denmark: Factor Endowments and Productivity, Selected Years	29
2-5	France: Factor Endowments and Productivity, Selected Years	30
2-6	Denmark, France and United Kingdom: Changes in Output, Input and Productivity	36
2-7	Denmark: Annual Exports of Selected Agricultural Products, 1865-1915	46
2-8	United Kingdom: Imports of Major Agricultural Products, 1000 Tons	63
2-9	France: Division of Agricultural Land by Farm Size	78
3-1	Indexes of Relative Factor Prices of Labor and Land	117
3-2	Residual Correlation of OLS Estimated Statistical Models	120
3-3 thru 3-5	Denmark: Statistical Tables	126 thru 128

(cont.)

Table		Page
3-6 thru 3-10	France: Statistical Tables	131 thru 136
3-11	Test for Structural Shift of Relationships Between Two Time Periods for France and the United Kingdom	140
3-12 thru 3-16	United Kingdom: Statistical Tables . . .	143 thru 147
3-17	United Kingdom: Estimated Coefficients for Demand-Type Equations, 1870-1965 . .	148
3-18	United Kingdom: Estimated Coefficients for Demand-Type Equations for Different Time Periods	150
4-1	France: Proportion of Arable Land Held Fallow	169
4-2	France: Farm Operators and Farm Day Workers	175
4-3	France: Number of Farms	176
4-4	France: Horsedrawn Machines	183
4-5	France: Labor Mobility: Percentage of People Born in One Department, Living in Another	192
4-6	France: Regressions of Workstock per Male on Relative Factor Prices Under Three Assumptions About Inputed Wages, 1852-1910	199
4-7	France: Animal Consumption of Crop Products, Composition of Fodder Component	214
4-8	France: Indexes of Livestock Output and Crops Fed to Animals Adjusted for Improved Nutritional Content	220

(cont.)

Table		Page
4-9	Livestock Units per 100 acres, Selected Countries	220
5-1	Comparison of Annualized Growth Rates of the Components of Observed Factor Augmentation, 1870-1965	265
5-2	United Kingdom: Comparison of Annualized Growth Rates of the Components of Observed Factor Augmentation Between Two Periods, Restricted Model III	266
5-3	Denmark and United Kingdom: Direction of Bias	268

LIST OF FIGURES

Figure		Page
1-1	Induced Innovation Hypothesis	9
1-2	Effect of Institutional Constraint on Induced Innovation	10
1-3	Historical Growth Paths of Agricultural Development: Japan and USA, 1880-1965; Denmark, France, and United Kingdom, 1880-1965	16
2-1	Indexes of Changes in Final Agricultural Output of Crop and Livestock Products, Constant Prices: 1870 = 100	33
2-2	Indexes of Selected Product Price Ratios: 1870 = 100	34
2-3	Indexes of Changes in Labor Productivity, Land-Labor Ratio and Land Productivity, Denmark, France, and United Kingdom: 1870 = 100	38
2-4	Denmark: Changing Land Use Patterns . .	43
2-5	Fertilizer Input Per Hectare of Agricultural Land	47
2-6	Consumption of Concentrated Feeds in Denmark and United Kingdom, 1870-1935 . .	48
2-7	Power-Labor Ratio: Workstock and Tractor Horsepower per Male Workers	50
2-8	Denmark: Land-Labor Price Ratio and Indexes of Input Price Ratios	51
2-9	United Kingdom: Tenure and Productivity	67

(cont.)

Figure		Page
2-10	United Kingdom: Changing Land Use Patterns	69
2-11	United Kingdom: Land-Labor Price Ratio and Indexes of Input Price Ratios	71
2-12	France: Changing Land Use Patterns	76
2-13	France: Land-Labor Price Ratio and Indexes of Input Price Ratios	83
2-14	France: Remembrement and Productivity	85
3-1	Flow Chart of the Determinants of Rapid Productivity Growth	157
4-1	France: Changing Rotation Patterns	170
4-2	The Effect of Labor Market Imperfections on Farm Size	187
4-3	France: Distortions of the Machinery-wage Price Ratio 1852-1908	196
4-4	France: Factor: Product and Product-Product Price Ratios	207
4-5	France: The Prevalence of Small Farms	210
4-6	France: Wheat Yield, 1820-1960	217
A-1	Product Transformation Curves for French Polyculture	254
5-1	The Effects of Ordinary Factor Substitution Neutral and Biased Technical Change on Factor Proportions	261
5-2	Components of Observed Factor (Labor) Augmentation	263

CHAPTER I

INTRODUCTION

Statement of Problem and Hypothesis

In recent years research has focused on the development of a theoretical framework and the empirical support for technological innovations as an endogenous variable in economic growth. Within the context of the Hicks-Ahmad induced innovation hypothesis,[1] technological change is related to factor scarcity as measured by relative factor prices. Hayami and Ruttan[2] discovered that in the United States and Japanese historical experiences, rapid agricultural growth in each country accompanied changes in relative factor prices. In each case, a continuous stream of new technology biased toward saving the relatively expensive factor was observed. They concluded that

---

[1]Ahmad (1) provided a framework for Hick's (20) early argument that changes in factor prices induce biases to save the relatively more expensive factor.

[2]Hayami and Ruttan (19) provided empirical support for the induced innovation hypothesis.

this stream of technology altered the production surface to conform to long-term trends in factor prices.

The empirical work that has been done on the induced innovation hypothesis[3] has suggested that a country's ability to achieve substantial growth in agricultural output and productivity hinges on the proper functioning of an inducement mechanism of relative factor prices. In a sense, the inducement mechanism defines the optimal direction for input substitution if the process is proceeding normally. If the mechanism is not functioning, the flow of technological advancements necessary to fuel continuing growth is impeded or not even developed. The pressures on the inelastic factors are not relieved. Bottlenecks occur in the economy and productivity grows slowly, or not at all.

The innovation inducement mechanism provides an essentially micro-economic basis for approaching the macro-economic problem of economic growth. This micro-economic focus has both a strength and a weakness:

---

[3]Binswanger (3) confirmed the Hayami and Ruttan findings while pointing out the difficulty of determining which part of the total increase in factor productivity is due to technical change narrowly defined.

strength attaches to the empirically observable effect that market prices influence the direction of innovative activity; weakness results from reliance on the market to communicate to various sectors of the economy the needed and optimal, in terms of both private and social cost, direction of factor saving innovation. For the policymaker not overly certain about the assumptions of the market, decisive action to stimulate growth may require a more inclusive model. In short, empirical evidence suggests that the normal maximizing assumptions are a necessary but not sufficient condition to explain the smooth stream of innovative technology that has come to be regarded as a necessary prerequisite for economic growth.

The desire for a more inclusive model suggests that the inducement mechanism should be recast in larger context to consider the responsiveness of institutional variables to economic forces. Market signaled inducement can be seen to hinge on the flexibility of the institutions of a nation. Shifting the inducement framework into the arena of institutional variables recasts the inducement mechanism in a three step analysis. Hayami and Ruttan established a direct statistically significant relationship between mechanical and biochemical innovation in the U.S. and Japan

in response to changing relative factor prices--a one-step analysis. The less spectacular growth cases, however, suggest the need to direct the search for technological innovation in terms of the responsiveness of specific institutions to changing economic conditions. The innovation and adoption of either new inputs or some new organization of the production activity depends first on the form of specific institutional arrangements in the society. This institutional context will integrate market behavior with extra-market variables[4] and will show that a rigid institutional structure will cause bottlenecks in the growth process.

This dissertation will pursue the hypothesis that there are institutional determinants of technical innovation and productivity growth in agricultural development. These institutional determinants can be isolated and their effect on the inducement mechanism identified. The degree of flexibility of these institutional determinants establishes the speed with

---

[4]This enlargement of the traditional view of the market economy to include the institutional determinants of the market and other economic activities reflects Ronald Walker's (45) opinion that for purposes of prediction and policy, economics must include an analytical view of extra-market behavior. Also, Davis (9).

which the inducement mechanism communicates the pressures on the inelastic factors and elicits the optimal direction for input substitution.

Definition

Drawing from Schultz,[5] and North and Thomas[6] relevant institutions are those that render services to the economy and, therefore, have economic value. They define and specify the ways by which economic units cooperate or compete. They govern behavior patterns. Specific institutions draw their form from the institutional structure of a society which is defined by the law, cultural traditions and philosophical attitudes within the society.

The institutional structure of a society is made up of all its specific institutions, and traces its ultimate roots to the value system of the society. Clearly, the institutional structure of a country, reflecting such vague attributes of a people as moral attitudes, philosophic systems, political feelings and cultural traditions is a tenuous concept. Specific institutions, however, are concrete: property rights,

---

[5] Schultz (37).

[6] North and Thomas (30).

education, mobility of labor, trade barriers. Separately they or their services to the economy can be identified: tenure system, tariffs, literacy, etc. In aggregate, their patterns of adaptability to changing forces reflect the flexibility or rigidity of the institutional structure of a nation.

At any two discrete points in time the institutional structure may differ markedly as both the value system of society changes and specific institutions cumulatively change. The change of the structure is imperceptible; specific institutional innovations are visible. Thus, an examination of pertinent institutions will intuitively describe the institutional structure.

Institutions can be changed if it becomes more profitable to individuals or groups in society to undertake the cost of a new institutional arrangement. Equilibrium among economic institutions implies that the cost of such change exceeds potential benefits. Institutional innovation is possible when some force adds weight to the profit side of the decision-making process. This disequilibrium can induce change among specific institutions if the institutional structure of a society is flexible; a rigid institutional structure, however, may offset the disequilibrating

force and thus prevent the inducement process or slow it down significantly.

Kindleberger, in his now classical 1951 article, hypothesized that the ability of a society to devise new institutions was a function of its "social cohesion," which, in turn, depended upon the society's internal social mobility, system of communications and set of values. Kindleberger suggested that "if social cohesion is high, it may be possible to find a response to external change which will bring about a new identification of the interests of the subgroup with those of the total group at an improved level of satisfaction for all."[7] In Kindleberger's terminology, a rigid institutional arrangement would imply low social cohesion.

The flexibility or rigidity of the institutional structure may be judged from the speed with which the profitability of a specific needed institutional change is recognized and acted upon. A flexible structure quickly will allow the institutional changes necessary to allow the economy to expand smoothly avoiding bottlenecks.

[7]Kindleberger (26), p. 46.

Theory: Induced Innovation Hypothesis and Institutional Forces

The essential concept of the induced innovation hypothesis is that technical change derives from endogenous forces of the economy and is biased by the conditions prevailing within the economy. Figure 1-1 demonstrates the essential non-neutrality of the induced innovation path and shows how relative factor prices determine the direction of innovative activity. Figure 1-2 introduces an institutional constraint to show how the inducement mechanism can be rendered ineffectual by rigid institutional forces.

Assumed is perfect competition, constant product prices, and constant output. Machinery (M) and Labor (L) are considered substitutes and are displayed on the axes of the right quadrant. The effect of mechanical innovation on the land-man ratio is displayed in the left-hand quadrant where land (A) is on the left horizontal axis. In the right quadrant, U^o is the envelope of potential production functions, the innovation possibility curve,[8] unconstrained by time, research or development costs. At a given time, equilibrium is evidenced at the tangent of isoquant u_1 and isocost line, P_o, at point A. Isoquant U_1 is

[8]Ahmed (1), p. 350.

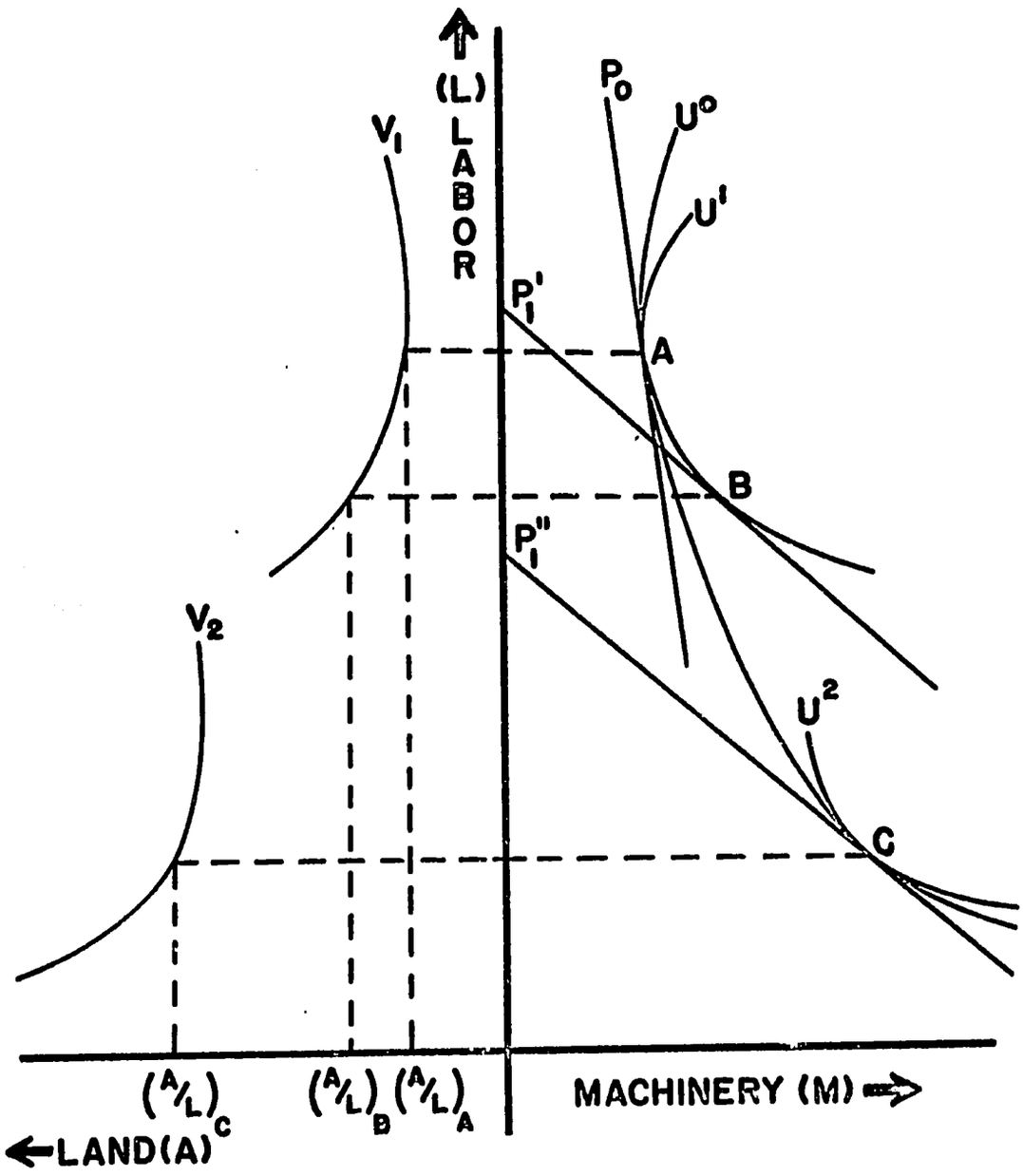


FIGURE I-1: INDUCED INNOVATION HYPOTHESIS

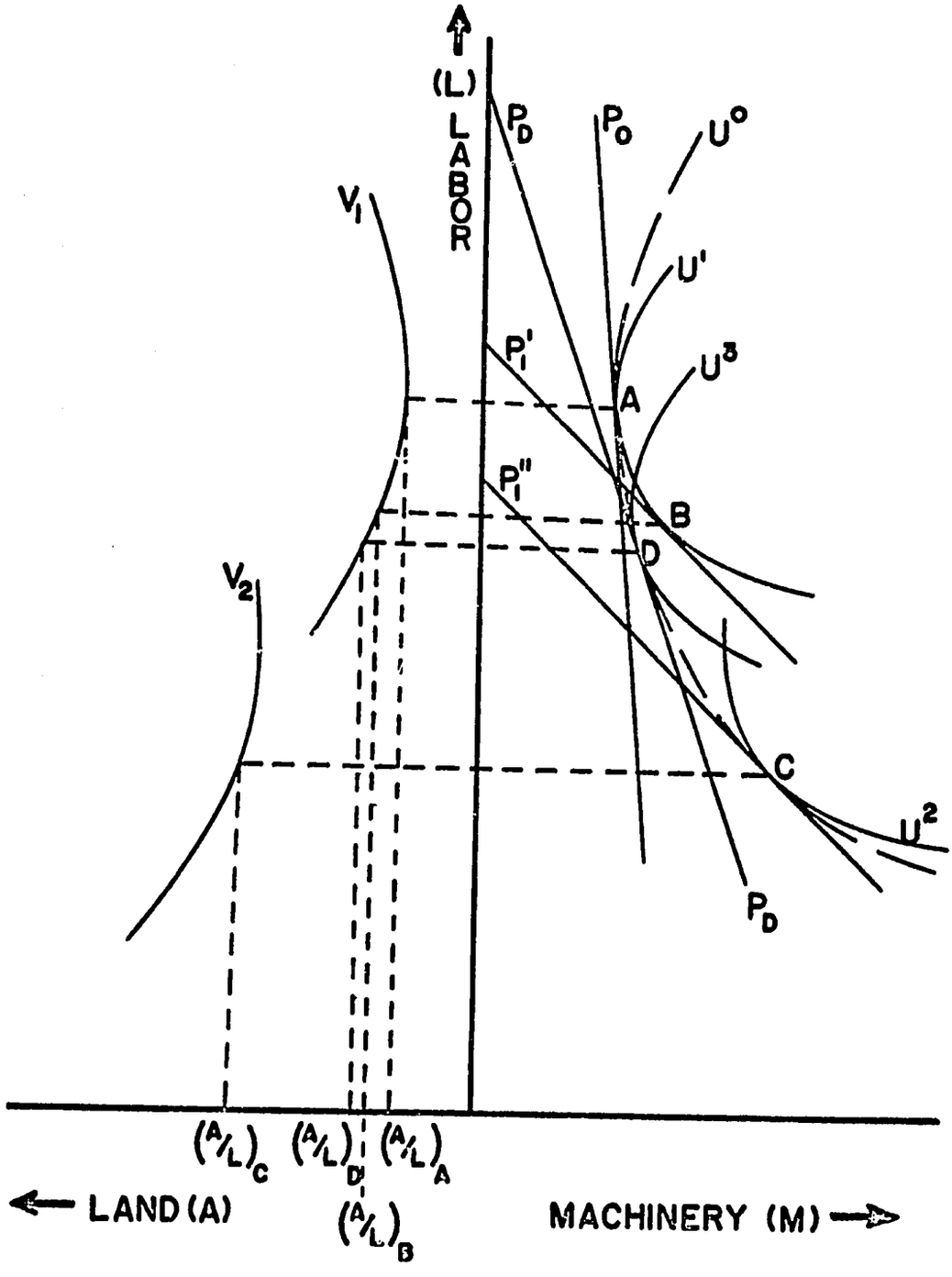


FIGURE I-2: EFFECT OF INSTITUTIONAL CONSTRAINT ON INDUCED INNOVATION

one of a subset of isoquants, U_1 ..... U_i ..... U_n, which might be developed at any point in time given the organization of resources. Each such isoquant is assumed to be characterized by a relatively small elasticity of substitution.

If the price ratio of labor and farm machinery changes through time the slope of the isocost curve may decrease to P_1. The profit maximizing entrepreneur substitutes along his existing isoquant to point B. If the slope of the isocost curve remains constant at the new factor-price ratio (assumed in this diagram), or shows a decreasing trend (more plausible), the public and industrial sectors will respond, according to the hypothesis, by developing new technology. The induced innovation makes possible an isoquant shift to u_2 at the new equilibrium point C. This new technology allows cost saving labor reduction measured by P_1P_1. As a result, the man-land ratio increases dramatically to $(A/L)_C > (A/L)_B$.

This graphical analysis can be repeated for biochemical innovation by relabeling the axes: the vertical axis becomes land, the right horizontal axis, fertilizer, again under the assumption that these are substitutes; the left horizontal axis becomes labor. As the system grinds with induced innovation to position

C, the land-man ratio declines. $(A/L)_C < (A/L)_B$.

The essential element of the induced innovation hypothesis is not just that the individual entrepreneur substitutes factors in response to relative factor price changes; rather, the public and industrial sectors, in response to the price ratio changes generate a flow of technological advancements biased in the direction of the inelastic factor. The individual entrepreneur may perceive that over a local range he may use more or less fertilizer; in so doing, he moves to a position on his existing isoquant according to the simple tenets of profit maximization. To move from this existing isoquant to another is considered a dynamic process involving both the development and adoption of the new technology. Only if the supporting sectors provide new, or improved inputs, can position C in Figure 1-1 be reached. To maximize the value of fertilizer usage, the farmer needs new fertilizer responsive seeds, water control measures, and knowledge about combining these factors that he currently does not have. Thus, the induced innovation thesis implicitly indicates that the production function is shifting out, along an envelope production function analogous to the innovation possibility curve, and

referred to as the meta-production function.[9]

In Figure 1-2, all conditions are the same except that it is hypothesized that the changing economic forces which cause the rising relative wage rate, isocost P_1, are not communicated to the specific sectors of the economy that would develop the mechanical technology. Thus, Position C on the innovation possibility curve is not achieved. The inducement mechanism is distorted by some institutional constraint. P_D, not P_1, results from the constraint. To the extent that the slope of P_D diverges from the slope of P_1, it is hypothesized that the constraint distorts the inducement mechanism to a greater or lesser extent. Given the equation of isocost P_1 as

$$L = C^o/P_L - P_M/P_L\ M,$$

then the equation of P_D has the form

$$L = D\ (C^o/P_L - P_M/P_L\ M),$$

where D is a distortion of the inducement mechanism. D may be sufficiently large that $P_D = P_0$. As D approaches 1, the distortion is reduced.

---

[9]Hayami and Ruttan (19), pp. 82-86.

It is hypothesized that a flexible structure would allow a steady movement in response to economic incentives from B to C, the tangency position of P_1 and the innovation possibility curve. In this case, institutions are sufficiently flexible that they either will allow the movement from B to D without altering their form or they will alter their form in a manner sufficient to allow a smooth march down the envelope curve.

Where institutional structures are rigid, the society cannot devise new institutional forms swiftly enough to accomplish its purposes under the changing conditions.

Research Objectives

Recent empirical research based on the Japanese and United States data developed support for relative factor prices as the inducement mechanism for biased innovation.[10]

Factor endowment differences between these two countries are extreme. Table 1-1 and 1-3 demonstrate the extreme differences in the land-man ratios of Japan and the United States and the resultant patterns of

---

[10] Binswanger (3), Hayami and Ruttan (19), Yeung and Roe (47).

Table 1-1: Factor Endowments and Productivity Measures Contrasted

		Japan	Denmark	France	United Kingdom	United States
Land Per Male Worker (Hectares)	1870/80*	0.7	8.4	7.1	13.6	25
	1965	1.1	11.2	15.5	25.5	109
Output Per Male Worker (Wheat Units)	1870/80	2.4	10.7	7.5	15.6	14.6
	1965	10.7	58.1	49.0	59.3	145.0
Output Per Hectare (Wheat Units)	1870/80	2.7	1.3	1.1	1.1	0.5
	1965	7.5	5.2	3.2	2.3	0.9

*Note: Japan and U.S.A. data are for 1880; European data are for 1870.

Sources: Appendix tables B-1, D-1, F-1
Hayami and Ruttan (19), Appendix tables B and C.

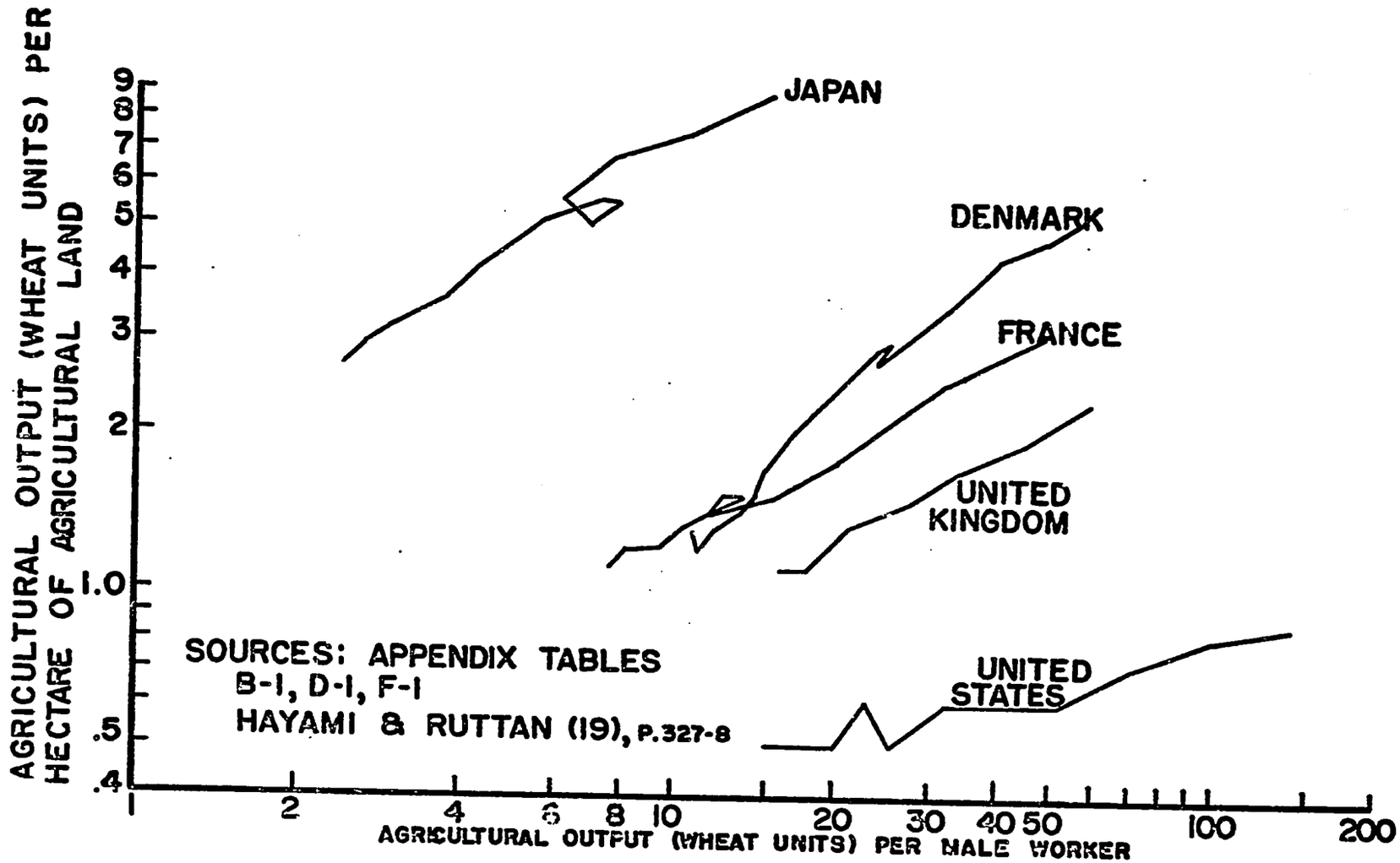


FIGURE 1-3: HISTORICAL GROWTH PATHS OF AGRICULTURAL DEVELOPMENT: JAPAN & USA 1880-1965, DENMARK, FRANCE, UNITED KINGDOM 1870-1965

of productivity growth. Japanese productivity growth was dominated by growth in output per hectare; United States productivity growth was dominated by growth in output per male worker.

Nathan Rosenberg[11] argued against the relative factor price inducement mechanism. Instead, Rosenberg argued that the demand for new techniques emerges from compelling and obvious needs. Rosenberg might argue that the extremely large United States land-man ratio was a compelling and obvious need to introduce mechanization or, conversely, that the extremely small relative land endowment of Japan was a compelling and obvious need to introduce biochemical advances. If, therefore, the argument for inducement through factor-price ratios can be shown to exist under less extreme factor endowments, then the case for induced innovation is enhanced.

The first objective of this dissertation will be to test the hypothesis of induced innovation by factor prices with the data of France, Denmark and the United Kingdom. These countries show clearly less extreme factor endowments and more balanced patterns of productivity growth than Japan and the United States.

---

[11] Rosenberg (34), p. 4.

Denmark, France and the United Kingdom are representative of the various types of European agriculture and are reflective of a cross-section of western European economic and social environments.

The European countries of this study display three unique productivity growth experiences which are not discernable from Figure 1-3.[12]

1. Danish agriculture evidenced sustained growth in productivity from 1885 throughout the study;

2. British agricultural productivity stagnated at 1870 levels for over 50 years and then experienced a productivity take-off[13] after 1930;

3. French agriculture enjoyed a productivity take-off only after World War II.

The second objective of this dissertation is two-fold: (1) to determine to what extent differential

---

[12]See Figure 2-3 in Chapter II to observe these productivity acceleration periods.

[13]Borrowing the term from Rostow, Lester Brown (5) defined a "yield take-off" as a rapid, continuous increase in yields sustained over an extended period. It is less restrictive and in fact allows different conclusions to substitute "productivity take-off." Brown specifically dates a U.K. yield take-off in the early 1940's and discounts yield increases in the late 1920's as attributable to shifting poorer land out of grain to less intensive use. While not denying this observation, it will be shown that land and labor productivity altered greatly in the mid-1920's.

productivity growth patterns of the three European countries were determined by differential economic forces; and (2) to determine to what extent their differential productivity growth patterns were associated with similar economic forces but differential institutional structures.

The goal of the second objective is to indicate how institutional forces can interact with the development of a biased technology, and , hence, productivity growth. Of necessity, much of this argumentation will be inferential.

The third objective of this dissertation is to examine in greater depth the unique French behavior patterns and government policies to determine how these actions determined specific institutions that impeded French innovative activity and productivity growth until after World War II. Whereas objective two will examine the effect of institutions on the productivity growth patterns of the three countries, objective three will deal with the economic and behavioral forces that determined institutions and the institutional structure of France.

Research Procedure

The general approach of this dissertation is an examination of the historical economic data of Denmark,

France and the United Kingdom from 1870 to 1965. Soon after 1870, new continental wheat imports became a significant part of the European market. After 1870, European wheat and grain prices began a precipitous decline. This caused a major change in European agricultural sectors. The advent of significant imported grain was a disequilibrating force that impinged equally on Denmark, France and the United Kingdom. Thus, the different institutional responses from the three countries is a good beginning to this dissertation.

The analysis will examine the induced innovation by factor prices hypothesis over the entire period but will primarily focus its attention on three separate time periods to examine the effect of differing institutional responses on the inducement mechanism. The first period, through World War I, will allow an investigation of the three country's divergent responses to the increased competition of imported grain. This period includes the Danish productivity take-off. In the second period, the inter-war period, the analysis will examine the institutional determinants of the British productivity take-off after 1930. In the third period, post World War II, the institutional determinants of the French productivity take-off will be examined.

Chapter II will review trends in output mix and

inputs among the three countries, product-product price ratios, and factor-factor price ratios for the period 1870-1965. Data to suggest the institutional determinants of the productivity take-offs will also be presented in Chapter II. In Chapter III the data will be subjective to various statistical tests. In Chapter IV French institutional rigidity will be considered in depth. Chapter V will present the conclusions and implications for policy makers.

The data upon which this study is based are presented and described in Appendices B, D and F. As is usually the case with long-term historical data, there are limitations in the data. Great effort has been made to maintain comparability of the data for the three countries. In some instances, the success of this attempt is less than would be preferred. With this in mind, the analysis must be regarded in terms of its broad trends of differences in the growth experiences of the three countries.

CHAPTER II

PATTERNS OF AGRICULTURAL DEVELOPMENT

Introduction

This chapter will investigate the sources of agricultural productivity differences among Denmark, France and Great Britain. Differences in both time of productivity acceleration and rate of growth will be explored in order to determine the effect of both economic and institutional forces on agricultural development.

In the context of the inducement model of agricultural development, growth of output and productivity results from a sequence of technical innovation biased toward offsetting the constraint of the limiting factor, land or labor. However, the proper functioning of the inducement mechanism of the model is possible only if either necessary institutions exist or if the institutional structure is sufficiently flexible to new forces to permit necessary institutional innovations. In either case, growth may be sustained with no dramatic bottlenecks.

In this chapter the data of the European countries will be examined to distinguish their periods of productivity take-off in view of institutional effects on the hypothesized inducement mechanism. Resource endowments, product mix in view of those endowments, trends in factor prices and trends in relevant factor-product and factor-factor ratios will be described.

A comparative overview of six important characteristics of the three countries' agricultural sectors is presented in Table 2-1. The hypothesized relationships between changes in relative factor prices and changes in factor use generated by the induced innovation model are summarized in Table 2-2. It will be useful to refer to these hypothesized relationships when reviewing the long-term trends in productivity growth and factor use in Danish, French and British agriculture.

Resource Endowments, Prices, Production and Productivity

While absolute endowments of agricultural land vary widely among the three countries--the agricultural land area of France is about 12 times that of Denmark, one and three-quarters that of Great Britain--relative endowments of land and labor were similar throughout the period of the study. Furthermore, the land-labor

Table 2-1: An Overview of Factor Endowments and Growth Rates

	1870 to 1915			1915 to 1935			1945 to 1965		
	Denmark	France	United Kingdom	Denmark	France	United Kingdom	Denmark	France	United Kingdom
1. Agricultural Output Growth Rate	1.4%	0.5%	0.0%	2.4%	0.7%	0.7%	3.0%	4.6%	2.2%
2. Agricultural Productivity	Accel-erating	Slug-gish	Stag-nant	Dynamic	Slug-gish	Accel-erating	Dynamic	Dynamic	Dynamic
3. Productivity Take-off	After 1880					After 1930		After 1940	
4. Land-labor Price ratio[a] (beginning of period)	152	852	1112	122	393	467	59	235	186
5. Hectares of land/male (beginning of period)	8.4	7.1	13.6	8.0	7.7	16.1	8.6	8.4	18.9

(cont.)

	1870 to 1915			1915 to 1935			1945 to 1965		
	Denmark	France	United Kingdom	Denmark	France	United Kingdom	Denmark	France	United Kingdom
6. % of males in non-agriculture (beginning of period)	45%	49%	81%	55%	60%	88%	67%	67%	91%

[a]Number of day's work to buy 1 ha. of arable land.

Table 2-2: Hypothesized Relationships Between Relative Factor Prices and Induced Changes in Factor Use

Dependent variable		Independent variables and hypothesized sign					
Biological Technology							
Fertilizer use per hectare	$\frac{F}{A}$	$\frac{\text{Fertilizer price}}{\text{Land price}}$	$\frac{P_F}{P_A}$	(-)	$\frac{\text{Farm wage rate}}{\text{Land price}}$	$\frac{W}{P_A}$	(+)
Concentrated feeds per hectare	$\frac{C}{A}$	$\frac{\text{Concentrate price}}{\text{Land price}}$	$\frac{P_C}{P_A}$	(-)	$\frac{\text{Farm wage rate}}{\text{Land price}}$	$\frac{P_L}{P_A}$	(+)
Mechanical Technology							
Agricultural land per worker	$\frac{A}{L}$	$\frac{\text{Land price}}{\text{Farm wage rate}}$	$\frac{P_A}{W}$	(-)	$\frac{\text{Machinery price}}{\text{Farm wage rate}}$	$\frac{P_M}{W}$	(-)
Horse power input per worker	$\frac{M}{L}$	$\frac{\text{Land price}}{\text{Farm wage rate}}$	$\frac{P_A}{W}$	(-)	$\frac{\text{Machinery price}}{\text{Farm wage rate}}$	P_M	(-)

ratios remained nearly stable until after World War II. Until 1945, Great Britain's land-labor ratio remained twice that of Denmark's and France's ratio. After the war, the French ratio doubled to 16 hectares per male worker by 1965 while the Danish ratio grew only 25% to 11 hectares and the British ratio grew 40% to 26 hectares. (The long-term series of these data, as well as data of prices, output and productivity are shown in tables 2-3, 2-4 and 2-5.)

The relationship of the relative prices of land and labor among the three countries has shown two distinct patterns. In 1870, the cost of land relative to labor for France and Great Britain was relatively high. More than 1100 days work were required to buy one hectare of British farm land; 850 days work were required to buy one hectare of French land.[1] The price ratio of land to labor for Denmark was very low--even lower than the United States price ratio. In 1880, in the United States 181 days of work would buy one hectare of arable land; in Denmark in 1870, only 152

---

[1]The land described is not exactly identical. French land is arable farm land. British land is only farm land and would include pasture land as well as crop land. Presumably, when comparing between countries, the different definitions bias down British values.

TABLE 2-3: UNITED KINGDOM: FACTOR ENDOWMENTS AND PRODUCTIVITY, SELECTED YEARS

		1870	1890	1915	1935	1945	1965
1.)	Agricultural Output (Thousand Wheat Units)	21657	21696	21696	25016	29417	45728
2.)	Agricultural Land Area (Thousand ha.)	18852	19331	19395	19571	19539	19624
3.)	Number of Male Farm Workers (Thousand)	1385	1235	1203	1131	1034	771
4.)	Output per hectare (1)/(2)	1.1	1.1	1.1	1.3	1.5	2.3
5.)	Output per male (1)/(3)	15.6	17.0	17.6	21.6	27.7	59.3
6.)	Hectares of land per male (2)/(3)	13.6	15.7	16.1	17.3	18.9	25.5
7.)	Value of Farm Land (Shillings/ha.)	2781	2194	1448	1210	2306	9337
8.)	Rental Cost of Farm Land (Shillings/ha.)	67.2	53.9	51.1	63.0	70.6	209.9
9.)	Farm Wage Rate (Shillings/day)	2.5	2.5	3.1	5.7	12.4	39.8
10.)	Days Work to Buy 1 ha. of Farm Land	1112	870	467	212	186	235
11.)	% of Livestock Products in Final Output	65[a]	71	75[b]	75	--	--
12.)	Livestock Units (Thousand)	8644	10968	12669	16839	13555	22854
13.)	Livestock Units per 10 ha. (12)/(2) X 10	5	6	6.5	9	7	12
14.)	Wheat Yield (Quintals/ha.)	18.8	20.0	21.1	22.4	23.0	39.5
15.)	Milk Yield (kg/cow)	1545	1727	1938	2527	2321	3188

a 1867-1869 b 1911-1913

Note: See Appendix B for explanations and sources of data.

TABLE 2-4: DENMARK: FACTOR ENDOWMENTS AND PRODUCTIVITY, SELECTED YEARS

		1870	1890	1915	1935	1945	1965
1.)	Agricultural Output (Thousand Wheat Units)	3310	3882	6110	9863	8670	15792
2.)	Agricultural Land Area (Thousand ha.)	2595	2913	2875	3242	3180	3033
3.)	Number of Male Farm Workers (Thousand)	309	326	358	390	371	272
4.)	Output per hectare (1)/(2)	1.3	1.3	2.1	3.0	2.7	5.2
5.)	Output per Male (1)/(3)	10.7	11.9	17.1	25.3	23.4	58.1
6.)	Hectares of Land per Male (2)/(3)	8.4	8.9	8.0	8.3	8.6	11.2
7.)	Value of Arable Land (Kroner/ha.)	198	251	414	497	908	3361
8.)	Farm Wage Rate (Kroner/day)	1.3	1.7	3.4	5.3	15.3	67.4
9.)	Days Work to Buy 1 ha. of Arable Land	152	148	122	94	59	50
10.)	% of Livestock Products in Sales of Typical Farm	48	75	83[c]	83[d]		
11.)	Livestock Units (Thousand)	1753	2211	3530	4141	4042	4563
12.)	Livestock Units per 10 ha. (11)/(2) X 10	7.0	8.0	12.0	13	12	15
13.)	Wheat Yield (Quintals/ha.)	22.5[a]	27.0	29.5	30.1	32.2	42.2
14.)	Milk Yield (kg/cow)	1350	1925	2750[b]	3429	3077	3725

a 1875 b 1910 c 1912 d 1929

Note: See Appendix D for explanations and sources of data.

TABLE 2-5: FRANCE: FACTOR ENDOWMENTS AND PRODUCTIVITY, SELECTED YEARS

		1870	1890	1915	1935	1945	1965
1.)	Agricultural Output (Thousand Wheat Units)	36159	38139	45801	53119	44682	108271
2.)	Agricultural Land Area (Thousand ha.)	34514	34429	36500	34883	32328	34211
3.)	Number of Male Farm Workers (Thousand)	4800	4580	4720	3870	3840	2210
4.)	Output per Hectare (1)/(2)	1.1	1.1	1.3	1.5	1.4	3.2
5.)	Output per Male (1)/(3)	7.5	8.3	9.7	13.7	11.6	49.0
6.)	Hectares of Land per Male (2)/(3)	7.1	7.5	7.7	9.0	8.4	15.5
7.)	Value of Arable Land (Old Francs/ha.)	1673	1674	1964	5170	35000	600000
8.)	Farm Wage Rate (Old Francs/Day)	2.31	2.43	5.0	20.4	149.2	2547.7
9.)	Days Work to Buy 1 ha. of Arable Land	852	689	393	253	235	235
10.)	% of Livestock Products in Final Output	34	42	43[c]	50	55[d]	--
11.)	Livestock Units (Thousand)	17113	17880	15172	18655	16110	21097
12.)	Livestock Units per 10 ha. (11)/(2) X 10	5	5	4	5	5	6
13.)	Wheat Yield (Quintals/ha.)	11.2	11.5	11.4	15.3	13.5	29.1
14.)	Milk Yield (kg/cow)	1500[a]	1650		1780	1870[b]	

a Estimated b 1950 c 1910 d 1950

Note: See Appendix F for explanations and sources of data.

days of work were required.[2]

After 1870, the British and French land-labor price ratio declined steeply to 1915. In the inter-war period, the ratio continued to decline. So, too, the Danish land-labor price ratio declined over the 1870 to 1935 period, but at a much slower rate. After 1935, the French and British price ratios stabilized but the Danish ratio continued to decline, dropping from 94 to 50 by 1965.

Between 1870 and 1915 distinctly different price changes in each country determined the changing factor price relationships. The price of British farm land declined 50% while wages increased 20%. The price of

[2]It is of interest to know the comparison of relative daily wage rates when considering the large differentials in the land-labor price ratios. Converting all the national currencies to German marks, the 1870/1880 wage levels were: Great Britain, 2.55 DM; France, 1.87 DM; Denmark, 1.46 DM; USA, 1.35 DM. To determine the relative cost of sustenance among the four countries, the average cost of a bushel of wheat for 1878-1882 was converted to marks and divided into the wage rate. The cost of wheat and the results: Great Britain: wheat, 4.82 DM/bu; relative wage, 0.530; USA: 4.64 DM/bu; relative wage, 0.291; Denmark: wheat, 5.64 DM/bu; relative wage, 0.259. Thus, Denmark with the lowest valued land in 1870 also had the lowest level of wages. The price data for these calculations were determined from Appendices B, D, and F. The conversion rates to German marks was taken from Weber (46), Appendix I, p. 6. USA wage data taken from Hayami and Ruttan (19), p. 339; wheat prices from Michael (89), p. 56.

Danish arable land more than doubled and wages increased more than two and one-half times. French wages more than doubled while arable land prices increased only slightly more than 15%.

The changes in output among the three countries in the period from 1870 to 1915 were as distinctive as the changes in land and labor prices. Table 2-15 shows that British output did not expand at all during the 45-year period. French output grew at the average annual compound rate of 0.5%. Danish output grew at the average annual rate of 1.4%. By 1915, Danish output was nearly twice its 1870 level.

The different rates of growth among the three countries for the period before World War I are the result of different responses to the shift in crop and livestock prices to favor the latter. Figure 2-1 shows the changes in crop and livestock production. Figure 2-2 shows selected wheat-livestock product price ratios. French prices after 1880 reflect tariffs primarily erected to protect against the influx of grain from the new continental countries. Such grain imports caused the changing price ratios in Danish and British markets.[3] Danish livestock output more than tripled in

---

[3]French tariff actions will be discussed in Chapter IV.

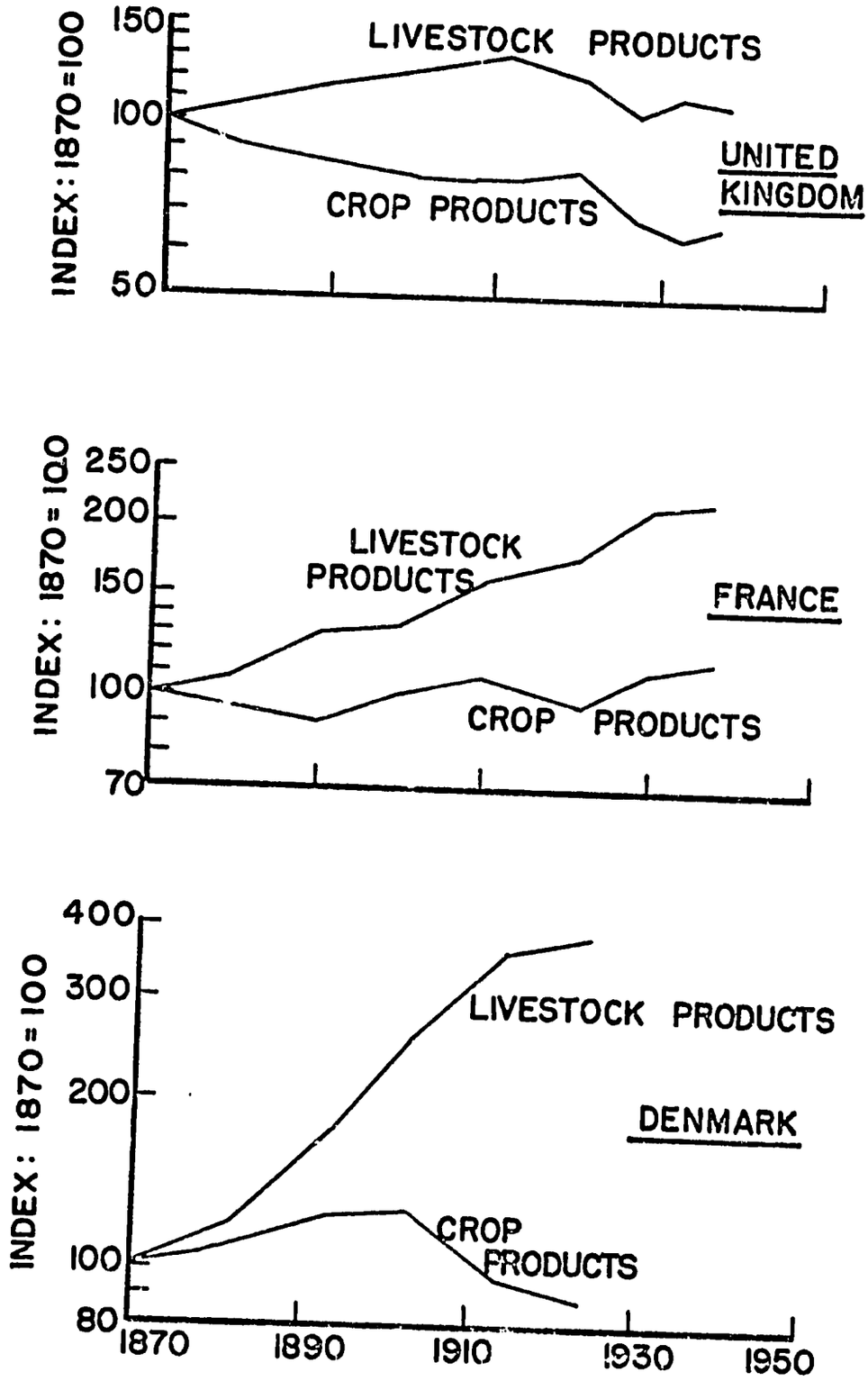


FIGURE 2-1: INDEXES OF CHANGES IN FINAL AGRICULTURAL OUTPUT OF CROP AND LIVESTOCK PRODUCTS, CONSTANT PRICES
SOURCES: APPENDIX TABLES B-2, D-2A, F-2

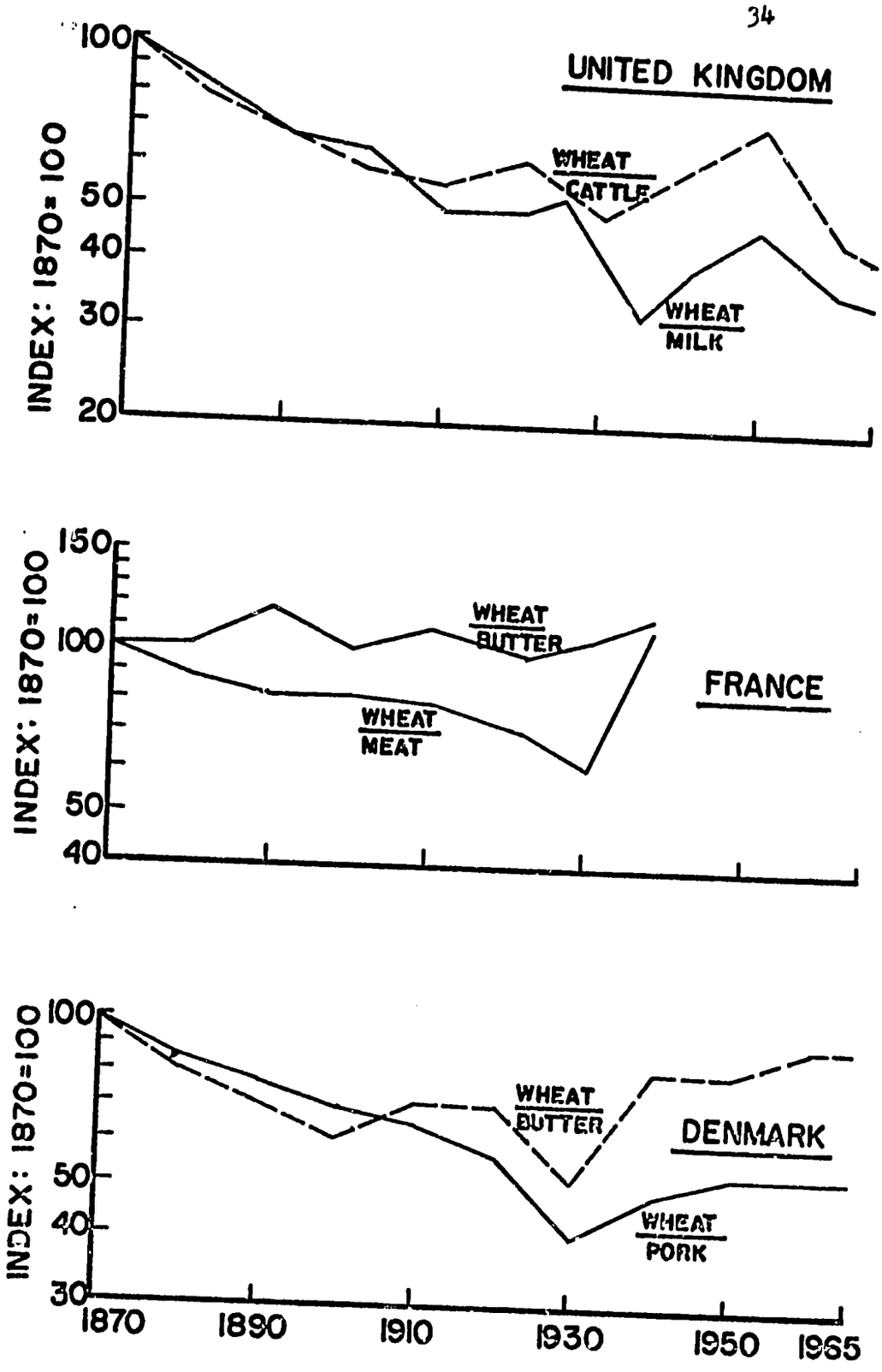


FIGURE 2-2: INDEXES OF SELECTED PRODUCT PRICE RATIOS
SOURCES: APPENDIX TABLES B-5, D-5, F-5

the 45-year period--an annual rate of growth just under 3.0%. British and French livestock output increased only 30% and 65% respectively--growth rates of 0.7% and 1.1%. Moreover, British agriculture essentially made an equal trade-off between crop and livestock products; reductions in crop output offset increases in livestock output.

In view of the changing mix of output among the three countries, the discussion of productivity growth in the period before World War I must focus on livestock production primarily.

Productivity growth in agriculture can be partitioned usefully with the following identity:

$$Y/L = (A/L)\ (Y/A) \qquad (1)$$

where:

Y = Output	Y/L = Labor Productivity
A = Land	A/L = Land area per worker
L = Labor	Y/A = Land productivity

Table 2-6 shows the growth rates of the resources, output and productivity measures for three periods: before World War I, the inter-war period, after World War II. Figure 2-3 shows the comparative rates of change of the productivity components of expression (1) Examination of the data reveals distinct trends in productivity growth.

TABLE 2-6: DENMARK, FRANCE AND UNITED KINGDOM: CHANGES IN OUTPUT, INPUT AND PRODUCTIVITY.

	Index: 1870 = 100						Annual Compound Rate of Change		
	1870	1890	1915	1935	1945	1965	1870 to 1915	1915 to 1935	1945 to 1965
United Kingdom									
1.) Output (Net of feed and seed)	100	100	100	116	136	211	0.0	0.7	2.2
2.) Number of male workers	100	89	87	82	75	56	-0.3	-0.3	-1.5
3.) Output per male worker	100	113	115	142	182	380	0.3	1.0	1.5
4.) Agricultural land area	100	103	103	104	104	104	0.1	0.1	0.0
5.) Output per ha. of agricultural land	100	100	100	118	136	209	0.0	0.8	2.0
6.) Land per male worker	100	115	118	127	140	188	0.3	0.3	1.5
7.) Livestock	100	127	147	195	157	264	0.9	1.4	2.6
8.) Milk Yield	100	112	125	164	150	206	0.5	1.3	1.6
Denmark									
1.) Output (Net of feed and seed)	100	117	185	298	262	477	1.4	2.4	3.0
2.) Number of male workers	100	105	116	126	120	88	0.3	0.4	-1.5
3.) Output per male worker	100	111	160	236	215	543	1.0	2.0	4.7
4.) Agricultural land area	100	112	111	125	122	117	0.2	0.6	-0.2
5.) Output per ha. of agricultural land	100	100	162	231	208	400	1.1	1.8	3.3
6.) Land per male worker	100	106	95	99	102	133	-0.1	0.2	1.3
7.) Livestock	100	126	201	236	231	260	1.6	0.8	0.6
8.) Milk Yield	100	143	204[a]	254	228	276	1.8	0.9	1.0

	Index: 1870 = 100						Annual Compound Rate of Change		
	1870	1890	1915	1935	1945	1965	1870 to 1915	1915 to 1935	1945 to 1965
France									
1.) Output (Net of feed and seed)	100	105	127	147	124	299	0.5	0.7	4.6
2.) Number of male workers	100	95	98	81	80	46	0.0	-1.0	-2.7
3.) Output per male worker	100	111	129	183	155	653	0.6	1.7	7.5
4.) Agricultural land area	100	100	106	101	94	99	0.1	-0.2	0.3
5.) Output per ha. of agricultural land	100	100	118	136	127	291	0.4	0.8	4.2
6.) Land per male worker	100	106	108	127	118	218	0.1	0.8	3.1
7.) Livestock	100	104	89	109	94	123	-0.3	1.0	1.4
8.) Milk Yield	100[b]	106	--	115	121[c]	--	--	0.2[d]	

a 1910 b 1880 c 1956 d 1890 to 1935

Note: Output, livestock and yield data are five-year averages centered on the year shown except where data limitations require some other averaged group of years about the year shown. Land and labor are measured at the year shown as single years, except where data limitations require that the data are averaged over some group of years about the year shown.

Source: Appendicies B, D and F.

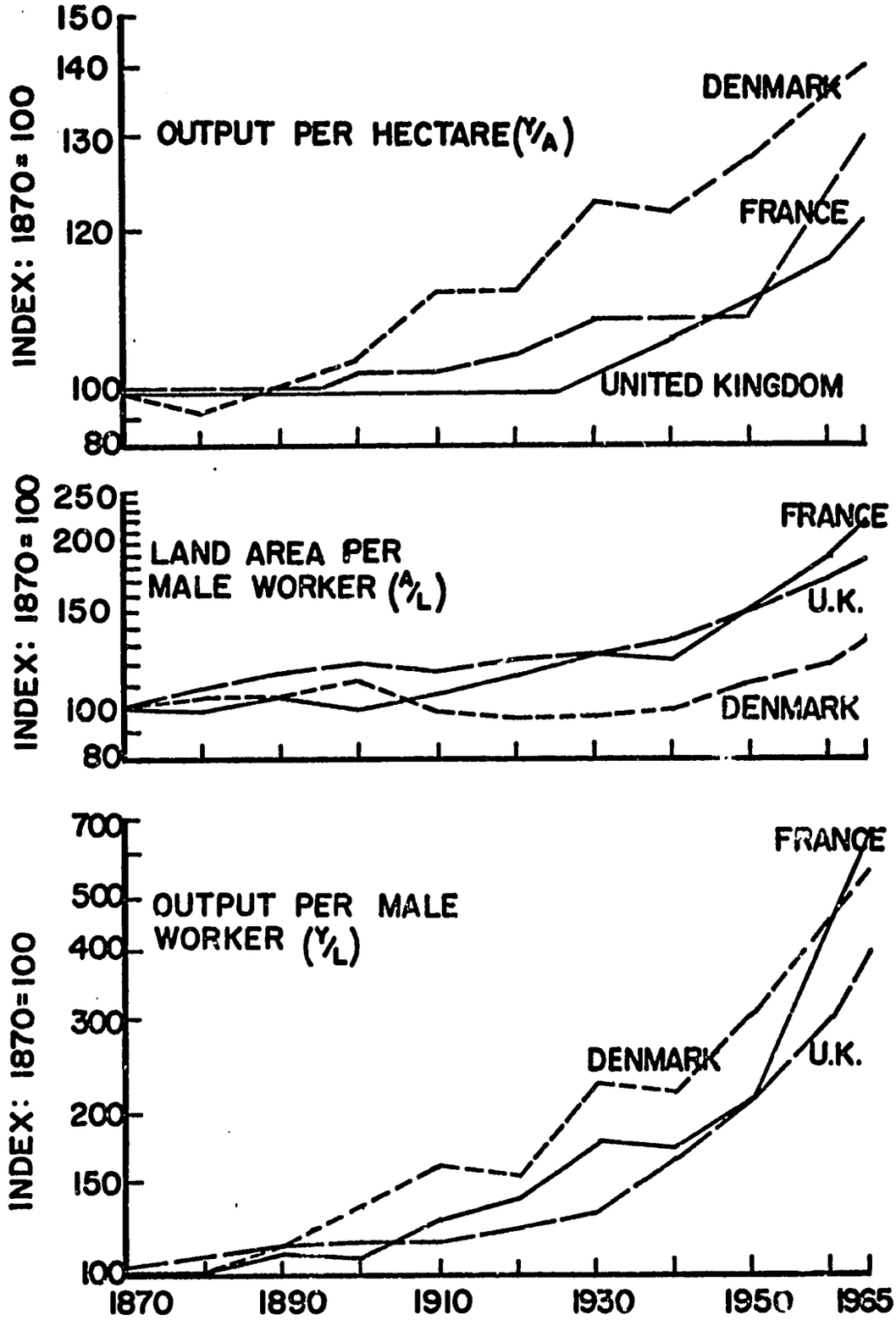


FIGURE 2-3: INDEXES OF CHANGES IN LABOR PRODUCTIVITY, LAND-LABOR RATIO & LAND PRODUCTIVITY SOURCE: APPENDIX TBLS. B-1, D-1, F-1

Britain. Labor productivity, which was twice that of French labor and 30% higher than that of Danish labor in 1870, grew only slightly during the period before World War I. This small change in labor productivity reflected only a slight increase in the land-labor ratio; the land productivity measure did not change at all. Stagnation properly described British agricultural productivity until after the 1920's. Soon after 1930, British land productivity dramatically accelerated. After World War II, labor out-migration caused the land area per worker to increase.

France. Sluggish growth rates of less than 1.0% annually in land productivity and land area per worker characterize French agricultural productivity until after 1940. In 1945, French labor productivity was still only one-half that of both Great Britain and Denmark. After 1954, French agricultural productivity rapidly accelerated as France finally began to mobilize its agricultural resources. By 1965, French labor productivity had nearly overtaken that of the other two countries.

Denmark. Allowing for the disruptive effect on exports and production of monetary fluctuations about

1920 and the Second World War, Danish agriculture has been characterized with uninterrupted growth in land productivity after 1880. Land productivity grew at annual rates of growth increasing from 1.1% in the period before World War I to 3.3% in the post-World War II period. Agricultural land per male worker initially expanded but then declined after 1900 to a lower level than where it stood in 1870. It did not return to its 1900 level again until 1950.

Major Influences of Productivity Trends

In view of the three distinct periods of accelerating productivity for the three countries--Denmark, mid-1880's; United Kingdom, after 1930; France, after World War II--the major trends of economic and institutional forces which related to agricultural productivity will be investigated in this section. Each of the countries will be dealt with in turn.

Denmark[4]. In 1870, Denmark was the most thinly populated of the three countries and had the highest proportion of males employed in agriculture--52%.[5]

---

[4]Danish agricultural and rural history is excellently covered by Jensen (59), Skrubbeltrang (63), Tracy (40), Denmark Agriculture (50), and Youngson (48). This discussion is based primarily on these references.

[5]Hayami, et al. (18), p. 37. 19% of British males and 51% of French males were employed in agriculture in 1870.

The population density was less than 40% of that of Great Britain.[6] The absolutely low Danish land prices indicated previously partly were explained by Denmark's low land density. Weber determined that among Denmark, France, Germany and Belgium for the period from 1850 to 1915, population density accounted for slightly more than 60% of land prices.[7] The relative elasticity of the Danish agricultural land area in the pre-World War II period accounts for an additional proportion of the difference between Danish and other European land prices. Agricultural land area expanded 25% over the period from 1870 to 1935. Table 2-4 indicates that Denmark, unlike France and Great Britain, had not exhausted its frontier land area by the end of the nineteenth century.

Danish agricultural labor also expanded 25% from 1870 to 1935. Both France and Great Britain's labor forces decreased nearly 20% during this same period. Furthermore, while footnote 2 showed Danish real wages in 1870 were the lowest of the three

---

[6]Weber (46), Table 2. Population density measures the number of persons per 100 hectares. In 1870: Denmark, 58; France, 75; Great Britain, 152. In 1910: Denmark, 97; France, 78; Great Britain, 231.

[7]Weber (46), p. 7.

countries and only 45% of British wages, by 1910 Danish real wages had increased 281% to within 95% of the level of British real wages.[8]

The increase in agricultural area after 1870 mostly was associated with the expansion of root fodder crops which served as winter feed for livestock. Figure 2-4 shows the dramatic change in land utilization to support livestock production. Until the expansion of root fodder achieved a substantial level, winter fodder was a constraint on year-round milk production. Cows were plentifully fed only in summer.[9] Tables 2-3, 2-4, and 2-5 confirm the Danish annual milk yield per cow was less than that of both British and French cows in 1870. However, Jensen's farm accounts[10] show that the sale of butter in 1871 accounted for less than 10% of gross income for a representative farm, while crop sales were more than 50% of sales.

---

[8]Converting national currencies to German marks, wages for 1910 were: Denmark 3.15 DM; Great Britain, 2.86 DM; France, 2.43 DM. Wheat prices per bushel: Denmark, 4.32 DM; Great Britain, 3.56 DM; France, 5.48 DM. Real wages at subsistence levels, or wages divided by price of wheat were: Great Britain , 0.802; Denmark, 0.729; France, 0.443. USA wage data taken from Hayami and Ruttan (19), p. 339; wheat prices from Michael (89), p. 56.

[9]Skrubbeltrang (63), p. 122.

[10]Jensen (59), p. 403.

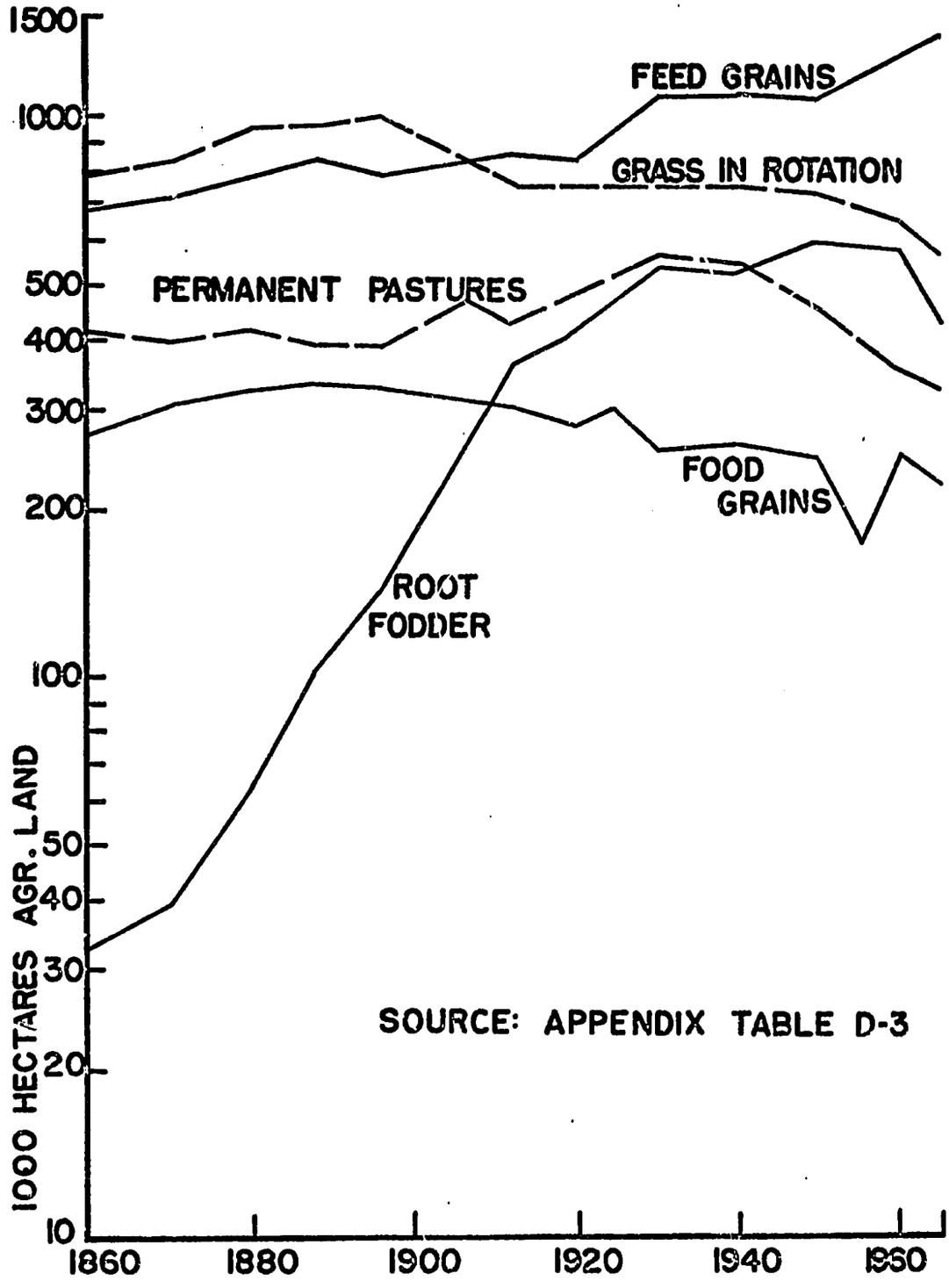


FIGURE 2-4: DENMARK: CHANGING LAND USE PATTERNS

There was only a small incentive to make the changes to improve the low yields from poorly fed livestock. Grain prices remained high and grain exports to Great Britain substantial. The transport facilities for handling livestock products were in their infancy. The markets for animal and dairy products were not well developed.[11] The period roughly coinciding with 1840 to 1870 has been referred to as "the period of golden corn sales."[12]

The remarkable adaptation of Danish agriculture to changing crop and livestock price ratios after 1870 has been discussed in the literature noted in footnote 4. The import of huge quantities of grain into Britain and Europe from the new continent countries lowered grain price dramatically from levels that had existed for decades preceding. Denmark's grain export position was disrupted. However, Denmark did not lose its position in the international trade of agricultural products. Danish farmers perceived the increased incentive to accentuate livestock products and shifted their farm enterprises with relative speed to process

---

[11] Youngson (48), p. 204.

[12] Skrubbletrang (63), p. 122. This 1840-1870 period essentially coincides with the British "Golden Age of Agriculture."

crop products and purchased inputs into livestock products. Table 2-7 indicates the switch from grain exports to feed grain and concentrated feed imports concomitant with the expansion of livestock products in trade.

The expansion of Danish livestock production was shown above to have been the source of rapid growth of labor productivity largely associated with increased output per unit of land. Indeed, Figures 2-5 and 2-6 show that the acceleration of land productivity after 1880 coincided with the adoption of both purchased concentrated protein feeds and purchased chemical fertilizers. The rate of diffusion of these new inputs was extremely fast.

Each of these new inputs is considered land saving biological innovation. Concentrated feeds permitted an expansion of livestock production without expanding farm size. In the Danish economy where crops are grown as intermediate products, fertilizer application permitted increased feed production without expanding farm size. The increased use of each of these inputs resulted in the expansion of the livestock enterprise. Since livestock per male worker nearly doubled from 1870 to 1915 while the area per male worker declined after 1900, it is reasonable to infer

TABLE 2-7: DENMARK: ANNUAL EXPORTS OF SELECTED AGRICULTURAL PRODUCTS, 1865-1915

	Grain (1000 Tons)	Grain and Concentrates (1000 Tons)	Butter (1000 Tons)	Pigs (1000 Head)	Pork and Bacon (1000 Tons)
1865-69	309	---	4.4	36.6	---
1870-74	297	---	8.5	110.9	---
1875-79	138	---	12.7	185.5	---
1880-84	---	- 97	11.1	274.8	6.1
1885-89	---	- 293	19.9	136.5	24.4
1890-94	---	- 658	36.2	130.3	35.5
1895-99	---	- 785	49.3	23.8	63.6
1915	---	- 1057	102.0	---	147.0

Source: Youngson /48/ p. 211
Denmark Agriculture /50/, p. 287 following.

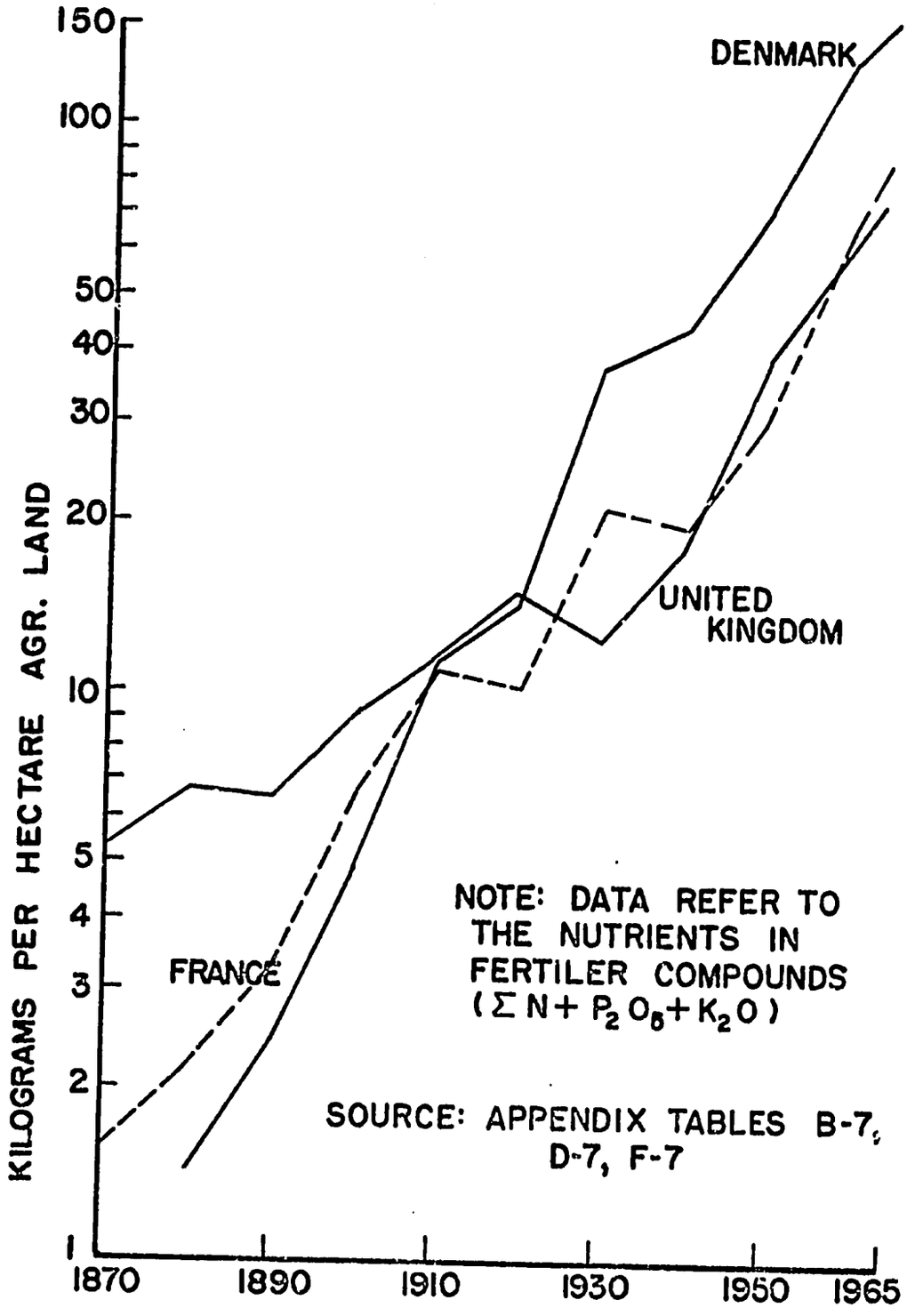


FIGURE 2-5: FERTILIZER INPUT PER HECTARE OF AGRICULTURAL LAND

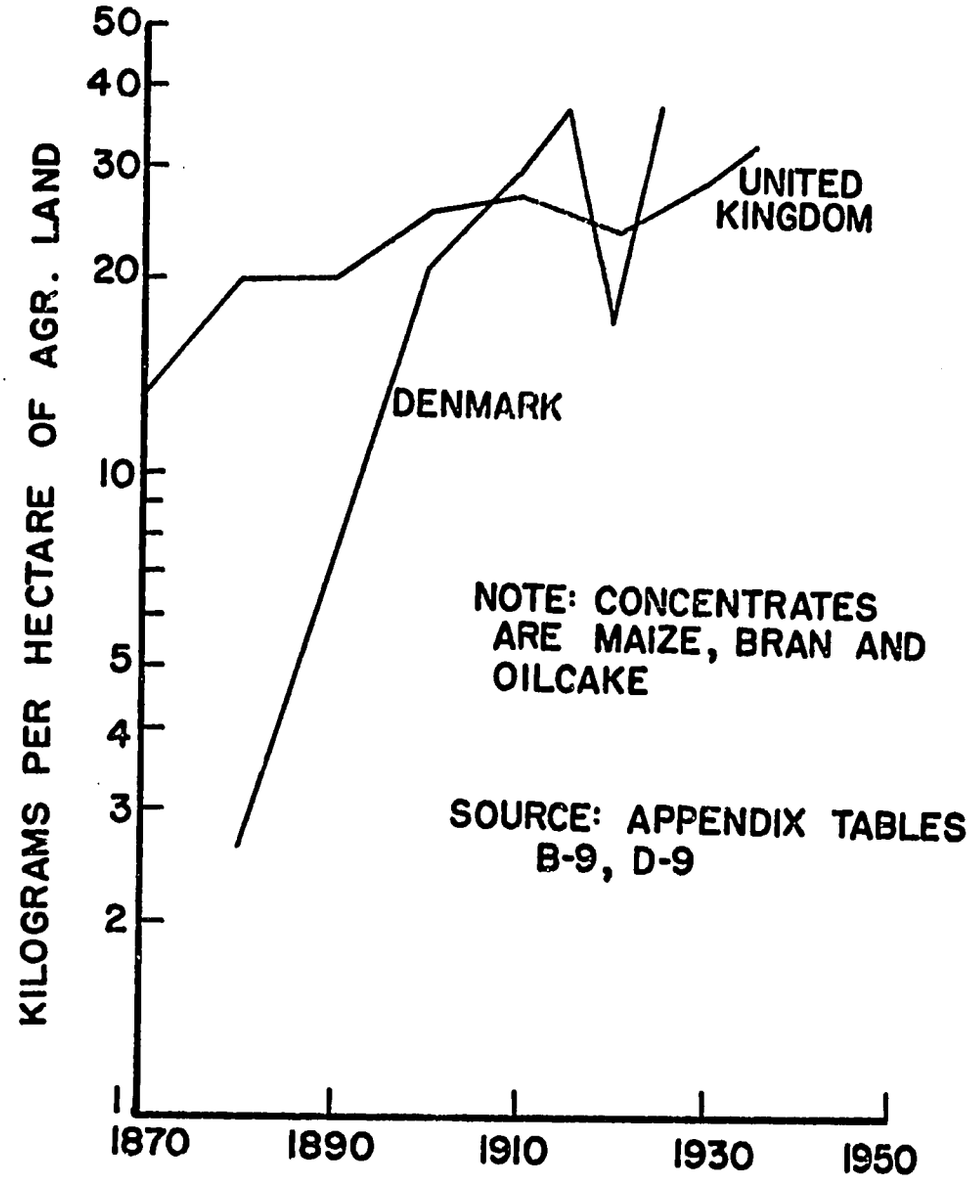


FIGURE 2-6: CONSUMPTION OF CONCENTRATED FEEDS IN DENMARK AND THE UNITED KINGDOM, 1870-1935

that livestock activities were labor using.

During this same early period, the increase in workstock per male worker shown in Figure 2-7 suggests that field preparation, cultivation and harvesting became more generally horse-mechanized. Jensen maintained that the period from 1875 to 1925 saw almost a "complete transition in farm work from the use of hand labor to the use of machines."[13] Mowers, binders, threshers, seed drills and cultivators became common on most Danish farms, diffusing from the larger manor farms to the more typical 10-25 hectare farms. By 1900, workstock per male worker was almost twice that of Great Britain. Thus, technology adopted for cropping activities appears to have been labor saving.

Complete data to test the hypothesis that biases of technical innovation were offsetting in Danish agriculture are not available as far back as 1870. Still, it is a reasonable hypothesis that the unit isoquant shifted neutrally toward the origin as a result of innovation of biological and mechanical technology. Figure 2-8 indicates similar declining trends in the fertilizer-land price ratio and the machinery-wages ratio after 1910. The statistical

---

[13] Jensen (59), p. 168.

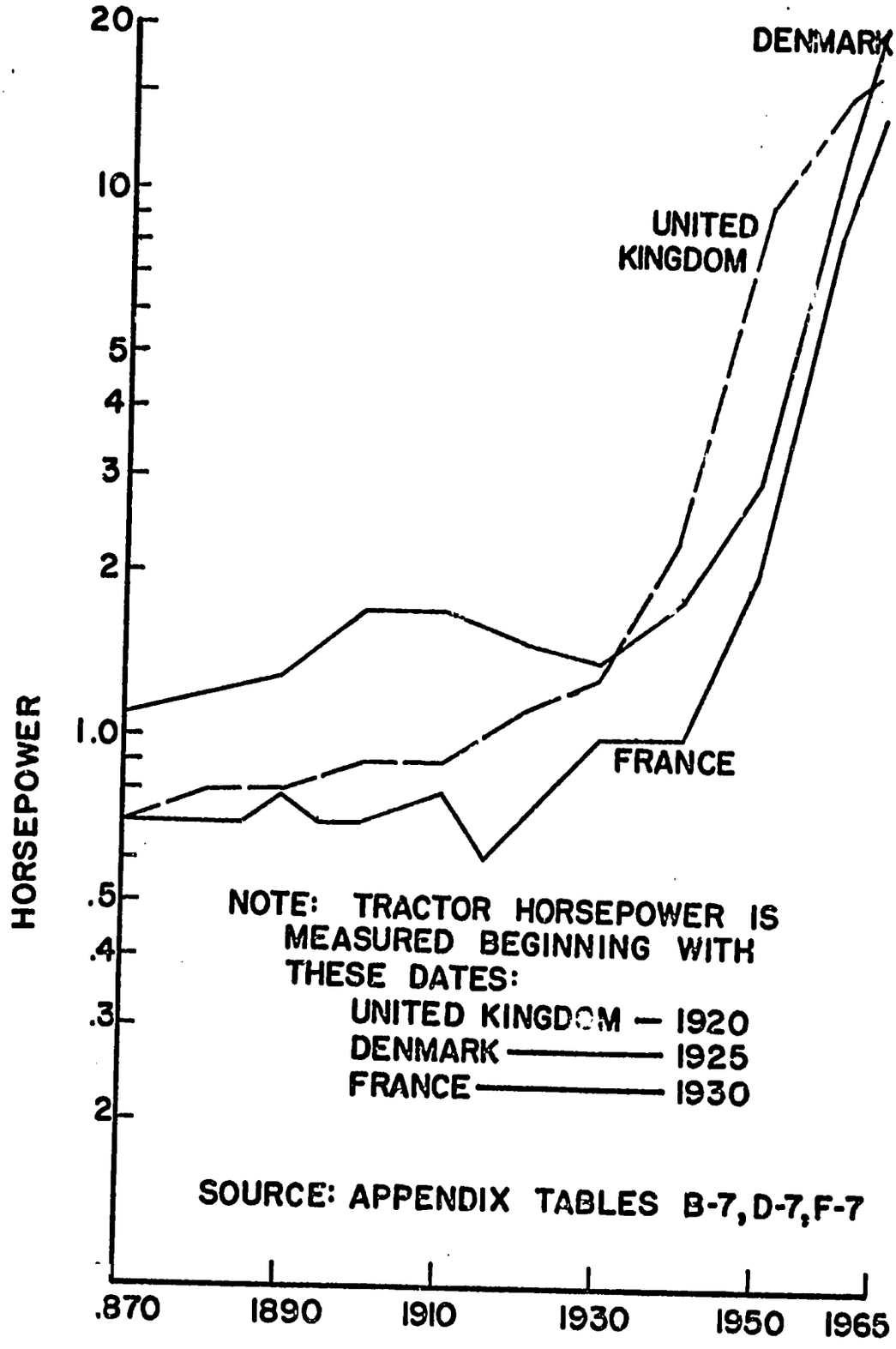


FIGURE 2-7: POWER-LABOR RATIO: WORKSTOCK AND TRACTOR HORSEPOWER PER MALE WORKER

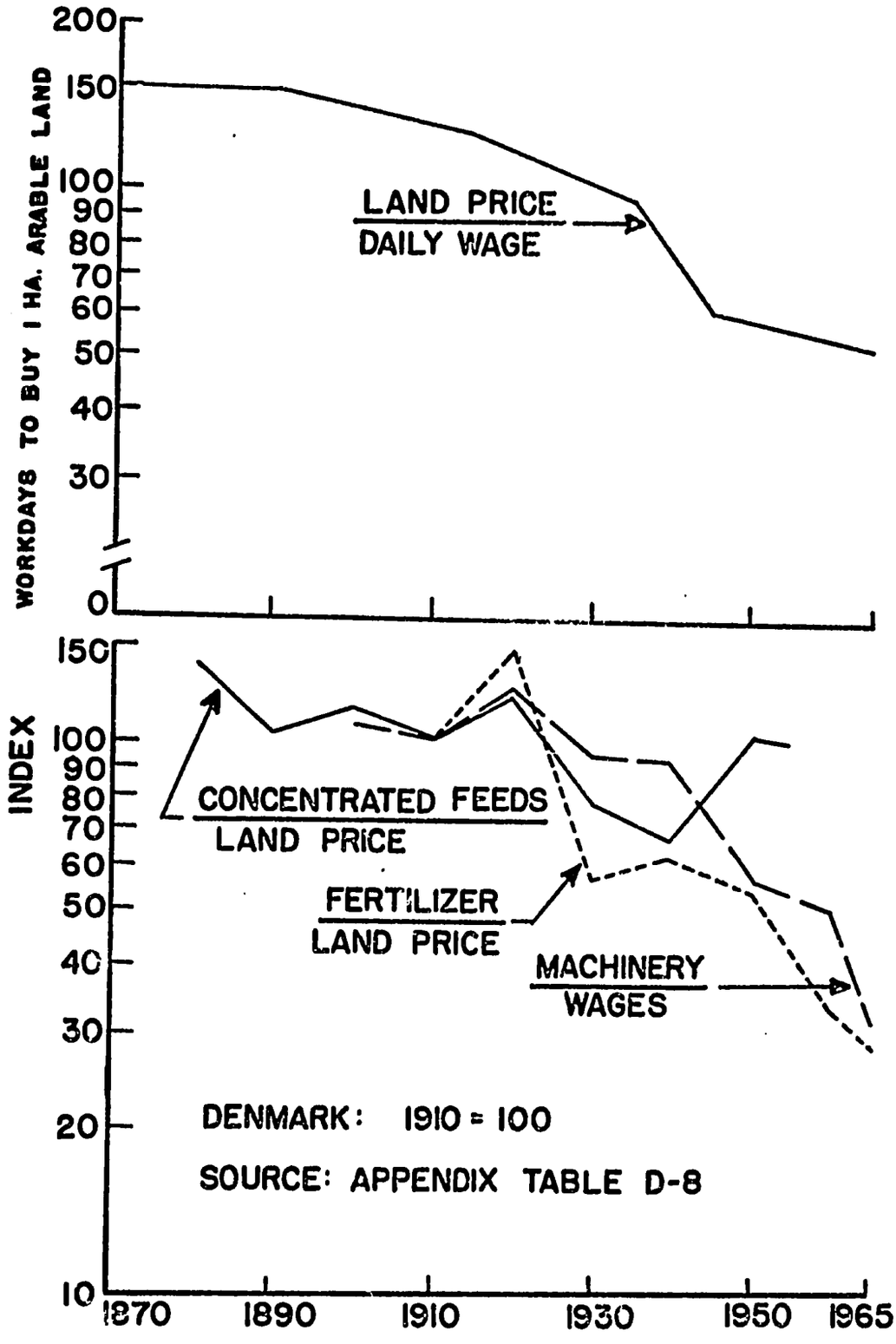


FIGURE 2-8: DENMARK: LAND-LABOR PRICE RATIO AND INDEXES OF INPUT PRICE RATIOS

analysis of the available data is presented in Chapter III.

Given the basic hypothesis of this dissertation that productivity growth is determined by the dynamic interaction of institutional and economic forces, Denmark can be seen to have taken maximum advantage of the economic opportunity in livestock by swiftly developing specific institutions which allowed a large scale conversion of the country's agriculture.

The major influence of productivity growth was due to the response of Danish small and medium sized farmers to the invention of the continuous cream separator in 1878.[14] This group of Danish farmers occupied two-thirds of farm land about this time. Before the invention of the continuous separator, technical problems and capital requirements impeded all but the large manor farms from competing in commercial buttermaking. The butter that was made by other than the manor farms was not uniform in quality and sold for 20% less than manor butter.

The continuous cream separator created the possibility for small farmers to enter into dairy

---

[14]This narrative of the development of the livestock-based agriculture is based mostly on Youngson (48), Jensen (59) and Denmark Agriculture (50).

production. It was essential, however, for several small farmers to combine to send their milk to one creamery. From this necessity evolved the cooperative creameries. The speed with which these cooperatives developed was phenomenal. By 1881 there were about 80 separators in Denmark--mostly on the manor farms which were a ready market for the machine. The first cooperative was founded in 1882. A total of three were founded in that year. By 1885 there were 87 cooperative creameries. By 1890 there were over 700. In 1889 over 1,000 cooperative creameries had been founded.

The development of the cooperative creameries led to the development of the bacon industry. The skim milk was returned to the farms and fed to the hogs. Some of the hogs were slaughtered in the country but most were sent live to German markets. In 1887, a cooperative bacon factory was established. By 1890, cooperative packing houses served all of Denmark. During this period, Germany closed its markets to Danish pork products. With no loss in momentum, the Danish exporters developed the British market. The data of Table 2-7 show that pigs exported annually from 1890-94 to 1895-99 declined from an average of 130,000 head to 24,000; pork and bacon increased from 36,000 tons to 64,000 tons.

The successful exploiting of the British market required a modification of the pig product. The British preferred a less fat pig. The Danish had the scientific capacity to achieve this modification in their breeds. Similar scientific capacity can be inferred from the changes in milk yield. Milk yield, which was lower than French and British yield in 1870, was higher than both by 1890. Between 1870 and 1910, milk yield doubled while butter yield almost tripled. Better breeding as well as better feeding both resulted from the development of scientific capacity.

The implication of the preceding discussion is that the changed product price ratios and the loss of the grain export business created the potential for new profit opportunities in livestock and a force to preserve the earnings from foreign trade. Achieving these goals required aggressive action to develop farm level production capacity and processing capacity.

Processing capacity resulted from the invention of the continuous separator and the institutional innovation of the cooperative creamery. The creamery need not have been cooperative in institutional form. Processing capacity could have been achieved with individual or corporate-owned creameries. Farm level ownership of the capital was not essential to the

development of the processing capacity. However, the fact that the farmers themselves rather than a small group of entrepreneurs developed the needed processing capacity attests to their perception of the profit opportunities and their ability to actualize the opportunities.

It will be seen that this perception and actualization of opportunities was in stark contrast to the French and British farmer response. So, too, the level of education in Denmark was in stark contrast with that of Britain and France. Mandatory education was initiated in Denmark in 1814. The Danish folk school movement began in the 1840's. Danish farmers were well prepared to recognize changes and communicate with other reasoned plans to respond to the changes.

The social interaction to facilitate a cooperative movement was also well established in the Danish institutional structure. From the earliest rural reforms of the 18th century the small farmers' role in agriculture was emphasized and his position as an independent producer enhanced.[15] As a result, Danish farmers early developed the ability to join together to create a political force. Later reforms in the 1849 constitution

---

[15] Dovring (10), p. 185.

guaranteed civil rights and abolished privileges attached to birth, title and rank.[16] The prevalence of owner-occupied land tenure[17] in the late 19th century may be considered an indicator of the degree of social equality in the society that resulted from freedom of interaction. The innovation of the co-operative business form was a result of the willingness of the farmers to join together as equals to create an economic force in the same way that they have previously joined to create a political force.

The institutional form of land tenure was also an important determinant of the ability to develop farm-level livestock capacity. The prevalent freehold form had the effect of avoiding the problem of who owned improvements made to increase livestock operations that tenant farmers faced in Great Britain in the 19th century. Owner-occupation eliminated the problem of coordinating the tenant-landlord relationship through the transition to livestock.

The productivity acceleration after 1880 can, thus, be attributed to the positive interaction that

---

[16] Skrubbeltrang (63), p. 116.

[17] Kindleberger (26), p. 45.

resulted from the interplay of economic and institutional forces in the Danish economy. The statistical analysis of Chapter III will assume that in Denmark the necessary institutional flexibility has been present to support continued growth in agricultural output and productivity.

United Kingdom. In examining the economic and institutional forces which affected the agricultural sector of Great Britain after 1870, it is not surprising to discover that Great Britain, like Denmark, experienced a relative shift in the wheat-livestock product-price ratios to favor livestock products. Both countries were affected by the same grain supply forces. Furthermore, since Denmark exported a large proportion of its livestock products to Great Britain, both countries were affected by similar--to a large extent, identical--demand forces. Figure 2-2 indicates the similar magnitude of product price ratio changes.

In view of the late 19th century Danish regard for British livestock breeding practices[18] and the high historical regard for the techniques and farming

---

[18] Skrubbeltrang (63), p. 191: "An agricultural journal declared as late as 1880 that the English farmer stood infinitely higher than his Danish counterpart when it was a case of selecting breeding stock according to a carefully prepared plan."

practices that became widely accepted before 1870 during the period of "High Farming," the differential response to the shift in relative farm product prices is surprising. Figure 2-1, referred to previously, indicated that Danish livestock output increased over threefold between 1870 and 1915 while British livestock output increased only by one-third.

The effect of livestock production on output and agricultural productivity growth after 1870 was shown in the partial productivity measures of Figure 2-3 and the growth rates of Table 2-6. British output did not increase from 1870 to 1915 while Danish output nearly doubled. Productivity measures of the two countries reflected the output changes.

It is hypothesized that the productivity stagnation of British agriculture before World War I was associated with the effect of British institutional forces on the transition to specialized production.

Any discussion of British agricultural efficiency must acknowledge the remarkable fact that in 1870 80% of the population was fed from home-produced food grown by 14% of the labor force.[19] Tables 2-3, 2-4, and 2-5

---

[19]Ashworth (103), p. 49, Sturmey (129), p. 285.

show that British labor productivity was twice that of France and 50% higher than that of Denmark in 1870. Clearly, the high labor productivity resulting from the British organization of agricultural resources was consistent with the urban labor absorption of Britain's early industrialization.

British agricultural resources in 1870 were organized very differently from Danish farms. Two-thirds of Danish farm land was in farms from 10 to 40 hectares in size and 80% were owner-occupied. Two-thirds of British farming hectarage was in farms greater than 40 hectares and 90% were tenant-occupied.[20] Land ownership was in the hands of the aristocracy and the institutional form of ownership was uniquely that of land as an investment medium, and not that of land as farm homestead. Thus, the institutional form of real property ownership in Great Britain created a second institution, the tenant in the role of homestead farmer. The institutional arrangement was a sophisticated division of labor and capital.

The landlord's responsibility was all fixed capital, including drainage as well as buildings and fences. The farmer provided movable capital including

---

[20] Kindleberger (25), p. 246.

stock, seeds, fertilizer and machinery. Any permanent improvements made by the farmer became the property of the landlord well beyond the passage of the Agricultural Holdings Act of 1883 which gave the tenant titular claim for compensation for improvements. Since most farms were too large to be worked by family labor alone, hired labor was necessarily employed.

The landlords largely controlled what crops could be grown and, thus, the rotation. The larger implication of this tenure arrangement was the responsibility placed on the landlords to keep up and improve their farm units. Considering the relatively small number of landlords who owned the bulk of the hectarage of Great Britain in the late 19th century, the well-being of agriculture depended to a large extent on whether this small number of landowners had "the capital, the inclination and the ability to ensure that the land was well equipped" and farmed well.[21]

Throughout the 18th and well into the 19th century, the evidence suggests that the landlords exercised their responsibility for leadership.[22] The literature

---

[21]Ashworth (103), p. 49. In 1873, half the total area of England and Wales was owned by just 4,217 persons, each of whom possessed 1,000 acres or more.

[22]This point is made over and over in the

has documented the flow of the landlords' capital investment through the third quarter of the 19th century and its impact on arable crop farming.[23] So, too, the literature has documented the contribution of landowner's associations to research for a scientific basis for cropping practices. Nineteenth century British agricultural research was developed and administered under the private enterprise of the landowners. There was a strong heritage encompassing such pioneers as Tull and Townsend in the 18th century and J. B. Lawes in the 19th century for aristocratic management of basic agricultural research.[24]

The effect of 19th century research for improving livestock, however, is not so clear. The judging for livestock shows was "on the basis of appearance rather than of performance."[25] The animals perfected were

---

literature. Refer to Ernle (114), Kerridge (120), Mingay (123), and Thompson (130).

[23]The advances of the 1830's which resulted from capital investment in drainage remain one of the most significant improvements in crop farming of the 19th century. Thompson (130), p. 248.

[24]Until 1889, there was no state assistance to agricultural research. Private enterprise and endowment developed all British research capability. Ernle (114), pp. 437, 169, 369.

[25]Kindleberger (25), p. 245.

show animals--"a rich man's plaything with the practical value obscured."[26] The Danish regard for British breeding practices may have been misguided.

After the period of "High Farming," which lasted until grain prices turned down significantly toward the end of the 1870's, the evidence of slow livestock output growth and productivity stagnation suggests that British agriculture could not efficiently produce the livestock products which changing demand forces called for. Foreign producers increased their position in the British market as indicated by the data of imports in Table 2-8. Capital investment in agriculture declined as new and more attractive investment alternatives appeared.[27] Landowner support for agricultural research waned. Government support for continued research did not come forth. In fact, at the 50-year anniversary of the Rothamsted Experiment Station in 1893, Rothamsted essentially remained the lone source of British agricultural research. Not until 1909 with the Development Fund Act was government money allocated for agricultural research. Previously, agricultural

---

[26]Ernle (114), p. 387.

[27]Ashworth (103), p. 51 indicates the decline in agricultural investments in the 1860's.

TABLE 2-8: UNITED KINGDOM: IMPORTS OF MAJOR AGRICULTURAL PRODUCTS, 1000 TONS

	Wheat & Wheat Flour	Beef	Mutton	Pork	Butter
1865-69	17500	100		100	600
1870-74	23500	150		150	650
1875-79	30500	300		200	850
1880-84	37000	500		200	1150
1885-89	38500	500	400	200	800
1890-94	46000	1000	600	200	1100
1895-99	49000	1500	1550	350	1550
1900-04	54500	2100	1800	450	1950
1905-09	56500	2800	2150	350	2100

Source: Tracy [40], p. 47.

research "had not been recognized as a matter for state assistance."[28] The fruition of public support for research was interrupted by the war, however. The system for state support finally was organized with the establishment of the Agricultural Research Council in 1930. This was set up to supervise the whole field of agricultural research.[29]

With the exception of some notable northeastern countries where livestock progressed,[30] the landlord-tenant system of farming, which was ideal for large scale grain farming, was poorly suited for labor intensive animal husbandry. To switch these large tenant-operated holdings over to livestock operations required dividing the farms and building new barns and houses. Such new investment was not forthcoming. Furthermore, the tenure system itself was biased against

---

[28]Ernle (114), p. 438.

[29]This account on the development of public support for agricultural research is taken from Ernle (114), Chapter 23.

[30]Fletcher (115), p. 245 has shown that the alledged depression in agriculture in the 1880's and 1890's has been exaggerated to some extent. Dairy farmers near cities did not suffer; nor did farmers in and around Lancashire. The successful livestock operations, however, were localized activities.

changeover. There was little tradition for the apportionment of costs and benefits among landlords and tenants. Capital investment by the farmer was all but precluded by the poor security afforded him by the law. This remained true until nearly the turn of the 20th century.[31]

The farmers themselves were limited by their own general lacking in education as well as by the traditional boundaries imposed on their innovative activities by the strict rules of the tenure system. Education was not made general until 1870; it was not made mandatory until 1880. Until 1870, the educational system was for the upper classes.[32] A contemporary observer found the farmers ignorant of new methods and unwilling to learn, possessed of superstition and prejudice.[33] Farmers even attempted to undermine the Education Act of 1870. There was a general rural view that education corrupted children's willingness to work in agriculture.[34]

---

[31]Kindleberger (25), pp. 246-47 refers to reports of two contemporary observers about the lack of security for tenants. See also Ashworth (103), p. 66.

[32]Ashworth (103), p. 196.

[33]Kindleberger (25), p. 245.

[34]Martin (121), p. 275.

After 1875, land values and rentals began to decline. The landlord's capital value of land was halved by 1915. Rentals declined, but more slowly. Among the farmers and landlords some of each group abandoned farming in the 1880's and 1890's. By this time, it is hypothesized that the traditional leadership position of the landlords was severely diminished but that farmers, limited by the lack of education and their traditional position in the institutional structure of Victorian British agriculture, were not prepared to replace the landlord's leadership position. The farmers had neither the managerial skills nor the experience for entrepreneurial risk-bearing. Neither did he have interest in or access to the type of agricultural research that the aristocrats had supported and employed. Until the status of the farmer was raised by education and experience and until state support for and dissemination of agricultural research was established, productivity stagnation continued.

Figure 2-9 indicates that the tenure system began to change after World War I. Owner-occupied farms increased from 12% to 36% of the total farm area between 1915 and 1930. Spurred by saved war profits and the agricultural price support acts of 1917 and 1920, land purchases and owner-occupiers increased

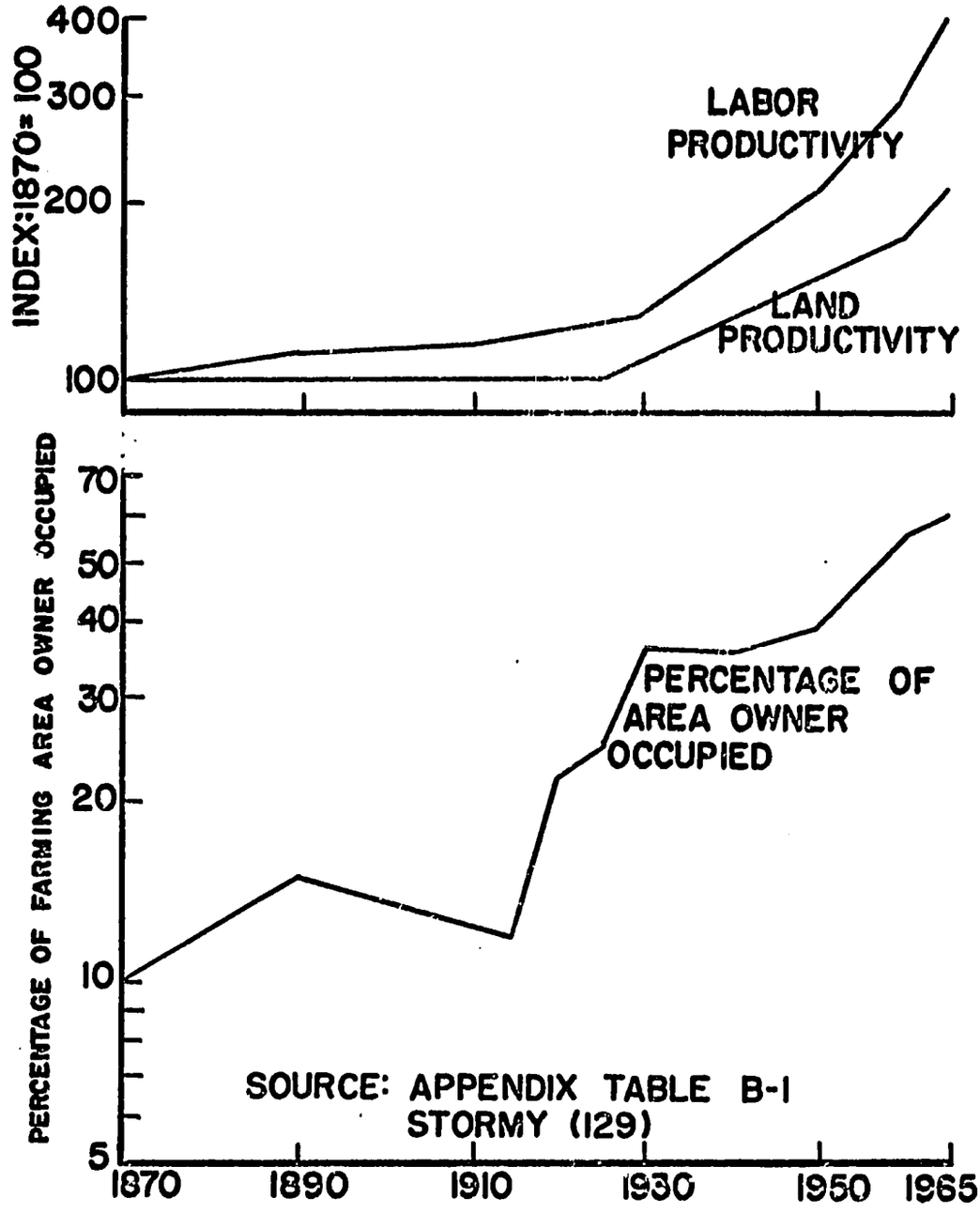


FIGURE 2-9: UNITED KINGDOM: TENURE AND PRODUCTIVITY

rapidly from 1917 to 1921. In 1921 government price supports were removed. The laissez-faire policy was restored. Production continued to stagnate throughout the 1920's but owner-occupied purchases continued to stagnate throughout the decade. When the Agricultural Marketing Acts of 1931 and 1933 restored price supports, 36% of farm land was under owner-management. The percentage has continued to increase.

Soon after 1930, Great Britain experienced a productivity take-off. It is hypothesized that both the innovation of price supports and the institutional modification of the tenure form were associated with the productivity acceleration. With the institutional forces in mind, the economic forces within the factor market will be described.

In contrast to the actions of Danish farmers who increased the area of feed grains, root fodders and grass fodders after 1870, the British land use response to the shift in relative product prices was to allow some of the wheat acreage to go to grass. Figure 2-10 shows that there was no increase in feed grains or cultivated grass fodders throughout the pre-World War I period.

Considering the extremely high relative land values that prevailed during the period of high farming,

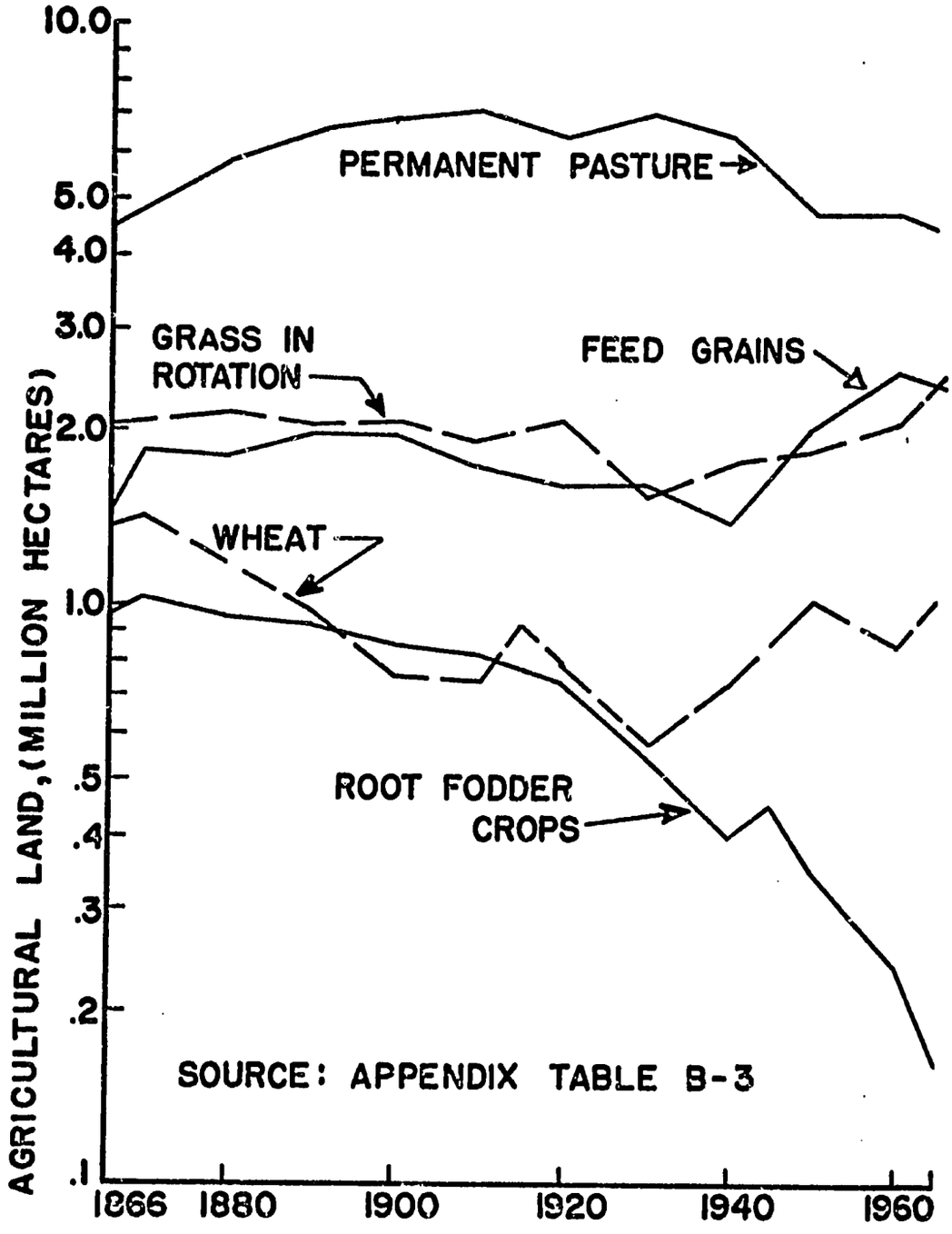


FIGURE 2-10: UNITED KINGDOM: CHANGING LAND USE PATTERNS

the early adoption of chemical fertilizers and concentrated feeds appears to have been a reasonable attempt to ease the pressure on the land constraint that existed before imports allowed for an expanded supply of food products. Figures 2-5 and 2-6 show that British fertilizer and concentrate feed usage per hectare was about fivefold that of Denmark in 1880. After 1880, the rates of increase of these purchased biological technologies was significantly different between Denmark and Great Britain. By 1910, Danish usage of the two inputs equalled British usage.

Figure 2-7 indicates a slight increase in the workstock per male worker between 1870 and 1900. Beginning with 1920, Figure 2-7 reflects the early British adoption of tractor mechanization.

The data of factor price ratios shown in Figure 2-11 suggests that the slow diffusion of biological technology before World War I was due to a limited force on the inducement price ratios. Figure 2-11 shows that the factor-price ratios before World War I were nearly constant after 1880. Declining prices in the product market lowered the marginal revenue products of the endowed resources; rentals declined and money wages were constant to 1890. The implication of the constant factor price ratios for the induced

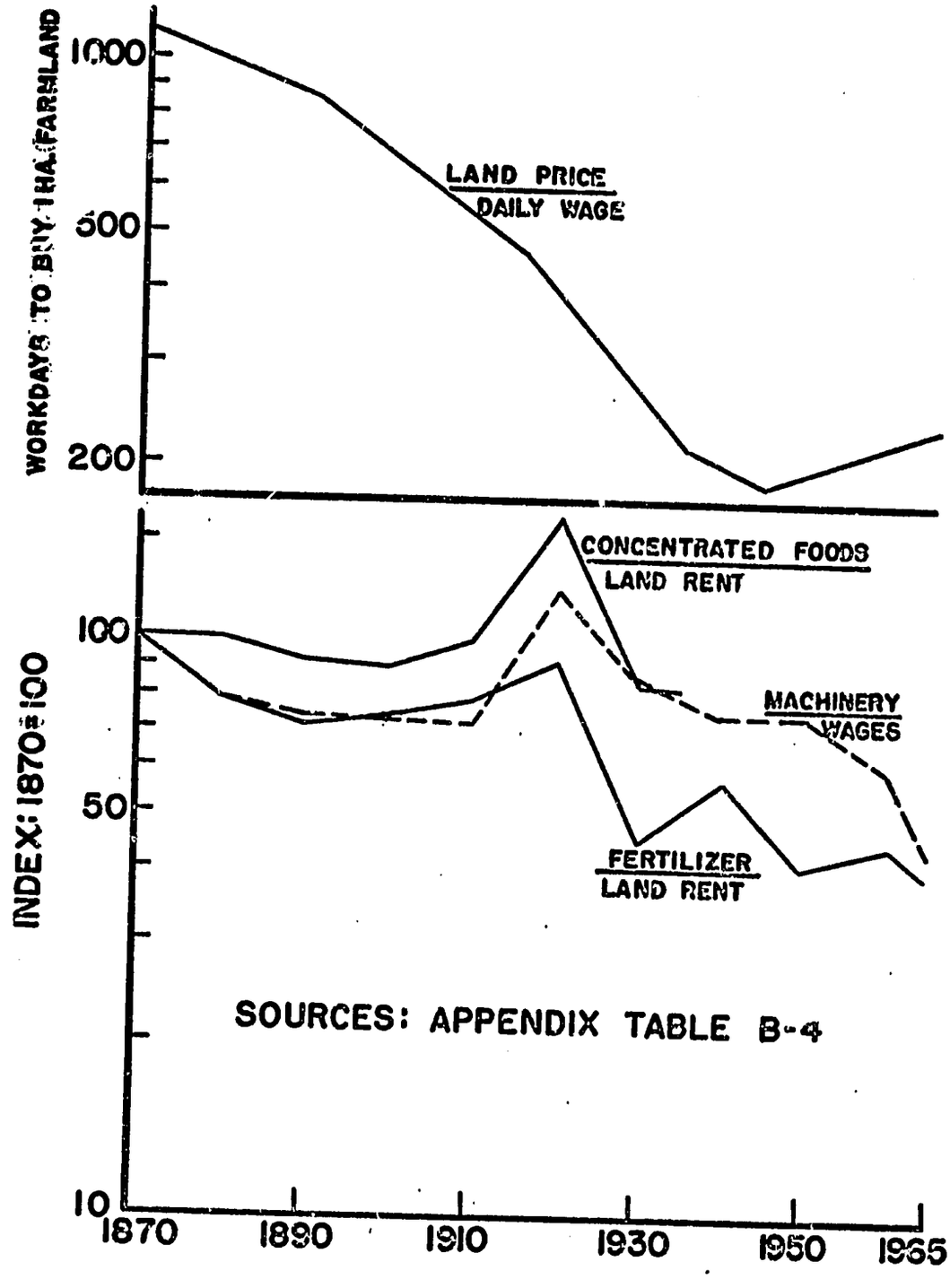


FIGURE 2-11: UNITED KINGDOM: LAND-LABOR PRICE RATIO AND INDEXES OF INPUT PRICE RATIOS

innovation hypothesis is that there was little force to innovate factor saving technology before 1920. The implication of the tenurial and educational institutional constraints is that the failure to shift resources to more profitable products kept the marginal revenue products of land and labor from rising and, thus, resulted in the constant concentrate-rent, machinery-wages, fertilizer-rent price ratios through 1910.

Figure 2-11 indicates a distinct change in the factor price ratios after 1920. The machinery-wage price ratio turned sharply down after 1920 and has continued to decrease. The fertilizer-rental price ratio also turned sharply down after 1920 but has leveled off at about its 1930 level. As can be seen in Table 2-3, rentals reversed their downward trend after 1915 and money wages nearly doubled between 1915 and 1935. It is hypothesized that during the inter-war period institutional innovations occurred which restored the profitability of farming. These created pressures to increase output. This placed pressure on the inelastic factor of production and technological innovation was induced. About 1930, productivity growth resumed.

The changes in the factor price ratios indicated by Figure 2-11--the decrease in the land price/wage

ratio and the continuous downward trend of the machinery price/wage ratio--appear to suggest that the bias of the inducement mechanism has been labor saving since 1920. This hypothesis will be tested in Chapter III.

The statistical analysis of Chapter III will also test the hypothesis that institutional changes occurred in British agriculture after World War I which allowed the resumption of growth in output and productivity after 1925.

France. French agriculture is an interesting contrast to the Danish and British cases because the value of French livestock output remained less than crop output until the 1930's. During the 1870 to 1935 period, British livestock output increased from 65% to 75% of total output, and Danish livestock sales from farm increased from 48% to 83% of total farm sales.[35] The failure of livestock farming to dominate French agriculture is surprising considering that 85% of farms were less than 10 hectares in size as late as World War I and 55% remained less than 10 hectares as late as 1955.[36]

---

[35] See Tables 2-2, 2-3, and 2-4.

[36] See Table 4-3.

If the British and Danish farm enterprises were representative of two types of European agricultural resource organization, then the small family farm of France would seem to have been similar to the Danish family farms. Hence, it would seem reasonable to hypothesize that since the sector of small farms did not significantly increase livestock output, its comparative advantage was not maximized.

In this section the economic and institutional forces that affected productivity in the agricultural sector will be explored. In Chapter IV, forces that affected the development of institutional arrangements will be examined.

The slow growth of livestock's share of total agricultural output is partially explained by French tariff policies. These policies offset market forces affecting the wheat-butter price ratio and muted changes in the wheat-meat price ratio. These institutional distortions to the free market price ratios can be seen in Figure 2-2 by comparing the French data to the Danish and British price ratios.

Tariffs were first invoked in 1881 to slow the import of grains from the new continental countries. These first tariffs proved insufficient. However, the protectionists continued to rally and in 1892 the

Meline Tariff was passed. Figure 2-2 suggests that these tariffs and subsequent modifications arrested for 20 years the forces that caused the downward trend of the wheat-livestock product price ratios in the free market prices of Denmark and Britain. Finally, in 1929, France adopted a 97% milling ratio as a quota device on wheat imports.[37]

The changing land use patterns shown in Figure 2-12 indicate only a small response through 1900 to the distorted wheat-livestock product price ratios. The area of wheat and rye declined slightly less than 8% through 1900 from nearly nine million hectares in 1870. The area of cultivated root and grass fodders increased from three million to four and one-half million hectares from 1870 to 1900. After 1900, Figure 2-12 indicates a decided expansion land resources allocated to livestock production. This represented an expansion of the agricultural land area, not a reallocation of resources. Table 2-6 shows that French agricultural land area expanded 6% from 1890 to 1915. After World War I the area devoted to food grains began to decline and continued to contract until 1950.

Wheat represented the dominant use of arable land

---

[37] Tracy (40), p. 123.

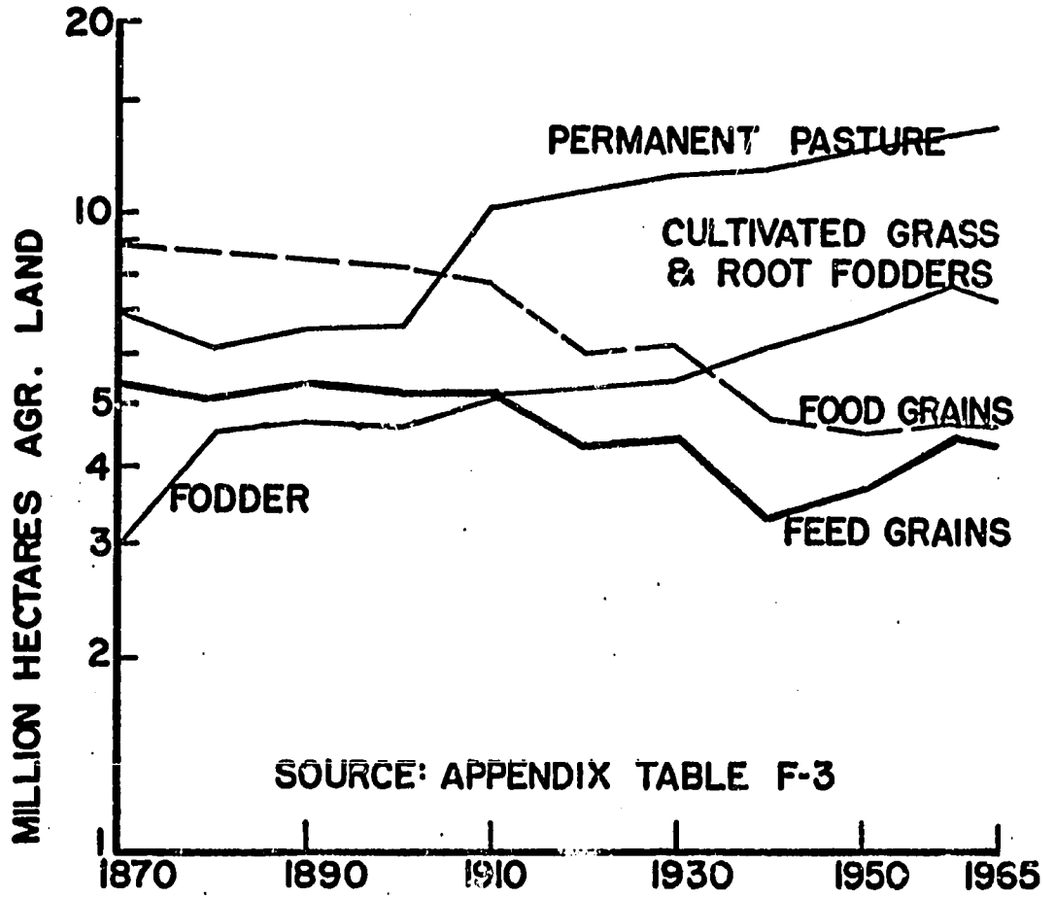


FIGURE 2-12: FRANCE: CHANGING LAND USE PATTERNS

in every department of France at least through World War I. Golob noted that in 1882 wheat occupied no less than 50% of arable land in all but ten of 87 departments and no less than 40% in all but Corsica.[38] Since there was no change in arable land use patterns before World War I, until then wheat still represented the dominant use of arable land resources.

Throughout the period from 1870 through World War I, 85% of farms were less than ten hectares in size. These occupied about 30% of French farm land. Another 35% of the land was occupied by medium-sized farms in the 10 to 40 hectare size. Of these farms, most were less than 20 hectares in size. The large farms, over 40 hectares, were less than three percent of the number of farms, but occupied the remaining 35% of farm land (see Table 2-9). The bulk of the large farms were located in the north and northeastern regions.[39] Therefore, among the small- and medium-sized farms spread throughout the departments of France, it is reasonable to infer that an important proportion of land resources was allocated to wheat at least through the First World War.

---

[38] Golob (77), p. 81.

[39] Hohenberg (82), p. 27.

TABLE 2-9: FRANCE: DIVISION OF AGRICULTURAL LAND BY FARM SIZE

	Less Than 1 ha. (1000 ha.)	1-10 ha. (1000 ha.)	10-40 ha. (1000 ha.)	Over 40 ha. (1000 ha.)	10-20 ha. (1000 ha.)	20-50 ha. (1000 ha.)	Over 50 ha. (1000 ha.)
1882 1/	1084	11,366	14,846	22,493	---	---	---
1892 1/	1327	11,245	14,313	22,493	---	---	---
1908 2/	1229	11,559	14,825	16,271	---	---	---
1929 3/	725	9,556	---	---	9,460	12,978	13,486
1942 3/	110	5,324	---	---	7,603	11,300	10,372
1955 3/	86	5,169	---	---	7,536	11,167	8,202
1963 4/	71	4,022	---	---	6,784	10,931	8,413

Sources:

1.) France, Statistique Agricole, 1892, p. 363.
2.) Golob, /77/, p. 218.
3.) EEC, Statisque Agricole, 10, October 1960, p. 24-26.
4.) France, Statisque Agricole, 1968, p. 98.

The literature is convincing that the tariff structures swiftly enacted to protect French agriculture from the influx of new continental grain disrupted economic stimuli that could have induced greater regional specialization to maximize comparative advantages.[40] The profusion of wheat hectarage in all departments through the First World War period confirms that no appreciable specialization had occurred at that time.

Thus, French agriculture entered the inter-war period essentially unchanged in its organization of resources. Just as it was in 1870, the agricultural sector was a maze of small owner-occupied farms, each parcellized into plots found all over the neighboring area of the resident farmer. In 1882, the agricultural census showed that the average farm was comprised of 20 parcels.[41] Excessive division into small parcels was the normal situation among all but the largest holdings.[42]

French agriculturalists practiced mixed farming, or polyculture, as it is usually labelled in the literature. Self-sufficiency in all his needs was the first

---

[40] Thompson (96), p. 127.

[41] Michael (89), p. 32.

[42] Ibid., p. 33.

aim of the typical peasant farmer. The subsistence level farmer occasionally sold a little grain, some dairy products and eggs, and an occasional animal at a neighboring town on certain market days.[43] A 1919 French study showed that one-third of the cash income of a farm at the mean size of the medium-sized farms was derived from grain sales with two-thirds derived from the sale of animals and livestock products.[44] These sales represented the major supply of marketed livestock products. Marketing practices were not significantly better organized than those of the smallest group of peasant farmers and self-sufficiency was still an important goal among this group. Although the larger holding produced a considerable surplus of animals and livestock products, they were the major source of France's grain supply.[45] Obviously, the large holdings gained the most from the tariff structures.

Clearly, two-thirds of French agricultural resources were organized around the small family farm and its polyculture cropping practices, at least until after the First World War. Polyculture farming represented a complex set of institutional arrangements.

---

[43] *Ibid.*, pp. 35-36, 121.

[44] *Ibid.*, p. 36.

[45] *Ibid.*

The interaction of the polyculture sector with the large-farm sector gave rise to another set of complex institutional arrangements. These institutional arrangements will be dealt with in detail in Chapter IV. For the purposes of this discussion, the institutional forces affecting agricultural productivity can be lumped together and referred to simply as polyculture, meaning by that the mixed cropping practices on small parcellized owner-occupied farms. This designation will facilitate an examination of data of the agricultural sector in view of the institutional forces of polyculture while deferring discussion of these forces to Chapter IV.

Even though the land resources devoted to livestock production increased continuously from 1870, there was no increase in the number of livestock units carried per unit of land. By 1915, Danish land supported threefold the number of livestock units and British land 65% more livestock units than French land. (See Tables 2-3, 2-4, and 2-5). In view of the increased availability of fodder, it is surprising to note in Figure 2-7 that workstock per male worker did not increase until after World War I. Since real

wages increased over 50% from 1870 to 1910,[46] increased horsedrawn mechanization might have been employed to reduce the pressure on the labor supply. The upper panel of Figure 2-13 shows that the machinery price-wage ratio decreased 30% from 1870 to 1910. Mechanization was cheapening relative to wage labor, but it was not increased.

Neither did the expanded availability of fodder increase the milk yield significantly. Between 1870 and 1935, British milk yield increased nearly 1,000 kilograms and the Danish yield increased over 2,000 kilograms. Table 2-5 shows that the French milk yield increased about 300 kilograms. These gross differentials in milk yields strongly indicate the vast difference between the scientific base of Danish farming and French farming. The large differences in wheat yields reinforces this indication. Danish wheat yields from 1870 to 1935 were at least twice French yields. British wheat yields from 1870 to 1915 averaged about 80% higher than French yields. Between 1870 and 1915, the French wheat yield increased only slightly.

The wide differentials in wheat yields in spite of the nearly identical level of fertilizer usage

---

[46] See the calculations in footnotes 2 and 8. Real wages used here refers to money wages divided by cost of wheat.

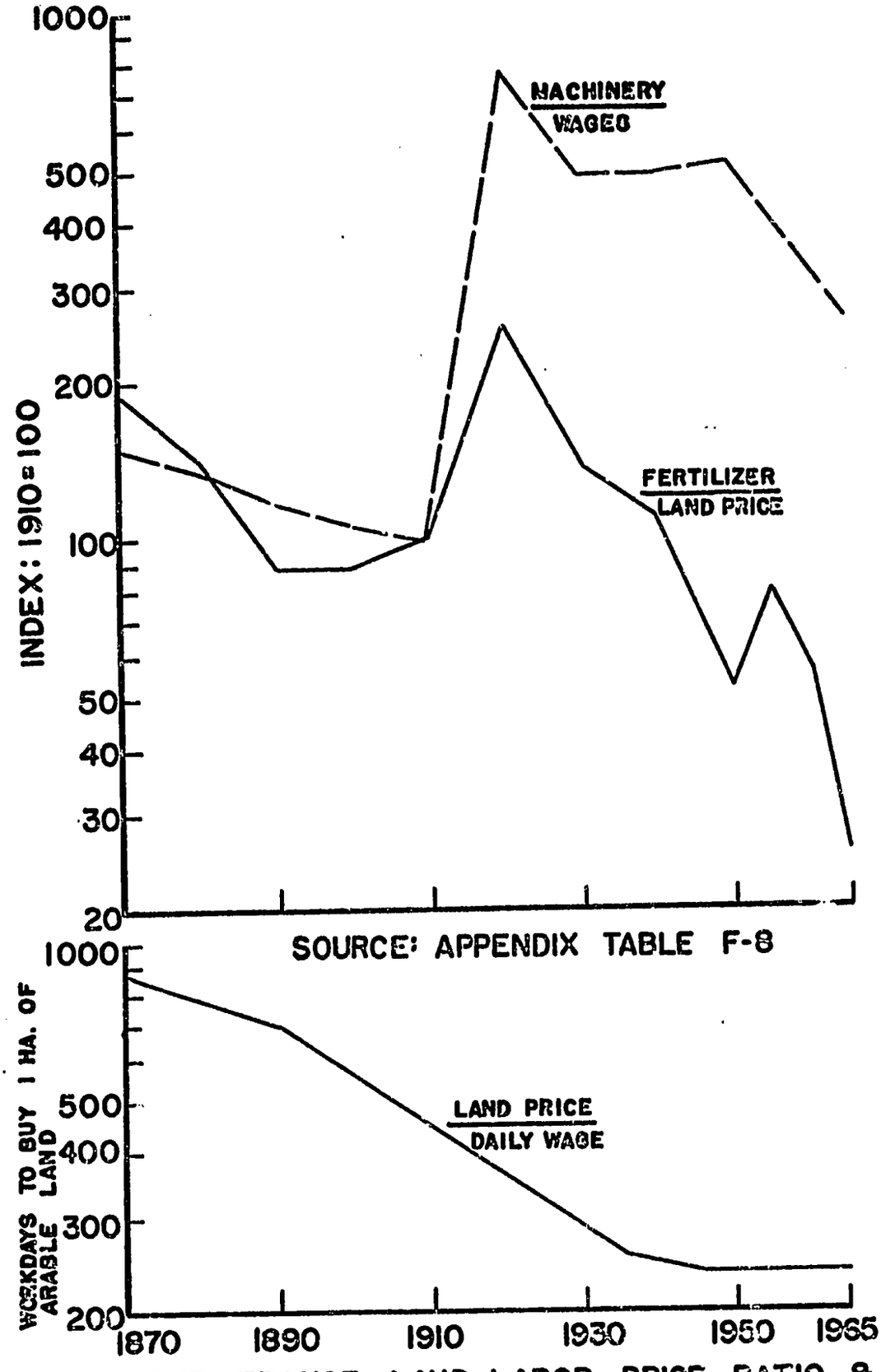


FIGURE 2-13: FRANCE: LAND-LABOR PRICE RATIO & INDEXES OF INPUT PRICE RATIOS

indicated in Figure 2-5 for 1910 confirms the vast difference in the productivity of cropping practices of French agriculture from those of both Danish and British agriculture. The French adoption of fertilizer, which the experience of the recent "Green Revolution" has shown to be the easiest technology to diffuse among peasant operators, was not accompanied by the "lumpy" but necessary complementary improvements in cropping practices and extension services. French output and the components of labor productivity continued to grow at rates of less than 1.0% annually until after World War II.

Figure 2-14 shows clearly that the French productivity take-off did not begin until after World War II. Thus, the early adoption of fertilizer did not produce any significant changes in productivity growth. It is hypothesized that there were no changes among the specific institutional arrangements of polyculture to facilitate more efficient agricultural production until after World War II.

The dramatic acceleration of productivity after World War II was intimately associated with the reconsolidation of land. The remembrement was not a new concept but after World War II was the first time agriculturalist responded to government attempts to

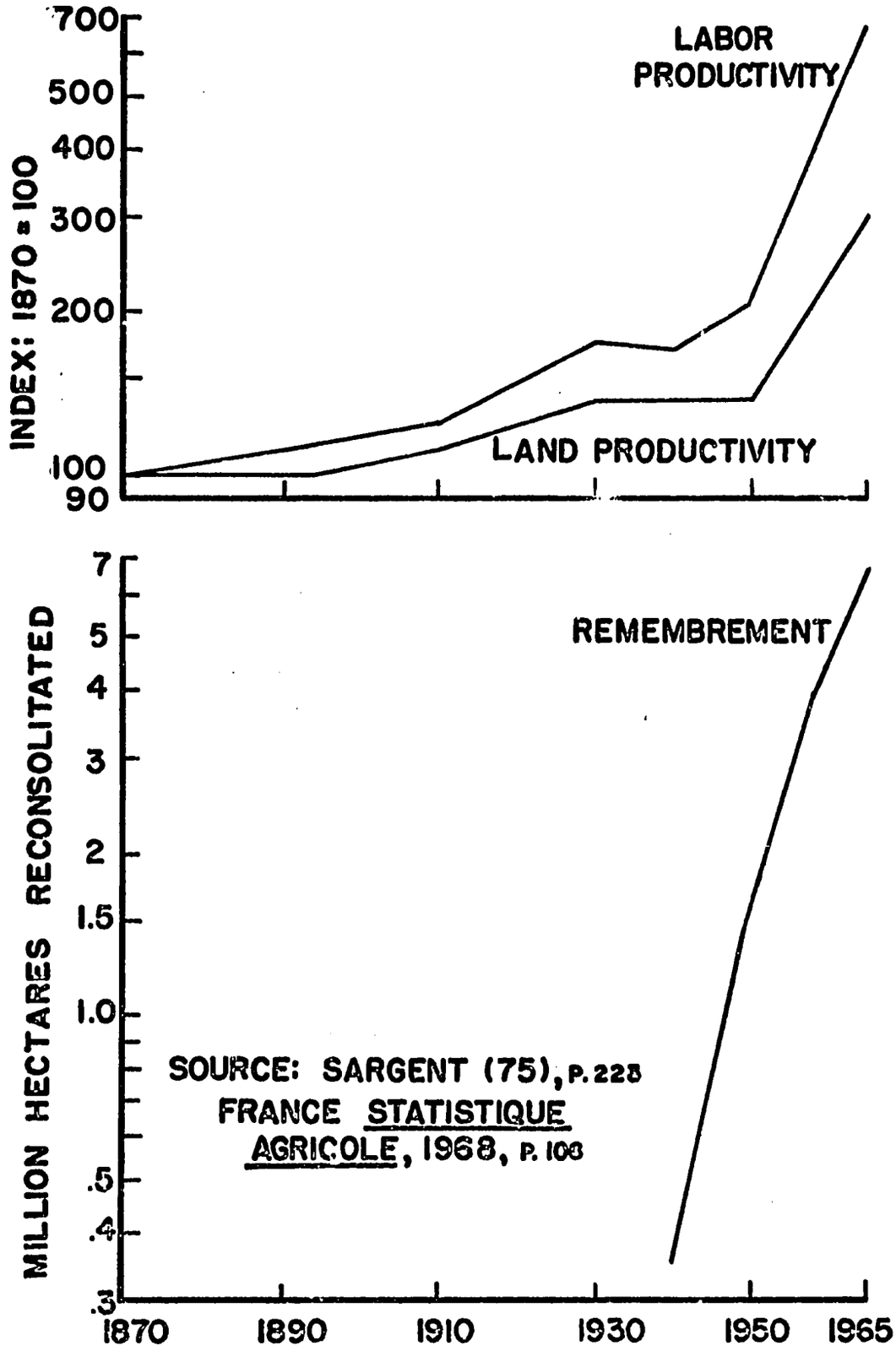


FIGURE 2-14: FRANCE: REMEMBREMENT AND PRODUCTIVITY

reconsolidate their holdings.[47] The acceptance of remembrement was a dramatic institutional innovation of property rights. Between 1945 and 1965, over six and one-half million hectares were affected by the remembrement.

The reconsolidation of land removed the bottlenecks to increased mechanization. More importantly, the remembrement was an indicator of a vast array of institutional modifications that took place in the agricultural sector after the war. Thus, institutional innovations as well as technological innovations were related directly to the acceleration in productivity indicated in Figure 2-14.

The statistical analysis of Chapter III will test the hypothesis that rapid productivity growth was institutionally constrained by polyculture practices until after World War II. The analysis will also test the hypothesis that the bias in technological innovation was labor saving.

Institutional Forces, Technological Change and Productivity Growth

A general pattern of productivity acceleration emerges in each of the three countries of this study.

---

[47] Sargent (95), p. 219.

Technological innovation in association with institutional innovation occurred in union with each country's period of productivity acceleration. This finding coincides with the general hypothesis of this dissertation that the proper functioning of the inducement mechanism is possible only if the institutional structure is flexible enough to new forces to permit necessary institutional innovations.

Denmark's productivity take-off in the 1880's was associated with the cooperative movement and the expansion of both biochemical and horsedrawn technology. Great Britain's productivity take-off after 1930 was associated with the new position of importance of the owner-occupier in the tenure structure as well as the adoption of price supports. So, too, the renewed application of fertilizer and, especially, the early adoption of tractor technology were important. France's productivity take-off after World War II was associated with the decline of polyculture practices indicated by the acceptance of the remembrement, as well as with the rapid adoption of tractor technology and the renewed application of fertilizer.

In each case, institutional innovations occurred in unison with new or increased profit opportunities. The cooperative dairy enabled Danish small farmers to

utilize successfully the cream separator. It also allowed them to internalize a larger share of the benefits than if private enterprise had organized the dairies. The French acceptance of remembrement, considered as an indicator of the desire of French farmers finally to modernize their agriculutral practices, accompanied government policies directed to correcting food shortages and eliminating imports. British tenure reforms, which began just after World War I under the aegis of high world prices and government guaranteed minimum prices, finally allowed the farmer class to internalize the gains of their entrepreneurial activities.

The association of institutional innovation with new or expanded profitable opportunities coincides with Schultz' and North and Thomas' view that institutional innovation occurs because it becomes profitable for individuals[48] or groups in society to undertake the cost of a new institutional arrangement. However, the great difference in the timing of the productivity increasing institutional and technological innovations between the three countries illustrates that new or expanded profitable opportunities are only a necessary

---

[48]See Chapter I.

condition, not a sufficient condition, for changing specific institutions to allow internalization of the profit.

Surely, the profitable opportunity in dairy and livestock farming captured by the Danish after 1880 was equally available to the British. After all, the bulk of Danish exports were going to London markets by 1900. Similarly, it is difficult to argue that French agriculture was condemned to the low productivity techniques of polyculture until after World War II because there was no profit incentive to undertake the cost of a new institutional arrangement before that time.

Thus, returning to the argument of Chapter I, sufficient conditions for institutional innovation may be said to be a flexible institutional structure. As before, the institutional structure is considered to reflect the internal value system of the society and, thus, have an effect on the behavior patterns of persons in the society. Specific institutions are arrangements designated to govern specific activities in the society. For a given society, for instance, French rural society, the internal value system may place a higher valuation on some specific institutional arrangement than would the market place. In this case,

the new profitable opportunity may go unperceived or not acted upon for an unspecified time period. This action would describe a rigid institutional structure. The length of time of the time lag may be considered an indication of the degree of rigidity within the institutional structure. A flexible institutional structure would allow a relatively smooth transformation of existing institutional arrangements to new arrangements to internalize the new opportunities.

Denmark, which reacted remarkably to the changing economic forces affecting agricultural product supply and demand in the last quarter of the 19th century must be considered to have had a flexible institutional structure. As a result, productivity growth has been almost uninterrupted to the present day. In this respect, Denmark's productivity growth pattern has been similar to that of Japan and the United States. Great Britain and France must be considered to have had rigid institutional structures of differing degrees of rigidity.

Since most countries of the world have not experienced rapid productivity growth, Chapter IV will examine the French case in an attempt to discover how rigid institutional structures constrain the development of agriculture.

CHAPTER III

ESTIMATING THE PARAMETERS OF NON-NEUTRAL INDUCED INNOVATION

Introduction

The process of agricultural development has been considered in Chapters I and II to result primarily from location specific technological innovation in association with institutional innovation. The development of technology has been considered to be an endogenous process dependent on conditions prevailing within the economy. The endogeneity of this process has been considered from the Hicks-Ahmad point of view that factor scarcities are considered to be expressed in terms of relative factor prices. Forthcoming technology is considered to be biased to relieve the constraint of the less elastic factor of production.

Institutional innovation has been considered part of the process of agricultural development because, clearly, necessary institutions to support the development and/or diffusion of new technology do not always

exist in an economy. The speed with which new institutional arrangements are developed to foster technological advancement and allow productivity growth has been considered an important element of the development process.

In this chapter the data of the three European countries are subjected to statistical testing to determine if, if fact, productivity growth in their cases has been associated with endogenous biases signalled by relative factor prices. The estimation procedures allow direct measures of the extent of biases induced by relative factor prices. The estimation procedures are designed to allow tests of hypotheses concerning the relative magnitude of the biases. The various hypotheses suggested by the survey of the historical data in Chapter II are tested in this chapter.

Two statistical formulations of the induced innovation hypothesis are estimated to allow a comparison of the results.

The estimated formulations do not allow a direct measure of the extent of institutional interaction within the inducement model of agricultural development. To allow an argument by inference, the French and British data are estimated over two time periods to conform to their historical periods of sluggish and

then accelerating productivity growth. The desired goal of this procedure is to infer that the inducement process is more complex than can be concluded from the usual version of Hicks-Ahmad induced innovation hypothesis.

Technological innovation is induced not simply as a one-step process directly in response to relative factor prices. It occurs in conjunction with a range of necessary institutional innovations that facilitate either the development and/or adoption of the biased technology. Technological innovation is, thus, best understood as a two-step process involving the effect of both relative factor prices and the effect of enabling institutional changes.

Estimating Non-Neutral Technical Change in a CES Production Function

Consider the CES Production Function

$$Q_t = (a\ A_t^{-p} + b\ L_t^{-p})^{-1/p} \qquad (1)$$

with appropriately shaped first and second derivatives where Q, A and L represent agricultural output, agricultural land area, and agricultural labor, respectively. a and b are referred to as the distribution parameters and p is the substitution parameter. The most common assumption about the nature of technical change is that

it operates as a smooth trend affecting average and marginal productivities in the same way so that the function takes the form

$$Q_t = (a\ A_t^{-p} + b\ L_t^{-p})^{-1/p}\ e^{\gamma t} \qquad (2)$$

where t stands for the time and γ is the parameter for the rate of neutral efficiency growth over time. Since equation (2) is assumed linear and homogeneous it can be transformed to indicate specifically that it implies equal land and labor-augmenting technical change.[1]

$$Q_t = [a(A_t e^{\gamma t})^{-p} + b\ (L_t e^{\gamma t})^{-p}]^{-1/p} \qquad (3)$$

Here $e^{\gamma t}$ is specified to be the coefficient of neutral factor augmentation. Factor augmentation is assumed constant over time at the rate γ in this model.

$$\frac{\partial e^{\gamma t}}{\partial t} = e^{\gamma t}\gamma$$

and

$$\frac{1}{e^{\gamma t}}\ \frac{\partial e^{\gamma t}}{\partial t} = \gamma \qquad (4)$$

To observe the effects of non-neutral technical change Kotowitz[2] respecified equation (3) in the form:

---

[1]Allen (2), p. 230.

[2]Kotowitz (28), p. 432.

$$Q_t = [a\ (A_t e^{\delta t})^{-p} + b\ (L_t e^{\lambda t})^{-p}]^{-1/p} \quad (5)$$

where δ and λ are rates of factor augmentation over time such that if δ and λ are equal and different from zero, then technological change is Hicks neutral[3] as in equation (3). The coefficients $e^{\delta t}$ and $e^{\lambda t}$, represent the levels of efficiency growth of the inputs of land and labor such that if $\lambda > \delta$ and the elasticity of substitution is less than unity, labor is augmented faster than land and the effect is labor saving. The rates of augmentation are still assumed constant at δ and λ according to (5).

There are certain weaknesses to Kotowitz's approach. (1) The model does not identify the sources of efficiency growth. The size of the parameter λ, identified as the rate of labor efficiency growth, may be the cooperative consequence of measures directed at increasing human capital or land efficiency; (2) neither does the model distinguish between induced or autonomous technical change; (3) furthermore, as Yeung and Roe indicated, the rates of factor augmentation are assumed to be fixed over time while there is no

---

[3]This technique closely follows a model formulated by David and Klundert (8).

a priori reason why this should be true.[4]

Yeung and Roe suggest that a direct test of the Hicks-Ahmad version of the induced innovation hypothesis could be achieved by replacing t in equation (5) with an index of the relative factor prices. By way of this substitution, a test of the hypothesis that $\delta = \lambda$ is a test for non-neutral technical change induced by factor prices.

The Model: assuming perfect competition and linear homogeneity, equation (5) can be specified according to Yeung and Roe's hypothesis:

$$Q_t = [a\ (A_t e^{\delta I_t})^{-p} + b\ (L_t e^{\lambda I_t})^{-p}]^{-1/p} \qquad (6)$$

where I_t is the index of relative factor prices of labor and land.

$$I_t = (W/R)_t / (W/R)_o \qquad (7)$$

In this model, factor augmentation explicitly is assumed to be induced by changes in I_t and varies as I_t varies. Thus,

$$\frac{\partial e^{\lambda I_t}}{\partial t} = e^{\lambda I_t} \lambda \frac{\partial I_t}{\partial t}$$

---

[4]Yeung and Roe (47), p. 5.

and

$$\frac{1}{e^{\lambda I_t}} \quad \frac{\partial e^{\lambda I_t}}{\partial t} = \lambda \frac{\partial I_t}{\partial t} \tag{8}$$

so that if I_t does not change in time, the rate of factor augmentation, in this case labor augmentation, is zero.

Other than the explicit assumption that augmentation is induced by, and varies with, I_t, equation (6) is interpreted just as Kotowitz's model. If δ and λ are equal and different from zero, then technical change is neutral. If δ exceeds λ and the elasticity of substitution is less than unity, factor augmentation has favored land efficiency growth and is land saving. Conversely, if λ exceeds δ and the elasticity of substitution is less than unity, factor augmentation has been biased to labor efficiency growth and is labor saving. Although the factor augmentation parameters, δ and λ, are still considered constant, the rates of factor augmentation are allowed to vary with I_t.

Even with the explicit hypothesis in the model that factor augmentation is induced by I_t, there remains the empirical problem of identifying such components of indicated augmentation as the complementary effects of the efficiency growth of one factor on another. Yield increasing measures induced to increase

land efficiency will also be reflected in the estimated augmentation parameter of labor.

Binswanger's recent empirical research on the induced innovation hypothesis[5] has suggested a method to take into account the change in total factor quality over time.

Binswanger pointed out that factor efficiency growth is actually a broadly-defined phenomenon. The measurable factor augmentation and hence the biases and rate of technical change result from improvements in factor quality from many sources such as technical change narrowly defined but also autonomous improvements in the factor. The marginal products of both factors of production in equation (6) may rise. It is of primary interest to be able to sort out the characteristic bias of innovation, if there is bias, from those sources of technical change broadly defined.

The model of equation (6) can be respecified to consider Binswanger's delineation of the components of measured factor augmentation.

$$Q_t = e^{\gamma t} \left[a \left(A_t e^{\delta I_t}\right)^{-p} + b \left(L_t e^{\lambda I_t}\right)^{-p} \right]^{-1/p} \tag{9}$$

---

[5]Binswanger (4), p. 23.

where the coefficient $e^{\gamma t}$ will be considered a measure of the rate of the component of neutral factor improvement and $e^{\delta I_t}$ and $e^{\lambda I_t}$ will be considered, as before, non-neutral factor augmentation coefficients that reflect biased induced innovation.

As was done in equation (3), $e^{\gamma t}$ can be multiplied through (9) to show distinctly that factor augmentation contains a neutral element of improvement as well as, possibly, a biased and induced element

$$Q_t = [a\ (A_t e^{\gamma t + \delta I_t})^{-p} + b\ (L_t e^{\gamma t + \lambda I_t})^{-p}]^{-p} \tag{10}$$

In this case

$$\frac{\partial e^{\gamma t + \lambda I_t}}{\partial t} = e^{\gamma t + \lambda I_t}\ (\gamma + \lambda \frac{\partial I}{\partial t})$$

and

$$\frac{1}{e^{\gamma t + \lambda I_t}}\ \frac{\partial e^{\gamma t + \lambda I_t}}{\partial t} = \gamma + \lambda\ \frac{\partial I_t}{\partial t} \tag{11}$$

If I_t does not change over time, the rate of factor augmentation, in this case labor, due to biased innovation is zero and measured augmentation is constant at the rate γ. Furthermore, if $\frac{\partial I_t}{\partial t}$ is less than zero, the bias of technical change affecting labor can be viewed as having had a retardative effect. Since I_t is the index of relative factor prices of

labor and land (W/R), if I_t decreases, which implies that labor is growing relatively less costly than land, the parameter governing labor augmentation, λ, would be expected to be negative while that of land augmentation, δ, would be expected to be positive.

<u>Estimable Equations</u>: Assuming that the factors of land and labor are paid according to their marginal productivities, the marginal products of (9) may be set equal to their real factor prices.[6]

$$w = b(Q/L)^{1+p} e^{-\lambda pI} e^{-\gamma pt} \tag{12}$$

$$r = a(Q/A)^{1+p} e^{-\delta pI} e^{-\gamma pt} \tag{13}$$

---

[6]These marginal products can be derived as follows:

$$Q_t = e^{\gamma t} [a(A_t e^{\delta I_t})^{-p} + b(L_t e^{\lambda I_t})^{-p}]^{-1/p} \tag{A}$$

$$\frac{\partial Q}{\partial A} = \frac{e^{\gamma t}[X + Y]^{-1-1/p} a e^{-\delta I_p}}{A^{1+p}} \tag{B}$$

where

$X = a(A_t e^{\delta I_t})^{-p}$ and $Y = b(L_t e^{\lambda I_t})^{-p}$.

If (B) is multiplied and divided by $e^{p\gamma t}$, then

$$\frac{\partial Q}{\partial A} = \frac{e^{\gamma t + p\gamma t} [X + Y]^{-1-1/p} a e^{-\delta I_p}}{e^{p\gamma t} A^{1+p}} \tag{C}$$

but

labor and land (W/R), if I_t decreases, which implies that labor is growing relatively less costly than land, the parameter governing labor augmentation, λ, would be expected to be negative while that of land augmentation, δ, would be expected to be positive.

<u>Estimable Equations</u>: Assuming that the factors of land and labor are paid according to their marginal productivities, the marginal products of (9) may be set equal to their real factor prices.[6]

$$w = b(Q/L)^{1+p} e^{-\lambda pI} e^{-\gamma pt} \tag{12}$$

$$r = a(Q/A)^{1+p} e^{-\delta pI} e^{-\gamma pt} \tag{13}$$

---

[6]These marginal products can be derived as follows:

$$Q_t = e^{\gamma t} [a(A_t e^{\delta I_t})^{-p} + b(L_t e^{\lambda I_t})^{-p}]^{-1/p} \tag{A}$$

$$\frac{\partial Q}{\partial A} = \frac{e^{\gamma t}[X + Y]^{-1-1/p} a e^{-\delta I_p}}{A^{1+p}} \tag{B}$$

where

$X = a(A_t e^{\delta I_t})^{-p}$ and $Y = b(L_t e^{\lambda I_t})^{-p}$.

If (B) is multiplied and divided by $e^{p\gamma t}$, then

$$\frac{\partial Q}{\partial A} = \frac{e^{\gamma t + p\gamma t} [X + Y]^{-1-1/p} a e^{-\delta I_p}}{e^{p\gamma t} A^{1+p}} \tag{C}$$

but

Dividing (12) by (13) shows that the Rate of Technical Substitution is equal to the factor price ratio and shows that the neutral component of efficiency growth drops out since it increases each marginal product equally.

$$w/r = b/a \ (A/L)^{1+p} \ e^{-(\lambda - \delta)pI} \qquad (14)$$

Taking the natural logarithms of equation (14) and rearranging terms,

$$\ln(A/L) = - (1/1+p) \ln b/a + (1/1+p) \ln (w/r) - \frac{(\lambda - \delta)p}{1+p} I \qquad (15)$$

$$Q^{1+p} = [e^{\gamma t} [X + Y]^{-1/p}]^{1+p} \qquad (D)$$

so

$$Q^{1+p} = e^{\gamma t + p\gamma t} [X + Y]^{-1-1/p} \qquad (E)$$

and expression (E) is contained in (C), so

$$\frac{\partial Q}{\partial A} = \frac{Q^{1+p} \ a \ e^{-\delta I p}}{e^{p\gamma t} \ A^{1+p}} \qquad (F)$$

or, rearranging terms and setting equal to r,

$$r = a(Q/A)^{1+p} \ e^{-\delta I p} \ e^{-p\gamma t} \qquad (G)$$

Yeung and Roe suggested that from equation (15) the elasticity of substitution along the meta production function could be derived.[7]

$$\sigma = \frac{d \ln(A/L)}{d \ln(w/r)} = 1/1+p + \frac{(\lambda - \delta)p}{1+p} I_t = 1/1+p \ (1 + (\lambda - \delta)p \ I_t) \qquad (16)$$

Yeung and Roe showed that the elasticity of substitution along the meta production function is dynamic and changes with I_t. Equation (16) essentially shows how the static elasticity of substitution, 1/1+p, is changed over time by factor augmentation induced by I_t. If there is no non-neutral augmentation, the term, $(\lambda - \delta)$, approaches zero and the elasticity of substitution approaches the constant elasticity value.

Equation (15) theoretically offers a direct test of the bias in the direction of induced innovation. The coefficients of ln(w/r) and I_t can be estimated and solved for p and $-(\lambda - \delta)$, such that if $p > 0$ then if $-(\lambda - \delta)$ is positive, then δ exceeds λ. However, two problems preclude this procedure: (1) I_t is the index of (w/r) so that high multicolinearity exists

---

[7]Yeung and Roe (47), p. 7, imposed the condition that $(\lambda - \delta)$ be expressed in absolute terms, $|(\lambda - \delta)|$. It is not reasonable to expect the adjustment factor to be negative if δ exceeds λ. The adjustment to the static elasticity of substitution is positive regardless of the direction of the bias to innovation.

between $\ln(w/r)$ and I_t; (2) equation (15) does not allow an estimate of γ which is considered to be the estimator of the components of neutral factor improvement. Therefore, equation (15) would result in a misestimate of the true value of $(\lambda - \delta)$.

The estimation of the desired parameters of (10) is best achieved by taking the neutral logarithms of (12) and (13) and rearranging terms.

$$\ln(Q/A) = -(1/1+p)\ \mathrm{Ln}\ a + (1/1+p)\mathrm{Ln}\ r + \delta p/1+p\ I + \gamma p/1+p\ t \tag{17}$$

$$\ln(Q/L) = -(1/1+p)\ \mathrm{Ln}\ b + (1/1+p)\mathrm{Ln}\ w + \lambda p/1+p\ I + \gamma p/1+p\ t \tag{18}$$

Equations (17) and (18) can be estimated and solved for the parameters of interest p, γ, ∂, and λ. The size of 1/1+p, the elasticity of substitution, is an important determinant of the factor-saving bias of technical change. If 1/1+p exceeds unity and λ is greater than δ, technical change is land saving. If 1/1+p is less than unity, and λ exceeds δ, technical change is labor saving.[8]

The estimation of the elasticity of substitution

---

[8]David and Klundert (8) provide a useful discussion of this point, pp. 362-63.

also allows the model to sort out the proportion of observed factor productivity change due to ordinary factor substitution from that due to biased innovation. To show how equations (17) and (18) account for ordinary factor substitution, observe first that equation (14), which is the Rate of Technical Substitution (RTS), can be simplified for discussion purposes by dropping its augmentation coefficient, $e^{-1(\lambda - \delta)pI}$. This procedure is only for the sake of simplifying the RTS expression. Thus,

$$(w/r) = b/a \ (A/L)^{1+p} \qquad \text{(A)}$$

is the usual form of the CES production function RTS. But

$$1+p = 1/\sigma \qquad \text{(B)}$$

So,

$$(w/r) = b/a \ (A/L)^{1/\sigma} \qquad \text{(C)}$$

which shows that the elasticity of substitution is directly involved in the expression of the RTS. Furthermore, (C) can be rearranged so that

$$A/L = (a/b)^{\sigma} \ (w/r)^{\sigma} \qquad \text{(D)}$$

to show that the constant elasticity of substitution is also the constant elasticity of the factor use ratio with respect to the factor price ratio. Expression (D) shows that the land-labor ratio is a power function of the wage-rent ratio and shows that

the factor-use ratio changes with the factor-price ratio according to the size of σ. Thus, in equations (17) and (18), the elasticity of substitution estimated from the changes in the factor prices shows how much of the change in the factor shares is accounted for as ordinary factor substitution. Furthermore, equation (14) shows that the augmentation coefficient $e^{-(\lambda-\delta)pI}$ accounts for that part of the change in factor shares explained by biased innovation.

<u>Statistical Model</u>. Equations (17) and (18) can be estimated according to Yeung and Roe's specification. Since the coefficient 1/1+p is common to both variables ln r + ln w, and γp/1+p is common to t in both equations, these equations can be combined to yield the following estimating equation.

$$Q = X\,B + e$$

where (19)

$$Q=\begin{bmatrix} \ln(Q/A)_{to} \\ \vdots \\ \ln(Q/A)_{tn} \\ 1\ (Q/L)_{to} \\ \vdots \\ \ln(Q/L)_{tn} \end{bmatrix} \quad X=\begin{bmatrix} 1 & 0 & \ln R_{to} & I_{to} & 0 & to \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & \ln R_{tn} & I_{tn} & 0 & tn \\ 0 & 1 & \ln W_{to} & 0 & I_{to} & to \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & \ln W_{tn} & 0 & I_{tn} & tn \end{bmatrix} \quad B=\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \end{bmatrix} = \begin{bmatrix} -1/1+p\ \ln a \\ -1/1+p\ \ln b \\ 1/1+p \\ \delta p/1+p \\ \lambda p/1+p \\ \gamma p/1+p \end{bmatrix}$$

and e is a 2 N X 1 vector of disturbances which are assumed to be randomly, log normally and independently distributed with a zero mean and a constant variance; that is:

$$E(e_i) = 0$$
$$E(e_i^2) = \sigma^2$$
$$E(e_i e_j) = 0 \text{ for } i \neq j$$

This formulation provides a restricted estimation of (1/1+p) and (γp/1+p) by ordinary least squares and therefore the derivation of unique estimates for equation (10).

The test for induced biased innovation is a test of the null hypothesis that B_4 is not different from B_5. This test is permissible because the sample moments distributed in the coefficients B_4 and B_5 are identical except for δ and λ . Therefore, this test allows an inference about δ and λ .

The test of B_4 is equal to B_5 is predicted on a prior test of the null hypothesis that B_3 is equal to one. The alternative hypothesis is that B_3 is not equal to one. If B_3 is equal to unity that implies p is equal to zero. In this case, B_4, B_5 and B_6 may not be solved for δ, λ and γ . Since p appears in the numerator, these coefficients go to zero.

Furthermore, since B_3 is the estimator of the elasticity of substitution, values of B_3 less than zero are inadmissable. Therefore, values of p less than -1 are inadmissable.

γ is the estimated parameter describing neutral factor improvement. Including the variable t in the model theoretically allows the claim that the estimates of δ and λ are more narrowly defined measures of the direction of bias in factor-efficiency growth. A test for the coefficient of t, B_6, is equal to zero is a test for overall factor-quality improvement. If the hypothesis is rejected, the conclusion is that factors have benefitted either (1) mutually from measures directed to improving one factor's efficiency; or (2) from measures directed to improving total factor efficiency. If the null hypothesis is rejected, this allows the inference that since γ accounts for total changes in factor quality, δ and λ specify more narrowly the direction of the biased innovation.

The statistical model, equation (19), is estimated twice--with and without the time variable. This enables a comparison of the changes to δ and λ caused by including the estimator containing the parameter in the model.

In the tabularized statistical results, which

will be discussed below, model I identifies the estimation without time. Model II identifies that with t.

Estimating the Effect of Institutional Effects on the Inducement Mechanism

The hypothesis of this dissertation is that there are institutional effects that impinge on the inducement mechanism and affect the ability to achieve rapid productivity growth. As a first step to investigate this hypothesis, no specific interaction mechanism will be hypothesized between institutional and technological innovation. The analysis will seek initial support for the hypothesis by searching for different statistical values attached to the measures of biases during the alternate periods of productivity sluggishness and acceleration.

Among the three countries, Chapter II described Denmark as having had rapid productivity growth over most of the period of analysis. Great Britain's productivity was described as stagnant until after 1925 and France's productivity was described as showing only sluggish growth until after World War II. In each case of productivity acceleration, institutional innovation was associated with the time of acceleration. Basically, it is hypothesized that when necessary, institutions are created to facilitate internalizing

some new profitable opportunity, the incentive to produce factor saving technology is enhanced.

In the Danish case where there has been rapid and accelerating productivity growth over nearly the entire period, it is hypothesized that there will be statistical evidence of either neutral or biased factor saving technological innovation. Chapter II suggested that the Danish technology of livestock production appears to have been labor using while that of crop production has been labor saving. Therefore, the measured biases may be found to be offsetting.

In the British and French cases where each had a period of no or little growth followed by a period of rapid growth, two cases are hypothesized as possible explanations of how institutional constraints impeded technological innovation and productivity growth.

Case 1: During the period of static productivity there were definite biases. Still, there was no productivity growth. This suggests that institutions constrained action to adopt the needed technology to offset the limiting factor of production. During the period of accelerating productivity, the indicated bias may or may not change. The bias measured over this period may reflect changing price relationships as purchased inputs are substituted to offset the

limiting factor. No a priori statement can be made.

Case 2: During the period of static productivity there was no definite bias. This may suggest that there was no economic pressure to innovate productivity-increasing new technology. Alternatively, it may suggest that the institutional constraints directly affected and distorted the factor price relationships to cloud the need for technological innovation and, thus, preserve the status quo. During the period of accelerating productivity, biases become dramatically apparent. As the institutional constraints are eased, the distortions to the inducement mechanism are removed. Technological innovation is induced and productivity growth accelerates. Under either case, the neutral component of augmentation, $e^{\gamma t}$, may or may not be positive. Slow neutral growth would allow γ to be positive.

Statistical Model: Equations (17) and (18) are modified to consider the differing periods of productivity sluggishness and growth for the cases of France and Great Britain. British data are estimated from 1870 to 1925 and from 1925 to 1965. French data are estimated from 1870 to 1935 and from 1940 to 1965.

The matrices of equation (19) are modified in

the following manner to provide the desired estimators,

$$Q=\begin{bmatrix} \ln(Q/A)_{to} \\ \vdots \\ \ln(Q/A)_{tn} \\ \ln(Q/L)_{to} \\ \vdots \\ \ln(Q/L)_{tn} \end{bmatrix} \quad X=\begin{bmatrix} 1 & 0 & \ln r_{to} & I_{to} & 0 & 0 & 0 & to & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & I_{tm} & 0 & \vdots & \vdots & tm & 0 \\ \vdots & \vdots & \vdots & 0 & I_{tm+1} & \vdots & \vdots & 0 & t_{m+1} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & \ln r_{tn} & 0 & I_{tn} & 0 & 0 & 0 & tn \\ 0 & 1 & \ln w_{to} & 0 & 0 & I_{to} & 0 & to & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \\ \vdots & \vdots & \vdots & \vdots & \vdots & I_{tm} & 0 & tm & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & 0 & I_{tm+1} & 0 & tm+1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & \ln w_{tn} & 0 & 0 & 0 & I_{tn} & \cdot & tn \end{bmatrix}$$

$$B=\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_{41} \\ b_{42} \end{bmatrix} = \begin{bmatrix} -1/1+p \ \ln a \\ -1/1+p \ \ln b \\ 1/1+p \\ \delta_1 p/1+p \\ \delta_2 p/1+p \end{bmatrix} \qquad \begin{bmatrix} b_{51} \\ b_{52} \\ b_{61} \\ b_{62} \end{bmatrix} = \begin{bmatrix} \lambda_1 \ p/1+p \\ \lambda_2 \ p/1+p \\ \gamma_1 \ p/1+p \\ \gamma_2 \ p/1+p \end{bmatrix}$$

$$Q = X\,B + e \tag{20}$$

and e is, as before, a 2 N X 1 vector of disturbances with the same assumptions.

There is no theoretical reason why 1/1+p, the elasticity of substitution, should be expected to remain constant over time while augmentation rates are allowed to change. There is, however, analytical

appeal to this procedure. If p is assumed constant, differences between the estimated coefficients may be weakly attributed to institutional changes affecting the augmentation rates. Furthermore, changes in the elasticity of substitution can be calculated from the dynamic elasticity of substitution of equation (16). Structural shifts in λ and δ as well as changes in I_t may be allowed to change the static estimate of the elasticity of substitution.

This formulation allows direct hypothesis testing within and between periods. As before, any hypothesis tests about B_4, B_5 or B_6 are predicated on the prior test of the null hypothesis that B_3 is equal to one. Furthermore, values of B_3 less than zero are inadmissable and preclude further testing.

The interesting null hypotheses are these:

(1) $B_{41} = B_{51}$

(2) $B_{42} = B_{52}$

(3) $B_{41} = B_{42}$

(4) $B_{51} = B_{52}$

(5) $B_{61} = B_{62}$.

Null hypotheses (1) and (2) allow inferences about the direction of bias within each period. Null hypotheses

(3), (4) and (5) allow inferences about changes in the biases between periods.

More specifically, rejection of null hypotheses (1) and (2) is interpreted as indicated in the preceding section. A rejection of null hypothesis (5) will suggest that a shift in the nature of the elements affecting overall factor quality improvement has occurred between the two time periods.

In searching for an indication that there were definite biases which were not acted upon during the first period, the statistical analysis will focus on null hypothesis (1). This is case one above.

In searching for an indication that the institutional constraint distorted factor price relationships, the statistical analysis will be interested in null hypotheses (4) and (5) with the expectation that $B_{41} = B_{51} = 0$. Furthermore, the expected signs of δ and λ will be compared with the direction of change of I_t to see if the factor augmentation coefficients correctly reflect the direction of change or if, in fact, the coefficients reflect some unknown distortion.

The interpretation of the statistical results concerning the interesting null hypotheses allow no more than weak support for the effect of institutions on the inducement mechanism.

In the tabularized statistical results, which will be discussed below, Model III identifies the estimation procedure over separate time periods for France and Great Britain.

Estimating Non-Neutral Technical Change in the Hayami-Ruttan Framework

Hayami and Ruttan's log-linear factor-demand type equations also are estimated over the data.[9] It is thought that a comparison of the results from these estimated equations with those derived from the CES production function will be useful.

The Hayami-Ruttan test for induced innovation considers the case of more than two factors; namely, land, labor, biochemical land substitutes and mechanical labor substitutes. The test assumes that at a particular moment in time, the elasticity of substitution among factors is small. Therefore, if overtime production points are observed with widely differing factor ratios, which are inconsistent with the assumption of a small elasticity of substitution, then technical change must have been non-neutral.

If, in addition, the factor ratios are observed to move in the direction of the scarce factor, then

---

[9]Hayami and Ruttan (19), p. 128, following.

this indicates both the non-neutrality of technical change and the influence of the factor prices on the direction of technical change.

Estimated Equations. Hayami and Ruttan required only that the underlying metaproduction function be normally shaped. By assuming the production function to be linear and homogeneous, they were able to predicate that the factor proportions can be expressed in terms of factor prices alone. The estimated regressions were specified in log-linear form.

The estimated equations in this section essentially show the relationship between the use of purchased land or man substitutes and the prices of the substitutes relative to land prices and wages. The exact relationships estimated and the expected sign of the coefficients are displayed in Table 2-2 of Chapter II.

The estimated equations are all of the following type:

$$\ln(A/L)_t = B_0 + B_1 \ln (R/W)_t + B_2 \ln ({}^{M}p/W)_t + e \qquad (21)$$

where

A = Agricultural land

L = Male labor

R = Land prices or rent

W = Wages

and e is the disturbance term assumed to be randomly, log normally and independently distributed with a zero mean and constant variance.

To enable a test for structural shifts between time periods, and for comparison with the results from Model III, these demand type equations for France and Great Britain were estimated over different time periods as well as over the whole time period.

The tabularized statistical results are discussed below.

Econometric Problems of Estimation

Models I and II for Denmark and I, II and III for France and Great Britain as well as the Hayami-Ruttan log-linear demand type equations are estimated by ordinary least squares procedures. The data of Table 3-1 and from Appendices B, D, and F arranged in quinquennial observations are employed. Observations on land and labor are measured at five-year intervals (or closest years) beginning with 1870. Prices of land, labor, fertilizer, concentrated feeds and farm machinery are measured, where data permit, as the average of five years centered on the recorded date. Data of output are averages of non-uniform periods about the recorded date. Purchased inputs, fertilizer, concentrated feeds and horsepower, are measured as the

TABLE 3-1 : INDEXES OF RELATIVE FACTOR PRICES OF LABOR AND LAND

	$I_t = (W/R)_t / (W/R)_o$, 1870 = 100		
	Denmark	France	Great Britain
1870	100.0	100.0	100.0
75	95.2	101.3	90.7
80	92.3	94.1	108.9
85	100.4	91.0	123.0
90	103.2	104.3	124.7
95	120.6	119.9	138.7
1900	142.1	124.0	142.0
05	140.1	133.1	145.4
10	140.3	137.9	149.3
15	125.1	185.2	163.1
20	132.0	295.5	349.4
25	145.1	267.3	243.2
30	147.5	275.2	285.5
35	162.4	287.0	243.2
40	189.2	463.0	285.0
45	256.6	310.1	472.1
50	279.6	279.0	588.5
55	298.3	461.6	520.1
66	215.4	439.0	551.0
65	305.4	308.9	509.7

Source: Appendix Tables B-4, D-4, F-4.

average of five years centered on the recorded date, where data permit.

The derivation of the data and its limitations are discussed in the footnotes of the appendix materials.

The ordinary least squares (OLS) estimators of the coefficients of equations (17) and (18) in Models I, II, and III are found to have a serious shortcoming in their statistical properties. While the estimators are unbiased, they are not efficient estimators. The assumption that $E(e_i e_j) = 0$ is not met.

The implications of non-efficient estimates is that tests of hypotheses give biased results even though the coefficient estimators are unbiased.[10] Since much of the analysis of this chapter depends on the outcome of many tests of hypotheses, equations (17) and (18) in Models I, II and III are re-estimated within the framework of the generalized least squares (GLS) regression model. The OLS results are not presented in the tables of this chapter.

The assumptions under GLS change. The model and its assumptions may be described as:

(1) $Y = XB + e$

---

[10] Kmenta (27), p. 520.

(2) The joint distribution of $e_1, e_2 \ldots e_n$ is multivariate normal

(3) $E(e_i) = 0$

(4) $E(e_i e_i) = \sigma^2_{ii}$

(5) $E(e_i e_j) = \sigma^2_{ij}$

Assumptions (4) and (5) essentially distinguish GLS from OLS. By way of the properties of the estimation procedures that stem from these assumptions, GLS estimation takes account of the covariance disturbance to yield BLUE estimators.

The problem with the OLS estimators is that the residual terms of the two equations estimated within the system of two equations are correlated with each other. Table 3-2 shows that the correlations are extremely high in some instances. One solution to this problem is called a two-stage Aitken estimator.[11]

The two-stage Aitken estimation procedure first calculates the OLS estimates for each equation separately. Then it uses the resulting residuals to estimate the variances and covariances of the disturbances. In the second stage, the computer program takes account of the calculated mutual relatedness of

---

[11] Kmenta (27) discusses the problem in detail and indicates the literature in Chapter 12. See especially p. 524 following.

Table 3-2: Residual Correlation of OLS Estimated Statistical Models[1]

	Denmark	France	United Kingdom
Model I	.927	.960	.791
Model II	.625	.998	.539
Model III	--	.911	.470

[1]It can be shown that when the disturbance in one regression under consideration is mutually correlated with the disturbance term in some other regression then the estimated variances under OLS estimation procedures are non-efficient. It can be shown that a gain in efficiency results from GLS estimation procedures equal to

$$\frac{\text{Var } \tilde{B}_{12}}{\text{Var } \hat{B}_{12}} = \frac{1-p_{12}^2}{1-p^2_{12}r_{12}}$$

where $\hat{B}_{12}$ is the variance of the OLS estimator of B_{12} and $\tilde{B}_{12}$ is the variance of the GLS estimator of B_{12} and p_{12} is the coefficient of correlation of residuals between equations and r_{12} is the coefficient of correlation between the explanatory variables. Kmenta (27), p. 524.

the disturbances, imposes the restricted estimations of (1/1+p) and (γ p/1+p)--B_3 and B_6--and calculates the desired estimates.[12]

Switching the estimating procedure is not without its problems. Model III in the restricted GLS formulation generates an unacceptable covariance matrix with several negative variances on the diagonal.[13] The restricted version of Model III is designed more for analytical ease than for theoretical necessity. It is desirable to have a single estimate for 1/1+p since this yields a single value for p and facilitates tests concerning δ and λ. However, the unrestricted version will allow identical tests of hypotheses if the estimator of B_3, 1/1+p, is statistically identical in each of the unrestricted equations. Model III unrestricted is specified:

$$Q_1 = XB + e \qquad (22)$$

Where

---

[12]The computer program employed was Stroud, Zellner and Chau (38) Fortran II program for the IBM 7094 adapted for use on the University of Minnesota CDC 6600.

[13]It is thought by the computer analyst that there exists an error in the computer program. The error may have occurred in converting the Stroud, Zellner, Chau program from the IBM 7094 to the CDC 6600. The error has not been determined.

$$Q_1 = \begin{bmatrix} \ln(Q/A) & to \\ \vdots & \\ \ln(Q/A) & tn \end{bmatrix} \qquad X = \begin{bmatrix} 1 & 0 & \ln R_{to} & I_{to} & 0 & t_o & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & 0 & \cdot & I_{tm} & 0 & tm & 0 \\ 0 & 1 & \cdot & 0 & I_{tm+1} & 0 & tm+1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 1 & \ln R_{tn} & 0 & I_{tn} & 0 & tn \end{bmatrix}$$

$$B = \begin{matrix} b_{11} = -1/1+p \ \ln a_{t1} \\ b_{12} \quad -1/1+p \ \ln a_{t2} \\ b_{13} \quad 1/1+p \\ b_{141} \quad \delta_1 p/1+p \\ b_{142} \quad \delta_2 p/1+p \\ b_{161} \quad \gamma_1 p/1+p \\ b_{162} \quad \gamma_2 p/1+p \end{matrix}$$

$$Q_2 = XB + e \tag{23}$$

where

$$Q_2 = \begin{bmatrix} \ln(Q/L) & to \\ \vdots & \\ \ln(Q/L) & tn \end{bmatrix}$$

$$B = \begin{bmatrix} b_{21} \\ b_{22} \\ b_{23} \\ b_{251} \\ b_{252} \\ b_{261} \\ b_{262} \end{bmatrix} = \begin{bmatrix} -1/1+p \ \ln b_{t1} \\ -1/1+p \ \ln b_{t2} \\ 1/1+p \\ \lambda_1 p/1+p \\ \lambda_2 p/1+p \\ \gamma_1 p/1+p \\ \gamma_2 p/1+p \end{bmatrix}$$

and X is identical to the preceding X matrix.

The essential difference between the restricted formulation of equation (20) and the unrestricted formulations of (22) and (23) is that coefficients b_3, b_6 and b_7 are not restricted to be equal in (22) and (23). The non-restricted estimation of B_3 does not preclude tests of hypotheses that involve coefficients in different equations. Theil provides an F-test[14] for coefficients of different equations which is incorporated within the Stroud, Zellner, Chau computer program. Any tests concerning coefficients containing the parameters δ and λ, however, must first be predicated on failure to reject the null hypothesis that 1/1+p estimated in Q_1 is equal to 1/1+p estimated in Q_2. If these coefficients are not equal tests concerning b_4 through b_7 between (22) and (23) do not allow exclusive inferences about δ or λ and are, therefore, of little use. Tests concerning b_4 and b_5, b_6 and b_7 within equations (22) and (23) depend only on the rejection of the null hypothesis that b_3 is equal to unity.

Empirical Findings

The results from fitting the several statistical

---

[14] Theil (39), pp. 312-14, equations 3.6. This test statistic involves complex matrix manipulation and will not be described.

models appear in the tables within this section. Interpreting the statistical results requires a certain degree of practicality. Although the OLS variance estimates are not efficient, the coefficients are unbiased. Furthermore, the OLS estimating program affords more information than the GLS. For instance, the GLS two-stage estimation procedure does not include a Durbin-Watson statistic. Nor does the Stroud, Zellner and Chau GLS program generate an analysis of variance for the regression. The missing error sum of squares is a serious limitation of statistical tests that can be performed. Neither does the GLS program generate a coefficient of determination, R^2.

Unfortunately, tests cannot be made with the OLS error sums of squares. However, the Durbin-Watson statistic from the OLS as well as the coefficient of determination are reported with the caveat that their actual values are questionable. Since

$$d = \frac{\sum_{t=2}^{n} (e_t - e_{t-1})^2}{\sum_{t=1}^{n} e_t^2}$$

the Durbin-Watson statistic clearly is constructed

from residual terms which suffer from non-independence. Furthermore,

$$R^2 = 1 - \frac{\sum et^2}{\sum (Y_t - \bar{Y})^2}$$

is constructed of the biased variance. With this caveat, the OLS estimates of Model I, II and III suggests that the statistical models appear to fit the data reasonably well. The coefficients of determination ($\bar{R}^2$) are high. Auto-correlation appears to be mostly non-existent. In the GLS estimates, signs of all but the intercept terms are correct in the estimation of French Model III.

Denmark. Coefficient and parameter estimates appear in Tables 3-3 and 3-4 for Models I and II and 3-5 for demand type equations. Estimates of the non-neutral components of augmentation and of the component of neutral efficiency growth are all significantly positive. Land and labor non-neutral augmentation is indicated as well as efficiency growth from unspecified sources. This is consistent with the hypothesis in Chapter II that livestock operations have shown a labor using bias while field operations have shown a labor saving bias.

The positive significance of δ and λ also

Table 3-3: Denmark: Estimated GLS Coefficients of the Statistical Models

	B_1 $1/1+p \ln a$	B_2 $1/1+p \ln b$	B_3 $1/1+p$	B_4 $\delta p/1+p$	B_5 $\lambda p/1+p$	B_6 $\gamma p/1+p$	t Test[1] $B_3=1$	$B_4=B_5$	$B_6=0$
Model I	-1.471** (.2111)	2.233** (.043)	.2894** (.032)	.00265** (.00041)	.01098** (.00215)		Reject**	Reject**	
Model II	- .2727 (.2884)	2.07** (.04083)	.037 (.0559)	.0020** (.00045)	.0153** (.0023)	.0457** (.0094)	Reject**	Reject**	Reject**

**Level of significance = .01

[1]The test statistic has the usual t distribution. The calculated t value was determined from the restricted covariance matrix of the generalized least squares model. This matrix takes account of the mutual relatedness of the error terms of the two component equations of the system. Kmenta (27), p. 519; Stroud, Zellner, Chau (38), p. 11.

Table 3-4: Denmark: Parameter Estimates of GLS Statistical Models I and II

	Substitution parameter p	Land Aug. δ	Labor Aug. λ	Neutral Efficiency γ	Inference From Tests of Coefficients			Direction of Bias
					$p = 0$	$\delta = \lambda$	$\gamma = 0$	
Model I	2.455	.0037	.0154		No	No		$\lambda > \delta$
Model II	26.027	.0021	.0159	.047	No	No	No	$\lambda > \delta$

Table 3-5: Denmark: Estimated Coefficients for Demand-Type Equations, 1910-1965

Dependent[1] Variable	Intercept	Fertilizer Relative to Land	Labor Relative to Land	Land Relative to Labor	Mach. Relative to Labor	Conc. Relative to Land	R^2	S	F	d	Auto Reg.*
Fertilizer Per Hectare	-4.08** (.133)	-1.12** (.348)	.958** (.43*)				.87	.31	38.5**	2.20	Pos.
Machinery per Male Worker	.679** (.172)			1.494 (1.01)	-3.18** (.861)		.83	.37	29.1**	1.51	In-conc.
Land Per Male Worker	2.12** (.014)			.148 (.084)	-.357** (.072)		.91	.03	59.7**	1.70	Pos.
Concentrates[2] Per Hectare	-1.73** (.08)		.494** (.124)			-.680** (.30)	.59	.167	8.27**	1.31	Pos.

* Level of significance = .05
**Level of significance = .01

[1] Equations are linear in logarithms.

[2] Estimated for 1880-1925.

coincides with the data of Figures 2-5 and 2-6, which show that Danish agriculture, among the three countries, showed the strongest, most consistent trend of biochemical technology adoption. So, too, Figure 2-7 shows that the indicator of adoption of mechanical technology was equally strong.

The further implication of statistical tests is that the labor augmenting bias has been slightly stronger. This is consistent with the positive trend of I_t. It is also consistent with the historical growth path shown in Figure 1-3. Labor productivity increased 543% while land productivity increased 400% from 1870 to 1965.

The positive significance of δ and λ conflicts, however, with the expected sign of δ suggested by equation (11). Equation (11) showed that a positive trend of I_t should cause λ to be positive and δ negative. Table 3-24 shows that the trend is I_t fluctuated before 1925. The overall impact of the trend in I_t does not appear to have been strong enough to have biased the direction of augmentation more than slightly in the direction of labor augmentation. The calculated signs and relative size of the factor augmentation coefficients describe very well the observed historical changes and hypothesized relationships.

The results from the demand type equations of Table 3-5 are consistent with the findings discussed above. The statistical models appear to fit the data reasonably well. The coefficients of the price ratios of the purchased inputs to the on-farm resources of land and labor are all negative and significant at the usual levels. Positive auto correlation is a problem, however, and biases these tests.

Thus, the models derived from the CES function indicate land and labor augmenting technical innovation and the demand-type equations indicate that the adoption of the purchased inputs technology was induced by changing price ratios to favor this adoption.

France. Coefficient and parameter estimates appear in Tables 3-6 and 3-7 for Models I and II, 3-8 for Model III restricted and unrestricted and Tables 3-9 and 3-10 for demand type equations. None of the estimates of the non-neutral components factor augmentation are significantly different from zero in Model I and II. The estimator for the coefficient of neutral efficiency growth is significantly positive. Since it is clear from a visual inspection of the data that little or no changes in factor proportions occurred before World War II, these statistical results are very

Table 3-6: France: Estimated GLS Coefficients of Statistical Models I and II

	B_1 $1/1+p \ln a$	B_2 $1/1+p \ln b$	B_3 $1/1+p$	B_4 $\delta p/1+p$	B_5 $\lambda p/1+p$	B_6 $\gamma p/1+p$	t Test[1] $B_3=1$	$B_4=B_5$	$B_6=0$
Model I	1.511**	4.153**	.1205**	.000269	.001116		Reject**	Accept	
	(.169)	(.10)	(.0248)	(.000387)	(.000544)				
Model II	2.009**	2.248**	.0345	-.000183	-.000336	.0345*	Reject**	Accept	Reject*
	(.1216)	(.0644)	(.0179)	(.00 501)	(.0 0502)	(.0122)			

* Level of significance = .05
**Level of significance = .01

[1]The t test is the same as in the Danish GLS estimation procedure for Models I and II. See note 1, Table 3-8.

Table 3-7: France: Parameter Estimates of GLS Statistical Models I and II

	Substitution parameter p	Land Aug. δ	Labor Aug. λ	Neutral Efficiency γ	Inference From Tests of Coefficients			Direction of Bias
					$p = 0$	$\delta = \lambda$	$\gamma = 0$	
Model I	7.299	.00031	.00126		No	Yes		$\delta = \lambda = 0$
Model II	27.99	-.00019	-.0003	.0357	No	Yes	No	$\delta = \lambda = 0$

Table 3-8: France: Estimated Coefficients of Unrestricted GLS Statistical Model III

	B_{11} 1/1+p ln a	B_{12} 1/1+p ln a	B_{21} 1/1+p ln b	B_{22} 1/1+p ln b	B_3[1] 1/1+p	B_{41} δ_1p/1+p
Q_1	3.417** (.461)	-.3719** (.381)			-.166** (.067)	.0017* (.00071)
Q_2			4.068** (.076)	-1.335 (1.11)	-.158 (.104)	

	B_{42} δ_2p/1+p	B_{51} λ_1p/1+p	B_{52} λ_2p/1+p	B_{61} γ_1p/1+p	B_{62} γ_2p/1+p
Q_1	-.00026 (.00048)			.012 (.011)	.303** (.058)
Q_2		.00265 (.0014)	.0004 (.0006)	.0321 (.017)	.4269** (.090)

* Level of significance = .05
**Level of significance = .01

[1]Values of B_3 less than zero are inadmissible. B_3 is the estimate for 1/1+p which is the elasticity of substitution. It must be positive and p must be greater than -1. Since p appears in the numerator of B_4 and B_5, further hypothesis testing is not valid. Parameters are not calculated.

Table 3-9: France: Estimated Coefficients for Demand-Type Equations, 1870-1965

Dependent Variable	Intercept[1]	Coefficients of Price of: Fertilizer Relative to Land	Labor Relative to Land	Land Relative to Labor	Mach. Relative to Labor	R^2	S	F	Residual Sum of Squares	d	Auto Reg.
Fertilizer Per Hectare	-5.482** (.291)	-.950* (.332)	-1.375** (.362)			.56	.776	13.5**	10.245	.981	No
Horsepower per Male Worker	-.3284 (.3062)			1.704* (.880)	-.705 (.614)	.16	.81	2.87	11.426	.403	No
Land Per Male Worker	1.954** (.071)			.398 (.202)	-.088 (.141)	.323	.189	5.54**	.607	.472	No

* Level of significance = .05
**Level of significance = .01

[1] Equations are linear in logarithms.

Table 3-10: France: Estimated Coefficients for Demand-Type Equations for Different Time Periods

Dependent[1] Variable	Intercept	Coefficients of Price of: Fertilizer Relative to Land	Labor Relative to Land	Land Relative to Labor	Mach. Relative to Labor	$\bar{R}^2$	S	F	Residual Sum of Squares	d	Auto Reg.
1870-1915											
Fertilizer per Hectare	-4.972** (.029)	-.0626 (.755)	2.73 (1.325)			.31	.56	3.063	2.2298	.366	No
Horsepower per Male Worker	-.3178** (.0358)			.3212 (.2489)	-.3994* (.1458)	.51	.064	5.678*	.0291	1.87	Pos.
Land per Male Worker	1.968** (.026)			-.1752 (.1912)	.1481 (.1134)	less than zero	.050	.923	.0176	1.73	Pos.

(cont. on next page)

(cont.)

Dependent Variable[1]	Intercept	Coefficients of Price of: Fertilizer Relative to Land	Labor Relative to Land	Land Relative to Labor	Mach. Relative to Labor	R^{-2}	S	F	Residual Sum of Squares	d	Auto Reg.
1920-1965											
Fertilizer per Hectare	-3.207** (.8239)	-.6643* (.2585)	.4849 (.7331)			.386	.538	3.826*	2.0264	1.06	Incon.
Horsepower per Male Worker	4.8676** (1.360)			-.4433 (.976)	-2.46** (.715)	.55	.705	6.689**	3.482	1.14	"
Land per Male Worker	3.106** (.316)			-.0503 (.2264)	-.4978* (.166)	.46	.164	4.909*	.1874	1.31	"

* Level of significance = .05
**Level of significance = .01

[1] Equations are linear in logarithms.

reasonable for that period but do not pick up the changes that occurred after 1940. For that reason, Model III was specified to estimate the differences in the parameters between periods. However, the GLS version of Model III estimated an unacceptable value for the substitution parameter, p, and further testing of the model was precluded.

Returning to Models I and II, the absence of factor augmentation and presence of unspecified neutral efficiency growth appears to be a reasonable explanation of the sluggish growth exhibited before 1940. It is interesting to note that while I_t as indicated in Table 3-24 has shown a stronger positive trend than I_t for Denmark, δ and λ are not different in sign in either Model I or Model II. A strong positive trend for I_t would be expected to produce a positive sign for λ and a negative sign for δ. (See equation 1). Of even more interest is the change in signs of δ and λ from positive to negative with the inclusion of γ in the Model. Model I incorrectly measures the effect of unspecified neutral efficiency growth within δ and λ. Model II sorts out this effect clearly and shows that with the exclusion of γ from the parameters of augmentation, the true effects of any existing biases have been towards retardation, not augmentation

of land and labor.

The results from the demand type equations of Table 3-9 are partially consistent with the finding that the biases were retardative in nature. The coefficients of the price ratios of mechanical technology for its substitute, labor, in the horsepower per male worker and land per male worker equations are not significant. Furthermore, the statistical model is shown to fit the data poorly in these two equations. In the fertilizer per hectare equation, the coefficient of the price ratio of fertilizer to land is correctly negative and significant over the whole 1870 to 1965 period. The conflict between the land retardation estimate from the CES Model and the signal to induce fertilizer technology may suggest than an insufficient amount of fertilizer was adopted to produce land augmentation.

The demand type equations were estimated over two periods to allow a search for hypothesized structural changes between the periods. To allow sufficient degrees of freedom, the time period was divided at 1920. The results shown in Table 3-10 are consistent with the dramatic upturn in productivity that occurred in the second period. In this period, the coefficients of the price ratios of fertilizer to land and machinery

to labor are significant and correctly display negative signs. In the first period, results are much poorer. Furthermore, the estimated equations fit the data slightly better in the second period. The low adjusted coefficients of determination, R^{-2}, suggest that even with the improved fit in the second period, there are other factors that explain the increased use of purchased inputs that took place within this period.

A test for a structural shift of relationships between the two periods was performed for the three equations.[15] In each case, Table 3-11 shows that the null hypothesis was rejected at the .01 level of significance. Murray Brown characterizes such a structural change as the introduction of new technology.[16] It appears reasonable to conclude that between the two periods the French production function underlying these demand type equations shifted causing a structural shift in the demand for purchased inputs. No strong evidence emerges for the direction of net biases; i.e., in period 2, $\lambda - \delta \gtrless 0$ remains unknown.

---

[15] Johnston (23), p. 199.

[16] Brown (6), p. 116.

Table 3-11: Test for Structural Shift of Relationships Between Two Time Periods for France and the United Kingdom[1]

Regression Dependent Variable	Residual Sums of Squares			Sample Size		F-Statistics	
	S	S_1	S_2	m_1	m_2	Computed[3]	Theoretical[2]
United Kingdom							
Fertilizer/ Hectare	.8052	.3247	.2288	12	9	2.274	5.42
Horsepower/ Male Worker	4.126	.0456	1.398	12	9	9.2941**	5.42
Land Per Male Worker	.0979	.0148	.0731	12	9	.5689	5.42
France							
Fertilizer/ Hectare	10.245	2.2298	2.0264	10	10	6.566**	5.56
Horsepower/ Male Worker	11.426	.0291	3.482	10	10	10.524**	5.56
Land Per Male Worker	.607	.0176	.1874	10	10	9.178**	5.56

(cont.)

[1]France: 1870-1915, 1920-1965; United Kingdom, 1870-1925, 1925-1965.

[2]Level of significance = .01

[3]F computed = $\frac{S - S_1 - S_2/K\ (p-1)}{S_1 + S_2/p\ (m-K)}$

Where: S = Residual sum of squares over the entire period

S_1, S_2 = Residual sum of squares for the separate time periods

K = 3, the number of parameters

P = 2, the number of time periods

m = Observations per time period

Johnston (23), equation 6-39, p. 199.

United Kingdom: Coefficient and parameter estimates appear in Tables 3-12 and 3-13 for Models I and II, 3-14 through 3-16 for Model III, and 3-17 and 3-18 for demand type equations. Estimates of the coefficients of factor augmentation and neutral efficiency growth show mixed results. The coefficient of land augmentation is significantly positive in Models I and II. So, too, is the coefficient of neutral efficiency growth positive and significant. Furthermore, the coefficient of labor augmentation is negative in both models and significant in Model II which adjusts for the positive component of neutral growth measured within λ and δ in Model I. The signs of the non-neutral parameters of augmentation are not the expected signs in view of the positive trend of I_t.

Model III unrestricted offers little improvement in the results. δ is less than zero but not significant in period one. This is reasonable since no land productivity growth occurred in this period. δ is positive but non-significant in period two. λ is negative and significant in both periods. The positive trend of I_t continued in period two so that λ less than zero remains unexpected. Furthermore, the null hypotheses concerning δ and λ between periods are mixed. The results suggest $\delta_1 = \delta_2 = 0$ and

Table 3-12: United Kingdom: Estimated CLS Coefficients of Statistical Models I and II

	B_1 1/1+p ln a	B_2 1/1+p ln b	B_3 1/1+p	B_4 δp/1+p	B_5 λp/1+p	B_6 γp/1+p	$B_3 = 1$	$B_4 = B_5$	$B_6 = 0$
Model I	.8207** (.149)	4.76** (.053)	.3761** (.037)	.0005** (.0000088)	-.000152 (.000276)		Reject**	Accept[2]	
Model II	1.388** (.1147)	2.155** (.035)	.2178** (.0289)	.00054* (.000092)	-.000343* (.00015)	.00912* (.00344)	Reject**	Reject**	Reject*

* Level of significance = .05
**Level of significance = .01

[1]The t test is the same as in the preceding case of Denmark for Models I and II. See note 1, Table 3-8.

[2]The hypothesis can be rejected at significance level .10.

Table 3-13: United Kingdom: Parameter Estimates of GLS Statistical Models I and II

	Substitution Parameter	Land Aug.	Labor Aug.	Neutral Efficiency	Inference From Test of Coefficients			Direction of Bias
	ρ	δ	λ	γ	$\rho = 0$	$\delta = \lambda$	$\gamma = 0$	
Model I	1.6589	.0008	-.0002		No	Yes[1]		$\delta = \lambda$
Model II	3.591	.00069	-.0004	.0116	No	No	No	$\delta > \lambda$

[1]At significance level .10 the hypothesis $B_4 = B_5$ can be rejected and the inference drawn that $\delta > \lambda$.

Table 3-14: United Kingdom: Model III Estimated GLS Coefficients of Unrestricted Statistical

	B_{11} 1/1+plna	B_{12} 1/1+plna	B_{21} 1/1+plnb	B_{22} 1/1+plnb	B_3 1/1+p	B_{41} δ_1p/1+p	B_{42} δ_2p/1+p	B_{51} λ_1p/1+p	B_{52} λ_2p/1+p	B_{61} γ_1p/1+p	B_{62} γ_2p/1+p
Q_1	1.654** (.285)	1.138** (.018)			.1804* (.069)	-.00013 (.00017)	.00008 (.00014)			.0060 (.0044)	.0469* (.0181)
Q_2			4.715** (.05)	4.961** (.065)	.8081** (.082)			-.0041** (.0007)	-.0010* (.0004)	.0269** (.0088)	.0545** (.0113)

F Tests[1]

	$B_3 = 1$	$B_{41} = B_{42}$	$B_{51} = B_{52}$	$B_{61} = B_{62}$	$B_{3Q1} = B_{3Q2}$
Q_1	Reject**	Accept		Accept	Reject**
Q_2	Reject**		Reject**	Reject	

* Level of significance = .05
**Level of significance = .01

[1]The test statistic employed has an F distribution as described by Theil ( ), equation 3.6, pp. 313-14.

[2]The rejection of the null hypothesis $B_{3Q1}=B_{3Q2}$ precludes tests within time periods for the direction of bias. Therefore, no test can be made for $B_{41}=B_{51}$ or $B_{42}=B_{52}$ because the estimated substitution parameter, p, is not identical in the coefficients.

Table 3-15: United Kingdom: Parameter Estimates of Unrestricted GLS Statistical Model III

		Land Augmentation		Labor Augmentation		Neutral Efficiency		Inference from Tests of Coefficients			
	P	δ_1	δ_2	λ_1	λ_2	γ_1	γ_2	p=1	$\delta_1=\delta_2$	$\lambda_1=\lambda_2$	$\gamma_1=\gamma_2$
Q_1	4.54	-.000152	.000099			.007	.0572	No	Yes		Yes
Q_2	.237			-.0214	-.00543	.140	.285	No		No	No

Table 3-16: France and United Kingdom: Estimated GLS Coefficients of Restricted Statistical Model III[1]

	B_{11} 1/1+p ln a	B_{12} 1/1+p ln a	B_{21} 1/1+p ln b	B_{22} 1/1+p ln b	B_3 1/1+p
France	3.169	-1.23	4.073	-.3991	-.1294[2]
United Kingdom	.0187	.6265	4.792	5.002	.5783

B_{41} $\delta_2 p/1+p$	B_{42} $\delta_2 p/1+p$	B_{51} $\lambda_1 p/1+p$	B_{52} $\lambda_2 p/1+p$	B_{61} $\gamma_1 p/1+p$	B_{62} $\gamma_2 p/1+p$
.00109	.00003	.00293	.00023	.0198	.3218
.00003	.00056	-.0029	-.00018	.024	.043

[1] Computational problems of the generalized least squares restricted model resulted in inconsistent values in the restricted covariance matrix. Therefore, variance estimates are not available for the restricted version of Model III. No hypothesis tests are possible, therefore. These values are displayed for comparison with Table 3-14 and 3-8.

[2] B_3 is the estimate for 1/1+p, the elasticity of substitution. It must be positive. This negative result is consistent with the value determined by the unrestricted model.

Table 3-17: United Kingdom: Estimated Coefficients for Demand-Type Equations, 1870-1965

Dependent Variable[1]	Intercept	Coefficients of Price of: Fertilizer Relative To Land	Wages Relative To Land	Land Relative To Labor	Machinery Relative To Labor	Conc. Relative to Land	R^{-2}	S	F
Fertilizer per Hectare	-5.338** (.091)	-1.13** (.025)	1.01 (.08)				.92	.218	111.3**
Horsepower/ Male Worker	-.784** (.186)			-1.12** (.295)	-1.09 (.527)		.81	.492	41.6**
Land Per Male Worker	2.658** (.028)	-1.236 (.061)		-.161** (.046)	-.133 (.081)		.77	.075	32.8**
Concentrates Per Hectare[2]			3.634** (.358)			-3.642** (.331)	.97	.137	123.8**

**Level of significance = .01

[1]Equations are linear in logarithms

[2]Estimated for 1870-1930 with three missing observations

(cont.)

Residual Sum of Squares	d	Auto Regression*
.0852	.453	No
4.126	.527	No
.0979	.706	No
--	2.17	Positive

Table 3-18: United Kingdom: Estimated Coefficients for Demand-Type Equations for Different Time Periods

Dependent Variable[1]	Intercept	Coefficients of Price of: Fertilizer Relative to Land	Labor Relative to Land	Land Relative to Labor	Machinery Relative to Labor	R^{-2}	S	F
1870-1925								
Fertilizer per Hectare	-5.119** (.141)	-.3984 (.4115)	.8687** (.1871)			.69	.189	13.0**
Horsepower/ Male Worker	-.3716** (.0385)			-.3660** (.0571)	-.4167** (.123)	.82	.071	25.8**
Land Per Male Worker	2.672** (.022)			-.1288** (.0326)	-.1391 (.0701)	.61	.041	9.59**
1925-1965								
Fertilizer Per Hectare	-5.659 (.2667)	-1.541 (.354)	1.111** (.226)			.92	.20	47.5**
Horsepower/ Male Worker	-2.265** (.671)			-2.836** (.693)	.0586 (1.12)	.81	.048	18.09**
Land Per Male Worker	2.545** (.153)			-.2785 (.1585)	-.0652 (.2564)	.44	.11	4.2

* Level of significance = .05
**Level of significance = .01

[1] Equations are linear in logarithms.

(cont.)

Residual Sum of Squares	d	Auto Regression*
.3247	1.52	Inclusive
.0456	1.58	Positive
.0148	1.39	Inconclusive
.2288	1.49	Inconclusive
1.398	1.29	Inconclusive
.0721	.742	No

$\lambda_2 > \lambda_1$. Althouth λ_2 exceeds λ_1, the implication of the negative signs is that labor retardation becomes less of a constraint to growth in the second period. No labor augmentation bias is indicated.

In addition to these results concerning factor augmentation, the impression from statistical inference concerning the coefficients of neutral augmentation is that this component of growth increased between periods.

No test is permitted concerning the direction of bias within the separate periods; i.e., $\lambda_1 = \delta_1$ or $\lambda_2 = \delta_2$, because the F-test that 1/1+p in equation Q_1 is equal to 1/1+p in equation Q_2 rejects the null hypothesis.

The general impression to be gathered from an overview of the results from the three models is that land augmentation was nil before 1925 and became positive after 1925. The retardative nature of the labor bias was eased between the two periods. Neutral efficiency growth increased between periods.

These results compare only fairly with the data of adoption of purchased inputs in Figures 2-5, 2-6, and 2-7. The level of use of concentrated feeds and fertilizer was relatively high in 1870 because of the early adoption of these inputs during the period of "High Farming." After 1870, the rate of increase of

these inputs was relatively slow suggesting, indeed, that land was augmented only slowly, if at all, in the early period. However, mechanization proceeded swiftly beginning in the 1920's. Labor would appear to have been augmented.

The results from the demand type equations shown in Tables 3-17 and 3-18 are consistent with the findings from the equations of the CES Model. Each of the equations fit the data well and auto-correlation is not a problem. The coefficients of the fertilizer price-land rent and concentrate price-land rent ratios are significantly negative for the fertilizer and concentrate equations estimated over the whole period. The coefficient of the machinery-labor price ratio is not significant at the usual levels in either the horsepower equation or the land per male worker equation. However, the land-labor price ratio is significant and negative in these equations and the normalized coefficients show it to be twice as important as an explanator of both the adoption of tractorization and the increase in the land area per worker.

When estimated over two periods, the British demand type equations reveal significant coefficients with correct signs to the ratios of land rent and wages in the three equations but non-significant

coefficients to the fertilizer price-land rent ratio in the early period and non-significant coefficients to the machinery price-wage ratio in the second period to the horsepower and land per male equations. The fertilizer equation in period two shows good results: correct signs, significance and a high R^2.

The results from the fertilizer equations support the alternating nil and then positive indication of land augmentation in the equations of the CES Models. So, too, the results from the horsepower equations parallel the indicated labor retardation of the CES models in that the hypothesized negative sign on the machinery price-wage ratio is missing in the second period and non-significant.

The test for structural shift between the two periods shown in Table 3-11 concluded only that the structure of the horsepower per male worker equation had changed. Clearly, the demand did change from horsedrawn mechanization to tractorization between the two periods. This finding is consistent with the *a priori* hypothesis of Chapter II that productivity acceleration after 1930 was associated with early mechanization.

The negative sign of λ and positive sign of δ are puzzling. The implication attached to the signs

of these parameters is that there has been a bias to favor land augmenting technical change and no bias to favor labor augmenting technical change. This is not consistent with the observed historical productivity growth path of Figure 1-3. From 1870 to 1965, land productivity increased 209%, labor productivity 380%. In other words, British productivity growth appears to have proceeded contrary to the bias for land saving innovation and in spite of the bias for labor retardation. This result is contrary to the induced innovation hypothesis.

Several possible explanations exist.

(1) The CES model does not describe the data. However, the demand-type equations suggest conclusions parallel to those from the CES model;

(2) Factor prices are not the correct inducement mechanism;

(3) The induced innovation hypothesis, indeed, is not relevant. Rapid productivity growth is not caused by induced biases.

However, if it could be demonstrated that the factor prices are, in fact, the correct inducement mechanism and the induced innovation hypothesis is correct, then it could be inferred that the British productivity growth path has been less than optimal.

Productivity growth could have been faster if more land saving technology had been adopted.

Implications of the Empirical Findings for Institutional Interaction

The statistical analysis of the preceeding section allows no direct measure of the interaction of technological innovation and the inducement mechanism with institutional effects. The following flow diagram allows a partitioning of the hypothesized determinants of rapid productivity growth that will allow indirect inferences about the interaction of technological innovation and the inducement mechanism with institutional effects (see Figure 3-1).

Changing demand opportunity is explicitly assumed to be the entry point of the flow chart. Explicitly this assumption implies either preference changes in product demand or other exogenous changes that alter basic economic conditions in the product market. The changes in crop and livestock product price ratios in the last part of the 19th century among the three European countries of this study confirm that basic economic conditions in the product market did change during the early part of this study.

Perception of opportunity is a behavioristic assumption that cannot be observed directly. It can

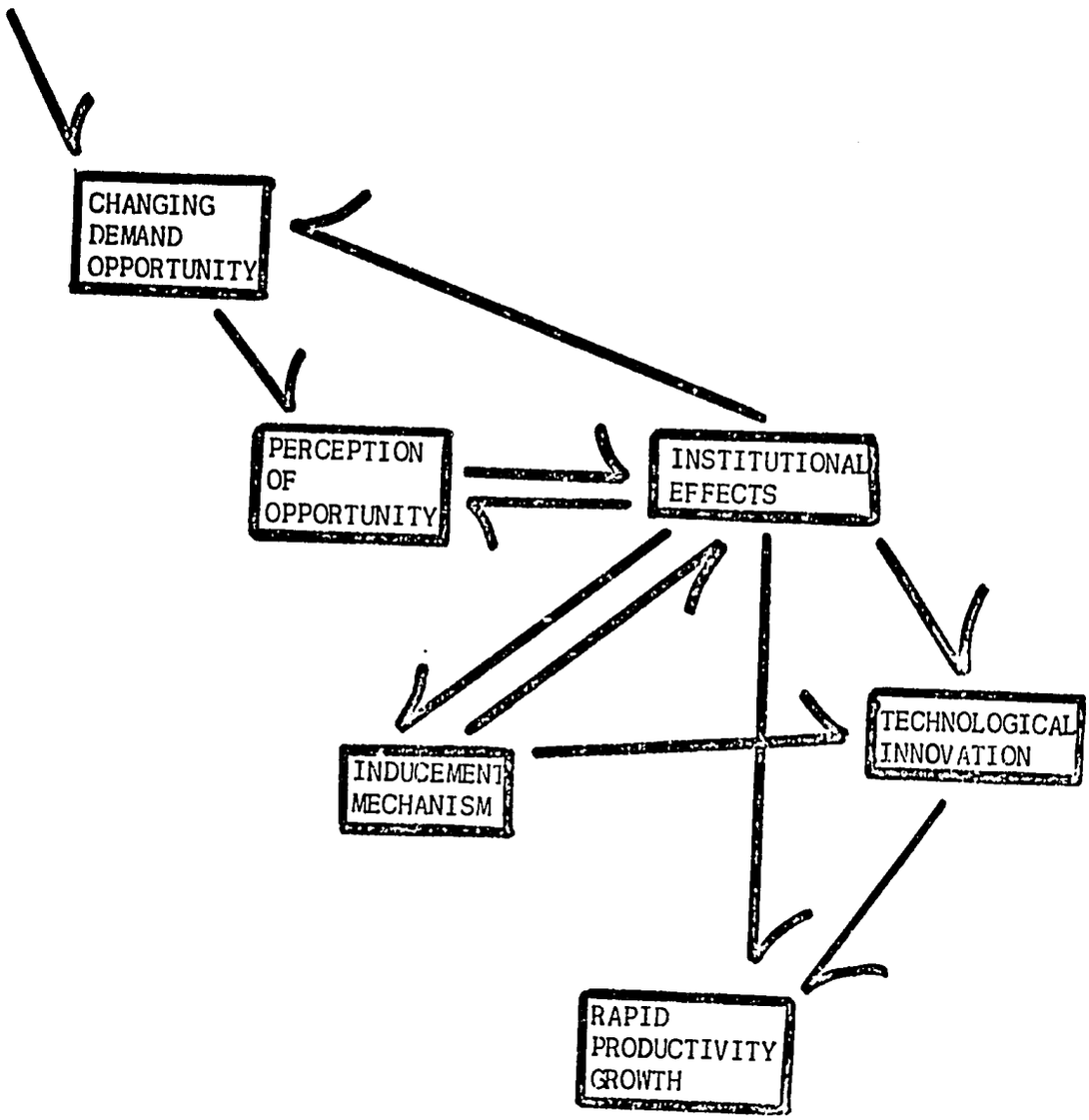


Figure 3-1: Flow Chart of the Determinants of Rapid Productivity Growth

only be inferred from actions taken to implement institutional and technological innovation.

The inducement mechanism has been predicated to be changes in factor price ratios and its indicated biases have been measured in the preceeding statistical section.

Institutional effects are considered to relate to the flexibility or rigidity of the institutional structure as it allows or constrains necessary institutional innovation. Rigid institutional effects may act directly on the inducement mechanism in the form of distortions. They may limit the opportunity for change. They may act to obscure the perception of opportunity. They may act to limit the ability to generate the required technology. When none of these constraining institutional effects occur, the institutional structure is implied to be flexible. The flow of the diagram under flexible institutional conditions is continuous.

Technological innovations have been defined in broad terms as the invention and diffusion of purchased biochemical and mechanical technology.

Rapid growth in response to the assumed changed demand opportunity is considered to be a two-step process involving first institutional innovation and

then technological innovation. Demand pressure creates the need to relieve existing factor shortages to achieve productivity growth. Changed economic conditions require, as North and Thomas have shown,[17] that institutional structures be modified. This allows a new equilibrium production organization which internalizes the net gains available because of the changed economic conditions. Rapid productivity growth is possible as new institutional arrangements are adopted to internalize the net gains and new technology is adopted biased to offset the constraint of the limiting factors of production.

In view of the hypothesized two-step process of productivity growth and the flow chart of Figure 3-1, the discussion will now seek empirical support for the effect of the interaction of institutional effects on the interaction of institutional effects on the inducement mechanism and technological change measured in the statistical results.

The phenomenal success of Danish agriculture in adapting to changing export opportunities in the last quarter of the 19th century has been heuristically associated with a flexible institutional structure.

---

[17] North and Thomas (30), p. 9.

Necessary institutional changes occurred swiftly to facilitate increasing livestock product output.

It is readily apparent that the expansion of Danish output caused pressures on the existing organization of land and labor resources. The statistical analysis strongly implied that factor augmenting technical change occurred with a stronger bias for labor saving innovation than for land saving. Furthermore, labor productivity, historically, was seen to grow faster than land productivity.

The inducement mechanism appears to have worked well. Biased technological innovation, clearly signalled by the inducement mechanism, resulted in rapid productivity growth.

It may be claimed that these good statistical results are consistent with the hypothesized flexible institutional structure and technical change in Denmark.

The British 50-year period of productivity stagnation from 1875 to 1925 offers a useful contrast to the Danish case because Chapter II indicated that the changing demand opportunity clearly impinged equally on British and Danish agriculture. Thus, the contrasting productivity experiences considered against similar demand pressures may allow an inference about institutional effects.

The statistical analysis of the British data showed that during the period of productivity stagnation there was no induced bias for factor augmenting technical change. The Ahmad version of the induced innovation hypothesis suggests the conclusion that the absence of technological innovation and the resultant static conditions of productivity are the logical expectation under conditions where no bias for technological innovation exists. However, in the British case with the presence of changing demand opportunities, it is reasonable to ask why wasn't there a signal from the inducement mechanism for biased technological innovation.

In a larger sense, this question has been asked before--and answered. The question has been "Why didn't British agricultural output keep pace after 1875 with British food demand?" The answer generally can be reduced to the involvement of several institutional arrangements, mainly tenure and government policy, to favor cheap imports for feeding the industrial labor force.[18]

The answer to the question of why there was not

---

[18]See the discussion in Kindleberger (25), p. 239 following.

a signal from the inducement mechanism similarly can be attributed to institutional interaction if it can be shown first that (1) the estimated model actually describes the data; (2) factor prices are the correct inducement mechanism; (3) the induced innovation hypothesis is correct. If these necessary conditions are met, and the assumption of the effect of changing demand conditions on the need for institutional and technological innovation is also true, then the lack of an indicated bias is consistent with the hypothesized retardative effect of rigid institutional structures on technological innovation. The achievement of rapid productivity growth is affirmed as a two-step process involving both institutional and technological innovation. Productivity stagnation is attributed not so much to the non-performance of the inducement mechanism, but due to some unspecified rigidity of the institutional structure.

Furthermore, the productivity growth that occurred after 1925 was seen to be in conflict with the indicated bias for land efficiency growth. Instead of biological innovation, mechanization was adopted. Labor efficiency growth was observed historically in Chapter II. It was previously indicated that if the induced innovation hypothesis is relevant, then British

agricultural productivity growth could have been improved if more land saving technology had been adopted. But Chapter II showed that British agricultural research effectively was not institutionalized under public support until after World War I.

Hayami and Ruttan have suggested that the failure to institutionalize public sector agricultural research has the effect of diminishing the development of biological technology and accentuating the development of mechanical technology even though the bias present in the agricultural economy indicates a need for induced biochemical technology.[19]

It may be claimed that the British historical growth path is consistent with the hypothesized effect of institutional distortions to technical change and productivity growth. Poorly established British biological agricultural research institutions resulted in the adoption of mechanical technology readily available from the industrial sector and readily available from abroad.

The French statistical analysis showed no bias for induced innovation. Furthermore, the coefficient of neutral efficiency growth evidenced a growth rate

---

[19]Hayami and Ruttan (19), p. 145.

nearly identical to the actual rate of growth for output--0.7%,[20] from 1870 to 1940. It would seem, therefore, that the model explains well French sluggish productivity growth. Furthermore, it would seem that the model supports the induced innovation hypothesis. The absence of bias was matched by the absence of technological innovation and the absence of rapid productivity growth.

However, this overlooks the fact that French product demand changes were distorted by institutional effects directed to preventing any change in the economic conditions. By this action, and other institutional effects discussed in Chapter IV, the opportunity for change was limited. In terms of the flow chart in Figure 3-1, the flow never started. The status quo prevailed.

The absence of any indicated bias is consistent with the hypothesized effect of rigid institutional structures on the inducement mechanism and technical change. Institutional distortions resulted in a non-operative inducement mechanism.

---

[20] Table 3-11 shows the parameter that governed neutral efficiency growth in Model II equal to .0357. This is interpreted as the percent rate of growth per five years because the observations are quinquennial. Divided by 5, annual rate = .71.

By contrasting the Danish case with the British and French cases, the individual arguments for institutional interaction with induced innovation and technical change are enhanced. Similar economic forces affecting food demand resulted in dissimilar productivity growth patterns due to the existence of unique institutional structures for each of the three countries.

CHAPTER IV*

THE RETARDATIVE EFFECT OF FRENCH POLYCULTURE ON TECHNICAL INNOVATION AND PRODUCTIVITY GROWTH

Introduction

In Chapter II, the economic and institutional forces that affected agricultural productivity were discussed for each of the three countries considered in this dissertation. The impact of institutional flexibility or rigidity on productivity growth was suggested to be due to the ability of a given society to perceive and act upon a new profitable opportunity. The degree of flexibility or rigidity was related to the speed with which needed institutional innovation did or did not come forth.

In Chapter III, weak support was discovered for the association of institutional innovation with rapid productivity growth.

The forces that lead to the formation of specific

---

*The author is indebted to William H. Newell of St. Olaf College, Northfield, Minnesota, for suggestions and comments on an earlier draft.

institutional arrangements in a society is an area of research that has become increasingly important. The need for institutional reform increasingly has been recognized as an essential element of economic development.[1] However, the mechanism to effect institutional reform has remained only tenuously defined.

This chapter will consider the development of the institutional arrangements of polyculture in France in the 19th century which directly affected the hypothesized inability of French agriculture to adopt a more advanced technology based on purchased inputs until after World War II.

This chapter is conceived to be a reconnaissance mission of the formation of institutions within an agricultural sector. The basic purpose is to analyze the institutional forces that impeded French agricultural productivity growth from 1870 until after World War II. Attention will be given to the period before 1870 to understand the formation of selected institutional arrangements that directly affected the inability to adopt a more advanced technology embodied in purchased inputs when other European economies were employing more purchased inputs. As a first step to

---

[1] Davis (9).

identify the effects of institutional arrangements on induced technological innovation, this chapter was facilitated by data newly available in 1971 and 1972.[2]

Overview and Hypothesis

Soon after the turn of the 19th century, French agriculture entered a period of acceleration of both total and per capita agricultural production. Although the changes in the productive processes that ensued were very evolutionary, the literature consistently refers to these changes as the French agricultural revolution. Throughout the remainder of the century forage and green manure crops slowly replaced fallow in the rotation. Mixed farming, or polyculture, as the "new husbandry" practices became known, began to diffuse and supplant the old two- and three-course rotations. The data of Table 4-1 and Figure 4-1 show the main indicators of the diffusion of polyculture: the replacement of fallow with cultivated grasses and root crops. The overriding impression from these data confirms that the spread of polyculture in France was very slow and evolutionary.

---

[2]Granthum (78) and Newell (91) present in their respective 1972 and 1971 dissertations regional data of France that has not previously been generally available.

Table 4-1: France: Proportion of Arable Land Held Fallow

	(1) Arable land[1] (1000 ha.)	(2) Fallow (1000 ha.)	(3) Percent of arable fallow	(4) Cropped land (1-2) (1000 ha.
1781-90	23,900	9,600	40	14,400
1840	25,500	6,800	22	18,700
1862	26,600	5,100	19	21,500
1882	25,600	3,600	14	22,000
1892	25,400	3,400	13	22,000
1913	23,600	2,600	11	21,000
20-24		4,900		
25-34		3,100		
35-38		1,700		

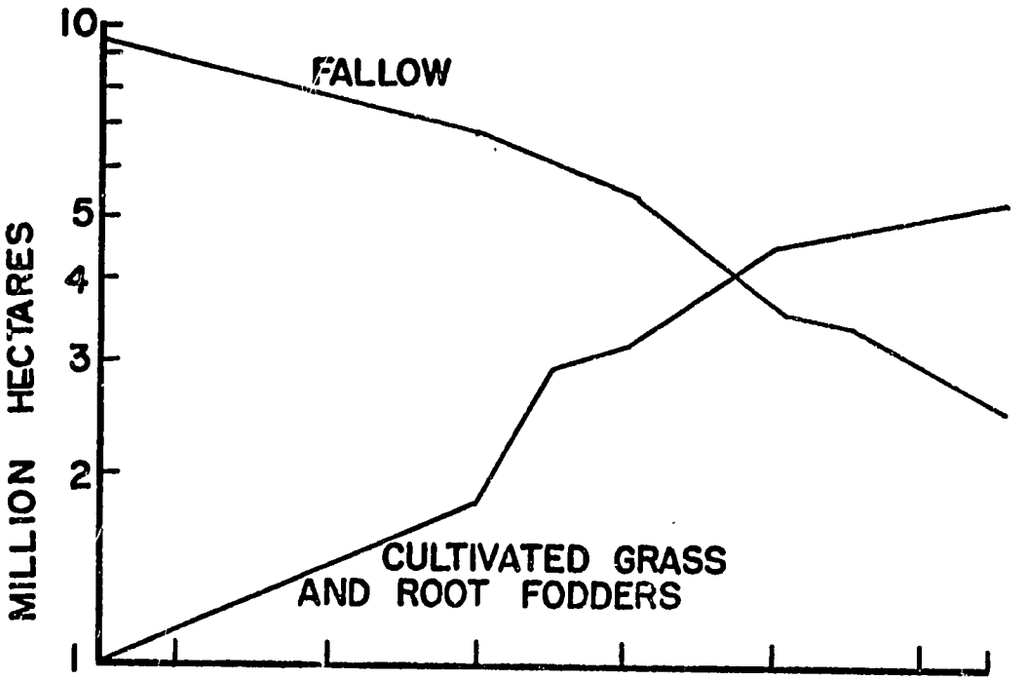
Note:

[1]Includes fallow of column 2.

Source:

Toutain (97), p. 48

Toutain (98), pp. 214-15.



SOURCE: TOUTAIN (98), PP. 13, 43, 52, 181, 214-5

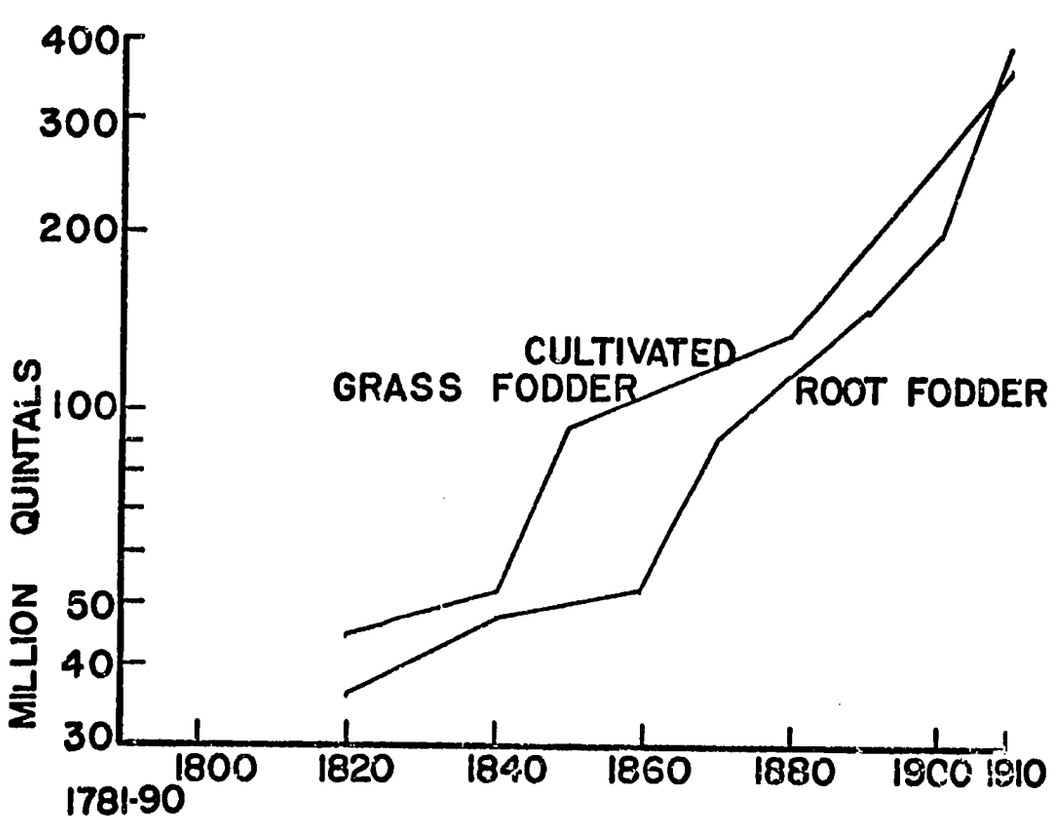


FIGURE 4-1: FRANCE: CHANGING ROTATION PATTERNS

The hypothesis with respect to the French pattern of productivity growth is that the transformation to polyculture created institutional constraints which seriously impeded the adoption after 1870 of a more advanced technology embodied in purchased inputs. Aspects of polyculture will be reviewed to examine the structural changes that occurred in the rural sector. Then the French tariff response to imported grains during the last few decades of the 19th century and early decades of the 20th century will be examined to see how these trade policies affected the institutional structures of polyculture. From the examination of the institutional arrangements of polyculture and government policy prompted by polyculture, this chapter will conclude that further productivity growth beyond that possible and usual under the diffusion of "new husbandry" practices was retarded until after World War II.

This chapter will examine the hypothesis that the primary reason for the failure to adopt a new technology based on more intensive use of purchased inputs was the inability of the agricultural sector to respond to changing economic opportunities.[3]

---

[3]More precisely, there was an inoperative inducement mechanism due to institutional constraints in the system. See Hayami and Ruttan (19), p. 122 following.

Besides the national time series data employed previously, reference will be made to findings of the two recent studies indicated in footnote two that employ disaggregated regional data. The French data have serious problems. Although continuing research by L'Institut de Science Economique Appliquée has done a great deal to rectify some of the problems of the data, patchwork remains only patchwork.[4]

Polyculture and the Demand for Labor

The changes in crop rotations after the 18th century were labor using. Two forces were at work to alter labor requirements. The first was simply the increase in output. Collins, using Toutain's data, showed that total grain output increased 66% from 1803-1812 to 1855-1864. By the late 1830's, this trend was causing a shortage of harvest labor.[5] The second force was a shift in the labor demand occasioned by the transformation in the crop mix. This force, however, did not have a significant impact until after 1840 when rapidly rising incomes combined with a high income elasticity of demand resulted in rapid growth

---

[4]A more detailed indication of the data problems may be found in Hohenberg (82), Toutain (98), and Granthum (78).

[5]Collins (68), pp. 65, 72.

in the demand for meat. Meat prices rose nearly twice as fast as grain prices between 1845-1870.[6] This changing price ratio offered a strong incentive to shift land usage patterns to support commercial livestock after 1840. Figure 4-1 confirms that after 1840 production of cultivated leguminous grass fodder dramatically accelerated; after 1860 production of root fodder crops dramatically accelerated.

Granthum has shown that the root crops demanded heavy labor inputs for soil preparation and cultivation of the growing crop. Grass forage created a sharp demand for labor concentrated in the haying season. The expansion of these crops after 1840 was the main cause of the shift in the agricultural labor demand.[7] Granthum demonstrated that the transfer of land from fallow to handworked root crops, green manure crops and sown meadows increased the demand for labor in France as a whole about 25 to 40% between 1840-1882. In the northeastern region where the expansion of root crops and forages was most extensive, the increase in labor demand was on the order of 60-70% over the same period.[8]

---

[6]Granthum (79), p. 4

[7]*Ibid.*, p. 6.

[8]*Ibid.*, pp. 14-15.

The available data for farm operators and farm laborers illustrate the changes that were taking place in the agricultural sector while these labor using fodder crops were diffusing across France. Table 4-2 shows that the number of farm operators increased from 2.85 million in 1862 to 3.26 million 30 years later. During this same period, those classed as day-laborers declined from 2.0 million to 1.21 million. The data of farm numbers in Table 4-3 show a trend parallel to the increasing number of farm operators. Operators and farm enterprises increased from 1862 to 1892. Day laborers decreased.

While recognizing that those classified as day laborers did not account for the entire work force (farm servants, not counted as day laborers, were available for many farm tasks), these data are a realistic indicator of increasing labor scarcity. Data of rising farm wage levels confirm the increasing scarcity--real farm wages rose nearly 30% between 1852-1882 and another 20% between 1882-1910.[9]

---

[9]Collins (68), p. 72, indicates that wages rose 60% between 1852-1882. Appendix table confirms this wage increase. The cost of living index which was used to compute real wages is taken from Marczewski (86), Table 40, CXXV.

Table 4-2: France: Farm Operators and Farm Day Workers

	1862[1] (1000)	1882[1] (1000)	1892[1] (1000)	1929[2] (1000)
Owner-operators	1802.4	2132.7	2183.1	1796.7
Hired managers	10.2	18.0	16.1	--
Cash renters	1035.3	968.3	1061.4	728.1
Total	2847.9	3119.0	3260.6	2524.8
Day-laborers	2003.8	1480.7	1210.1	--
Ratio:				
$\frac{\text{Laborers}}{\text{Proprietors}}$	.70	.47	.37	--

Sources:

[1]France, Statistique Agricole, 1892, pp. 248-49.

[2]Hunter (83), p. 72.

Table 4-3: France: Number of Farms

	Garden plots less than 1 ha. (1000)	Total over 1 ha. (1000)	1-10 ha. (1000)	10-20 ha. (1000)	20-50 ha. (1000)	Over 50 ha. (1000)	Total of all holdings including garden plots (1000)	% of total 1-10 ha.	% of total 10-50 ha.
1862[1]	--	3226	2435	364	315[a]	--	--	--	--
1882[2]	2168	3501	2635	431	352	86	5669	46.5	13.8
1892[2]	2235	3468	2618	429	336	85	5703	45.9	13.3
1908[3]	2088	3418	2524	450	346	98	5506	45.9	13.6
1929[1]	1015	2952	1864	593	380	115	3967	47.0	24.5
1942[1]	220	2162	1130	544	383	104	2382	47.5	39.0
1946[1]	--	2066	1059	527	367	95	--	51.2	43.3
1955[4]	150	2110	1112	530	374	95	2260	49.2	40.0
1963[4]	127	1773.5	841	473	363	98	1900	44.3	44.0
1967[4]	113	1577.2	683	413	372	109	1690	40.6	46.5

[a]Estimated by extrapolation.

Sources:

[1]EEC, Statistique Agricole (69), pp. 24-26.

[2]France, Statistique Agricole, 1892, p. 363.

[3]Golob (77), pp. 218-19.

[4]France, Statistique Agricole, 1968.

Rail Transportation and Regional Integration

In view of the changing agricultural product mix after mid-19th century and the attendant pressure on the labor supply, pertinent organizational structures of French agriculture will be examined to discover how these structures impinged on the changes that occurred. In 1860, French agriculture contained both a large farm sector and a peasant sector. While there were distinct regional patterns of predominant large or small farming, this analysis will not focus on the regional differences.[10] The large farms were predominantly market oriented while the peasant farms cultivated a mixture of subsistence and cash crops. Before railways became general about mid-century, the flow of agricultural products between regions was slow and expensive. Each area essentially produced most of the various food products that the inhabitants required for sustenance. So long as the two- and three-course rotation grain economy dominated the countryside, isolated regions were vulnerable to natural hazards such as drought and disease. The transition from the predominant grain rotations to

---

[10] See Granthum (78), for a breakdown of regional patterns of large farm and small farm practices.

the "new husbandry" practices marked by the replacement of the fallow with leguminous and root crops offered increased economic security from crop failure. The expanding variety of crops integrated with livestock provided a wider basis of diet.

The wave of railroad construction that began in the early 1840's effectively ended regional isolation. Railroads provided a strong stimulus for the growth of livestock product consumption after mid-century. By 1851, the rail network had grown to 3550 kilometers from 575 kilometers a decade earlier. By 1881, the rail network extended to 27,000 kilometers.[11] The production area supplying Paris spread from a radius of 50 to 250 kilometers from 1830 to 1855.[12]

The wines of the Midi drove local vintages off the market by the hundreds with the advent of transportation.[13] The increasing availability of transport, as indicated by the example of the wine trade, suggests that market conditions would have allowed increased crop specialization by region after mid-century. Indeed,

---

[11] Cameron (66), p. 69.

[12] Kindleberger (25), p. 213.

[13] Ibid., p. 28.

Kindleberger claims that "from 1865 on, France formed a single market in which there was a single price for each product."[14] While this is clearly an overstatement, transport costs did fall continuously after mid-century and interregional market integration did increase.

The literature is convincing that the expansionary influences of the Second Empire sprang greatly from the decreased cost of transportation after 1850. Furthermore, in support of this rail expansion, French scientists, engineers and entrepreneurs made important contributions to steam technology and laid the foundations for an "important machinery and engineering industry."[15] By 1850, French machine exports exceeded imports by more than three to one and France had more steam engines employed in industry than all the other Continental countries combined.[16] France was a leader in technology. In both pure and applied science, the contributions of the French revaled those of any other nation of the mid-19th century.[17]

---

[14] Ibid.

[15] Cameron (66), p. 66.

[16] Ibid.

[17] Cameron (65), p. 329.

While recognizing that polyculture was a great improvement over older rotations to minimize regional risk of famine, transportation advances about mid-century went even further in removing this risk. The lower cost of transport increased the feasibility of inter-regional trade. Granthum argued that in view of increasing labor scarcity, decreasing transportation costs after mid-century could have stimulated increased regional crop specialization to offset rising labor costs among areas having different factor endowments.[18] Newell's regional data indicate that such specialization did not take place. The major grain crops showed changes in land usage of similar magnitudes in all the regions from 1820-1870. Wheat and oats hectarage increased appreciably in each of the nine regions Newell distinguishes. Rye hectarage declined in eight of the nine regions and increased only 1% in the ninth. Barley hectarage declined in seven of the nine.[19]

---

[18] Granthum (79), p. 18.

[19] Newell (92), Table 1, p. 13. The only exception appears in the western region, an area which Granthum (78), p. 188, describes as an area of large farms of from 20 to 100 hectares. Here wheat and oats area increases were double those of the national average.

The labor shortage also might have been countered by the substitution of labor saving mechanization. The leadership of France in machinery production and applied mechanical science about mid-century suggests that the supply capacity for agricultural machinery was present. Granthum confirms that, indeed, the cost of manufactured materials did fall as improvements in the art of joinery and power transmission went forward.[20] In fact, much improvement in farm implements did take place during this period. Granthum and Collins provided an excellent discussion of the advances in hand tool technology that took place after mid-century. Some of these advances had a significant impact on labor requirements, particularly harvest labor.[21]

Granthum demonstrated that the proliferation of farms of a size that could be worked by family labor with hand tools was the French response to agricultural

---

[20]Granthum (79), p. 19.

[21]Collins' (68) discussion of harvest methods showed that the substitution of the scythe and reaping fork for the sickle allowed labor savings of about 25%. This substitution only began the slow process of diffusion after mid-century. The sickle was the predominant harvest tool well past mid-century, pp. 83 and 88.

labor shortage.[22] In the following sections, Granthum's argument will be examined to determine how this evolution of farm size constrained French agriculture from adopting a technology based on purchased inputs.

Labor Market Imperfections and the Lag in Horse Mechanization

Hohenberg characterized the area of large farms of the northeast as a modern agricultural sector during the last half of the 19th century.[23] It will be useful to accept this dichotomy between modern and peasant farming to examine the impact of mechanization on French agriculture. It is reasonable to assume that mechanization proceeded fastest in the modern sector of large farms. Table 4-4 shows data of animal powered mechanization to indicate the extent of labor saving mechanization 1862-1908. (These data are to be considered indicators of trends rather than absolute numbers). It is the hypothesis of this discussion that given the gross differential of mandays of labor between manual techniques and draft animal techniques in tillage and cultivation procedures--Granthum's

---

[22] Granthum (78), Chapter 5, *passim*.

[23] Hohenberg (82), p. 27.

Table 4-4: France: Horsedrawn Machines

	Ploughs[1] (1000)	Seed[1] Drilling Machines (1000)	Hay Mowers[1] (1000)	Threshers[1] (1000)	Reapers[1] (1000)	Horses[2] mules & asses (1000)
1840						3606
1862	3200	11	9	101	8	3641
1892	3669	52	39	234	23	3581
1910						3752
+++						

	Farms[3] over 1 ha. (1000)	Farms 10-40 ha. (1000)	Farms over 40 ha. (1000)	Horsepower[4] per farm over 1 ha.	Horsepower[5] per male farm worker
1862	3226	637	154	1.1	.7
1892	3466	711	139	1.0	.8
1908	3418	746	148	1.1	.8

[1]Clapham (67), p. 172.

[2]France, Annuaire Statistique, 1951, p. 119.

[3]Data of farm numbers from Table 4-3.

[4]Horses, mules and asses divided by number of farms over 1 hectare.

[5]Horses, mules and asses divided by male farm workers.

data indicate that the labor savings obtainable by shifting from manual work to draft powered cultivation may have been as high as 50 to 75 man-days per hectare[24]--the failure to make a decisive change from manual cultivation (culture a bras) to plow cultivation (culture a la charue) was a missed opportunity for technical change and was a major impediment to productivity growth.

The data of Table 4-4 show that the horse and mule population expanded by less than 5% in the 70-year period 1840-1910. During this same period, cultivated fodder output increased sevenfold. If animal feed was a constraint to draft herd size before 1850, clearly this constraint was removed with the increased output of fodder after 1850 shown in Figure 1-1. Considering that draft power was a substitute for manpower, the significance of the static horse population is emphasized by the essentially unchanged ratios of horsepower per male farm worker: there was little change in factor proportions of these substitute inputs. Furthermore, since oxen was the predominant source of power in much of French agriculture, the growing commercial importance of livestock products

---

[24]Granthum (79), p. 21.

during this period suggests that the total availability of draft power must have declined over the 50-year period before 1910. While the national cattle herd grew slightly less than 10% between 1870-1910, per capita consumption of meat doubled from 57.1 lb. to 105.4 lb., 1862-1910. This was accompanied by a reduction in the age of marketing from 6-8 years in the former period to 3-5 years in the latter. At the same time, the dressed weights of cattle increased nearly 40% and that of calves nearly doubled.[25] All of the above would have substantially reduced the availability of cattle for draft work.

The data of reapers and hay mowers in Table 4-4 in 1862 and 1892 leave little doubt that the greatest bulk of the harvest cutting was accomplished with hand implements in both periods although the scythe had displaced the sickle by the later date. So, few reapers, mowers and seed drills are in evidence that so late as 1892 draft power mechanization of these farm evolutions had made no definitive impact even on the largest farms. The data indicate only one reaper for every six farms over 40 hectares in 1892.

Having previously noted the way farm wages rose

---

[25]Michael (89), pp. 115-16.

from 1850 to 1910, the effect of not adopting horse-drawn mechanization can be examined in Figure 4-2. Assume perfect competition in the product market. All workers are using manual implements. Under peasant farming conditions with little fixed costs and a production function with an area of constant returns to scale, C_1 which is tangent to the price line from A to B describes the long-run average cost curve of a farm employing off-farm as well as family labor. C_3' and C_3'' describe an identical horsedrawn technology under different assumptions. In the case of C_3' there is no advantage to horsedrawn technology over manual technology up to output level q_o. Output q_o can be produced at the same cost with either technology. If, however, farm wages rise in the labor market, the farm cost function shifts to C_2 where C_1 and C_2 are identical to family labor capacity output, q_1, if family labor does not impute its new market value. (Implicitly, C_1 and C_2 contain divergent labor supply schedules. C_1 implies the horizontal family labor supply function; C_2 implies the upward sloping curve of the labor market). The farm operator must adopt horsedrawn technology C_3' to maintain his output level q_o or reduce output to q_1 where the farm can be managed without hired labor. The divergence in family labor

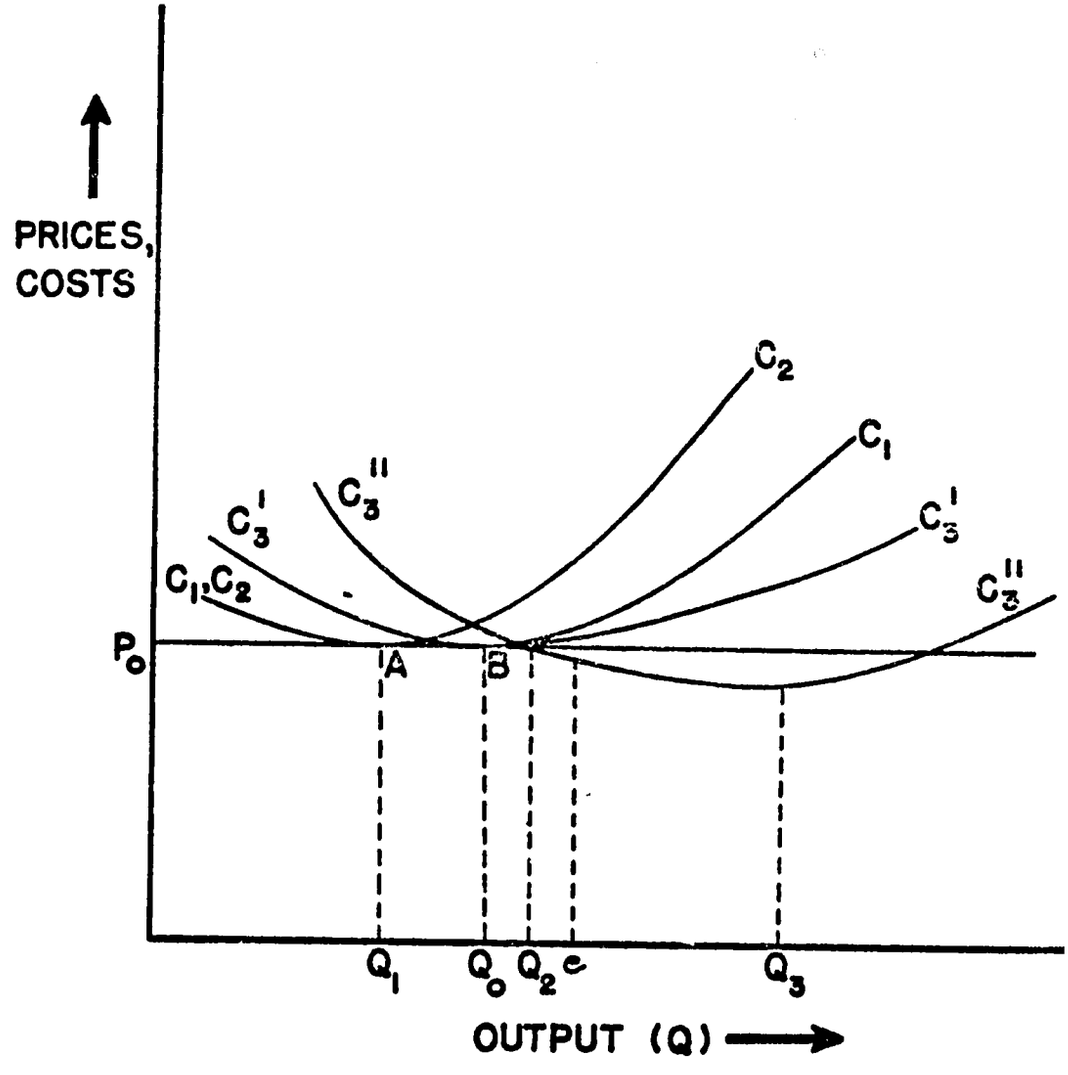


FIGURE 4-2: THE EFFECT OF LABOR MARKET IMPERFECTIONS ON FARM SIZE

cost and hired labor cost biases his decision to reduce to q_1 since at q_1 returns to family are the same as they would be at q_o.

C_3'' represents the same horsedrawn technology where it is assumed now that this technology is superior to manual technology but precluded by imperfections in either the land or credit market which prevent the farm operator from expanding to some threshold output q_2. Initial equilibrium at q_o assumes there is equilibrium with the forces which cause the land or credit market imperfections, as well as the standard microeconomic equilibrium assumptions.[26] As wages rise to C_2 there may be added inducement for some operators to marshall the necessary resources to overcome the institutional deficiencies of the land or credit market to enable them to expand to threshold size and eventually to q_3. However, such action is not cost free: to get from q_o to q_2 requires the acquisition of land regardless of the deficiencies of the land market. To reduce to family farm size q_1

---

[26]North and Thomas (30), define an institutional arrangement that which specifies the ways by which economic units can cooperate or compete. These institutions would be in equilibrium so long as the discontinued expected costs from changing some institutional arrangement exceed the discounted expected gains, p. 5.

is cost free assuming the operator views his own opportunity cost as C_1, less than market labor value. The willingness to accept less than opportunity market value creates a bias against adopting the horsedrawn technology.

Granthum's thesis has demonstrated that the peasantry were risk avoiders rather than income maximizers.[27] The technical and economic constraints on interregional trade meant that regional crop failure resulted in little or no work, no reliable income and possible starvation for the landless laboring class. This reinforced other incentives to own land because even in years of bad crops, the land could be counted on to provide a minimum subsistence for the family. This "perception of the riskiness of life"[28] provided an economic explanation--emotional and psychological reasons aside--for why the peasantry were willing to accept less than their opportunity cost to work their own land. "Faced with the choice between working at high but uncertain wage and low but stable rates of return to effort on their own farms, French peasants

---

[27] Granthum (78), p. 208 following.

[28] Ibid., p. 184.

and workers in the second half of the 19th century chose small farming."[29]

In the early part of the 19th century, the expected value of the return from farming their own land may have been greater than the expected value of the return from wage labor even though the land was worked to a point well below the marginal return to wage labor. The expected return to own farm work would have been higher due to the possibility of zero income to day laborers in years of crop failure.

With the diffusion of polyculture and improved transport, the probability of local famine was mitigated. However, the indicators of the diffusion of polyculture, cultivated leguminous and root fodder crops, shown in Figure 4-1 that the diffusion process only gathered momentum after 1840. It was previously indicated that this date also marked the beginning of the expansion of rail transport. Famine possibilities in rural France did not cease suddenly. Nor did peasant expectations of famine. The riskiness of the dependability of wage income apparently remained a major consideration in both the peasant avoidance of wage income and the peasant demand for land long past mid-19th century.

---

[29] *Ibid.*

While these attitudes toward risk cannot be directly measured, a measure of labor mobility, the willingness to relocate in search of employment, may be considered to reflect the rate at which these attitudes either prevailed or waned. The data in Table 4-5 show that in 1862 only one person in ten had relocated away from the department of his birth. By 1910, only two in ten were mobile. During this same period, money wages in agriculture decreased from 75% to 61% of industrial wages. From 1860 to 1930, relative agricultural income per capita declined from 72% to 41% of non-agricultural per capita income.[30] These data of relative wages and incomes support the hypothesis of peasant risk minimizing behavior. Peasant farm operators were willing to accept less than their opportunity value to work their own land. They were unwilling to leave their small plots of land to move in search of work.

Table 4-3 shows that, indeed, the number of small

---

[30] Kindleberger (25), p. 228 following. There has been disagreement in the literature about the difference in French agricultural and industrial wage and per capita income levels. Kindleberger reviews the argument and concludes that "one must conclude that the majority of observers are right and that the average income in agriculture has been below that in the rest of the economy by some substantial fraction," p. 231.

Table 4-5: France: Labor Mobility: Percentage of People born in one department, living in another.

Year	%	Year	%
1862	11.3	1911	21.0
1872	15.0	1921	23.7
1881	15.0	1931	25.0
1891	16.8	1936	25.5
1901	19.6		

Source: Kindleberger /25/, p. 233.

farms increased while the number of the largest farms decreased throughout the last half of the 19th century. Peasants desired small farms more than labor market participation. Large farmers unable or unwilling to hire labor sold or rented unused land. One result of this proliferation of small farms was the worsening of the parcelization of the rural landscape. By 1882, the nearly 5.6 million farms were located in about 125 million parcels--over 20 parcels per farm.[31]

The Effect of Labor Market Imperfections on the Induced Innovation Hypothesis

The induced innovation hypothesis would suggest that the labor shortages of the last half of the 19th century might have been expected to induce labor saving mechanization. The hypothesis would predict that this relative factor shortage was signalled to the industrial sector by changing factor prices. However, the existence of two separate labor supply functions of the large farm sector and the small farm sector had the effect of confusing the inducement signal. Granthum has shown that those peasants who were risk minimizers preferred not to enter the labor market. Instead, they apparently imputed their labor at subsistence level so

---

[31] Michael (89), p. 32.

that they could garner the financial resources to rent or buy land. The evidence of declining day laborers and increasing small farm numbers was shown by Granthum to confirm that peasants were withholding market labor to buy and farm their own land.[32]

In a traditional subsistence economy such as France in the 19th century, this was the one sure source of wealth. With self-sufficient production, the primary mode of the polyculture sector wealth was measured in land, not in income. The possession of land was the basis of social hierarchy and sign of prestige.[33] It is not surprising that historically in France the prices paid for small plots of land were 20% or more higher than land sold in a larger block.

The divergence between the assumed horizontal curve for labor in the polyculture sector and the upward sloping curve of the large farm sector was due to institutionally determined labor market deficiencies. The peasant belief in the insecurity of wage income in conjunction with the emphasis placed on land ownership discouraged labor market participation. This avoidance of the labor market resulted in the institutional

---

[32]Granthum (78), p. 208 following.

[33]Mendras (88), pp. 29 and 51.

form of the small farm. Existing farms reduced their size to an area compatible with family labor. Landless laborers acquired small plots and became small operators.

To see how these diverging labor supply schedules confused the signal to induce labor saving mechanization, examine Figure 4-3. Figure 4-3 shows that the true machinery-wage price ratio, the bottom curve of the graph, declined decisively throughout the last half of the 19th century. This curve reflects the actual market wage rate. However, the bulk of those economically active in the agricultural sector preferred to work their own farm at a subsistence level rather than offer labor service at the going wage rate. This preference may be assumed to have caused the price ratio to decline only as shown in the upper curve of Figure 4-3. This curve assumes that the wage level of 1852 was imputed by peasant operators throughout the century. If we assume the wage level of 1852 was the subsistence level, then as wages rose in the labor market after 1850, those who did not participate in the market continued to view their 1852 imputed wage level as their marginal value. They did not impute the wage increases after 1852 to the value of their work. In effect, the upper most curve of Figure 4-3 reflects only the changes in the machinery price index.

NOTES:

1. SUBSISTENCE WAGE IS CONSIDERED AS THE 1852 WAGE LEVEL CONSTANT OVER THE PERIOD
2. SUBSISTENCE WAGES ADJUSTED FOR COST OF LIVING CHANGES IS THE 1852 WAGE LEVEL ADJUSTED
3. MARKET WAGES ARE THOSE REFLECTED IN THE FARM LABOR MARKET

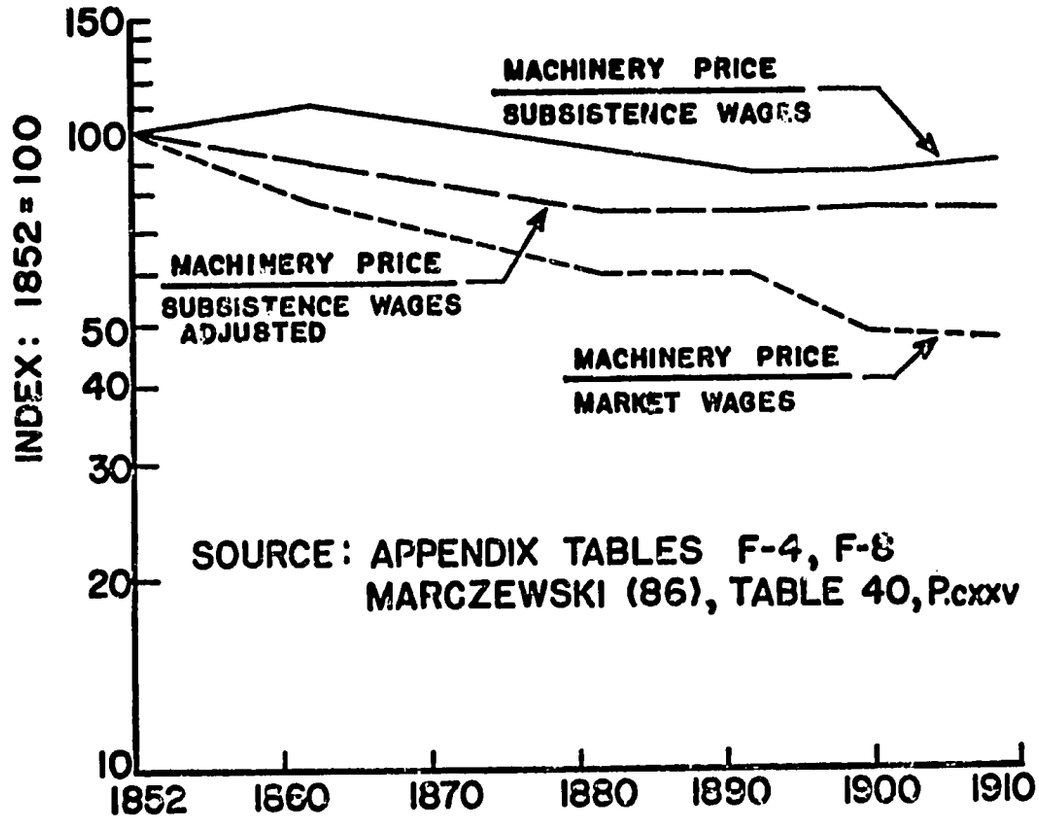


FIGURE 4-3: FRANCE: DISTORTIONS OF THE MACHINERY-WAGE PRICE RATIO, 1852-1908

Alternatively, the middle curve holds constant that wage level of 1852 after adjustment for cost of living changes. Under either assumption describing the imputed subsistence wage rate of small farm operators, a distortion is evident between the market price ratio and the price ratio viewed by the bulk of the agricultural sector. Nearly 85 percent of agricultural holdings in 1892 were less than ten hectares in size. Clearly, therefore, the bulk of the agricultural population lived and worked on those farms subject to the subsistence view of their opportunity cost.

The assumed mechanism to signal the direction of needed technical advancement is the change in factor prices to reflect increasing scarcity among the factors. Since mechanization is a substitute for labor, when labor becomes scarce, the induced innovation hypothesis implies that mechanical innovation will come forth to ease the pressure on this inelastic factor.

The bulk of the French agricultural labor force clearly imputed or received not the market wage but a wage near the subsistence level. Thus, for those in this sector, their view of the machinery price-wage ratio did not decline as the bottom curve of Figure 4-3. There was a gap between the change in the price

ratio perceived by those who were in contact with the labor market and the perceived change by those in the subsistence sector. This gap will be considered a measure of the institutionally determined labor market deficiency.

Linear homogeneous demand-type equations of the sort employed in Chapter III were estimated in an attempt to search for the impact on the inducement mechanism of the gap in the different factor-price ratios indicated above. The dependent variable was work stock per male worker. Independent variables were indices of the machinery-wage price ratio and the land-wage price ratio. Quinquennial observations were made from 1850 to 1910. Three equations were estimated employing first actual market wages and then the two assumed subsistence wage levels discussed above in the ratios. The results are presented in Table 4-6.

The results of the estimated equations show no association of the workstock per male worker with either of the independent variables in any of the equations. F-tests of the regressions and t-tests of the coefficients are all non-significant at the usual levels of significance.

During this time period, workstock per male worker varied only between 0.7 and 0.8. The conclusion

Table 4-6: France: Regressions of workstock per male worker on relative factor prices under three assumptions about imputed wages, 1852-1910.

Regression Number	Intercept	Coefficients of Price of: Machinery Relative to Wages	Land Relative to Wages	R^{-2}	S	F
1.) Actual market wages	.463 (.464)	.014 (.211)	-.199 (.281)	.17	.464	2.05
2.) 1852 wage level adjusted for cost of living	3.905 (1.880)	-.10 (.16)	-.85 (.48)	.31	1.88	3.24
3.) 1852 wage level constant	2.913 (1.704)	-.432 .22	-.274 (.30)	.21	1.70	2.36

Equations are linear in logarithms.

Data are taken from Appendix F. Data before 1870 not contained in Appendix F are from sources indicated in Appendix F.

Reproduced from best available copy.

suggested by these non-significant regressions is that the demand for labor saving mechanization was not related to either the relative cheapening over time of machinery or the relative increase of wages compared to land cost. This conclusion supports the hypothesis that there was no inducement signal generated by the agricultural sector because most of the sector was divorced from the labor market.

There is no doubt that peasant operators imputed less than their opportunity cost to become or remain small cultivators. It is unquestionably true that French peasants historically have bid their own labor services at low levels to acquire and hold land. Yet, there remains the question of why this behavior was so pervasive well into the 20th century.

Granthum demonstrated that possession of even a small plot offered security that more than outweighed the higher wages that were available in the labor market. However, Granthum's argument loses credibility towards the end of the 19th century. By that time, the spread of polyculture had substantially raised per capita production and reduced the chance of local famine. Nevertheless, it is important to recognize that while the initial forces that gave impetus to non-participation in the labor market and the proliferation of small

farms were removed before the end of the century, the institutional arrangements of small farming still required a family labor force to produce the labor intensive crops. Furthermore, the institutional arrangements that evolved with the diffusion of labor intensive polyculture in the 19th century created a new set of barriers to labor market participation.

So long as the mere possession of land remained the basis of wealth, and income from its product was secondary to self-sufficiency, the perception of loss of wealth was much greater to the farmer's son thinking about migration than the perception of grain from higher wages.

Furthermore, Glenn Johnson has demonstrated that it was not necessarily irrational for the peasant to have continued working in agriculture for less than his apparent opportunity cost. If the peasant's earnings were less than non-farm income but still attractive enough to keep him in farming after discounting the costs of moving, disruption of family ties and costs of retraining involved to change occupations, then the peasant remained trapped in agriculture.[34] Considering the level of education of the peasantry, retraining

---

[34]Johnson (22), p. 83.

expense could have been quite high.

French education laws made schooling available only in larger villages and cities until 1867 when the law was changed to provide schooling for all villages of more than 500 inhabitants. This village system still missed most of the peasantry. Compulsory education for all children was not made law until 1881.[35] Even then, parents contrived to keep their children out of school. Education was not part of the peasant tradition[36]--not part of the institutional structure of polyculture.

Since 85% of farms in 1892 were less than ten hectares, the overwhelming majority of the agricultural population were part of the polyculture sector. The overwhelming majority of the rural population was, therefore, affected by economic drives and behavior patterns that derived from the institutional arrangements of polyculture. One result of these institutional arrangements was the imputation of less than actual market opportunity cost of labor. Figure 4-3 demonstrated how this would have affected the hypothesized signal mechanism of inducted innovation.

---

[35]Toutain (98), Chapter IV, passim.

[36]Auge-Laribe (64), pp. 123-24. "Lire est pour lui une fatigue et une ennui."

The effect on productivity of failure of the inducement mechanism due to institutional constraints has been demonstrated in Figure 1-2 in Chapter I. When the inducement mechanism does not reflect the need to lessen the constraints of the inelastic factor, no new technology is developed by the industrial sector and productivity increasing isoquant shifts along the meta-production function are not facilitated.

While the labor using diffusion of new husbandry in France in the 19th century might have induced labor saving mechanization as market wages rose, the existence of two separate labor supply functions for the large farm sector and the polyculture farm sector resulted in either no effective inducement signal (as the regression results of Table 4-6 suggest) or a confused signal. The result was little or no supply response from the industrial sector and little improved mechanization in either sector. The few data of harvest and planting machinery previously discussed confirm that these forms of mechanization had not conquered the larger holdings as late as 1892. Even on the larger farms, the scythe remained the primary harvest technique.

Instead of some productivity increasing technological innovation, Figure 4-2 suggested that the existence of two separate labor supply functions induced

a distribution of production to farms having the cheaper labor supply. Thus, the proportion of output from the low productivity polyculture farms increased in the 19th century. The decreasing man-land ratio and constant workstock-man ratio reinforce this hypothesis. (Hectares per male worker decreased from 8.3 to 6.6 from 1820 to 1875. The man-land ratio did not exceed 8.3 again until 1925. Appendix table F-1). Had the proportion of output from the large farm sector increased in a significant manner, these two ratios would have expanded.

The relative abundance of threshing machines among the data of Table 4-4 appears to be an interesting contrast, or exception, to the general failure of the adoption of mechanization. Collins attributed the early adoption of the thresher to its cost divisibility through hiring as well as the fact that the flail required the "services of strong adult males"[37] who, Granthum indicated, were needed back in the fields to carry out the early autumn plowing and the harvesting of the root crops. The adoption of the thresher, thus, seems to have been a narrowly focused response to a

---

[37] Collins (68), p. 94. Collins also sites the lack of an intermediate technology between the flail and the thresher.

specific bottleneck in the grain harvest that impinged universally on both the peasant and modern sector. As the adoption of root crops went forward, this created a pressure on the farm operator of the type Rosenberg has described as "compelling and fairly obvious"[38] to simultaneously get his grain threshed and his root crops harvested. The more intensive rotations did not allow time for flail threshing. The threshing machine was, therefore, adopted.[39]

Productivity Under Dualism in Agriculture

The large farm, small farm dichotomy provides a useful focusing device through which to view the effect of the spread of the more land intensive, labor using crop rotations on changes in output and productivity. It also facilitates a view of the time span required for the diffusion of the new husbandry techniques.

The data of output mix in columns 1, 2 and 3 of appendix table F-2 indicate that the value of crop products grew proportionately until nearly the last quarter of the century; the ratio of crop to livestock

---

[38]Rosenberg (34), p. 4.

[39]The narrative of the thresher follows Granthum's treatment of its use (79), p. 25.

products in final output was constant at about 2:1 from 1790 to 1870. Thereafter, the value of crop products declined about 10% through 1890 and then began to increase again; livestock products continued their uninterrupted growth. In 1910, the real value of livestock products in final output was 60% higher than their value in 1870; the value of crop products in final output was 10% higher than in 1870.

The 50-year period prior to 1870 was one of rising agricultural prices; the 40-year period after 1870 was one of declining prices. Grain prices fell more than livestock prices so that the relative profitability of these two output classes continued to favor livestock products. Figure 4-4 shows that the price ratio of wheat to meat declined from about mid-century to 1890 and then leveled off to World War I. At the same time, the price ratio of meat to fodder input essentially rose throughout the same period. Fodder supply was expanding and its price was declining.

It is noteworthy that although the comparative profitability of livestock and grain products had shifted to favor the former by mid-century, the area planted to wheat remained within two percent of 7 million hectares until 1900. In fact, as Figure 2-12 indicated, there was no significant reduction in either

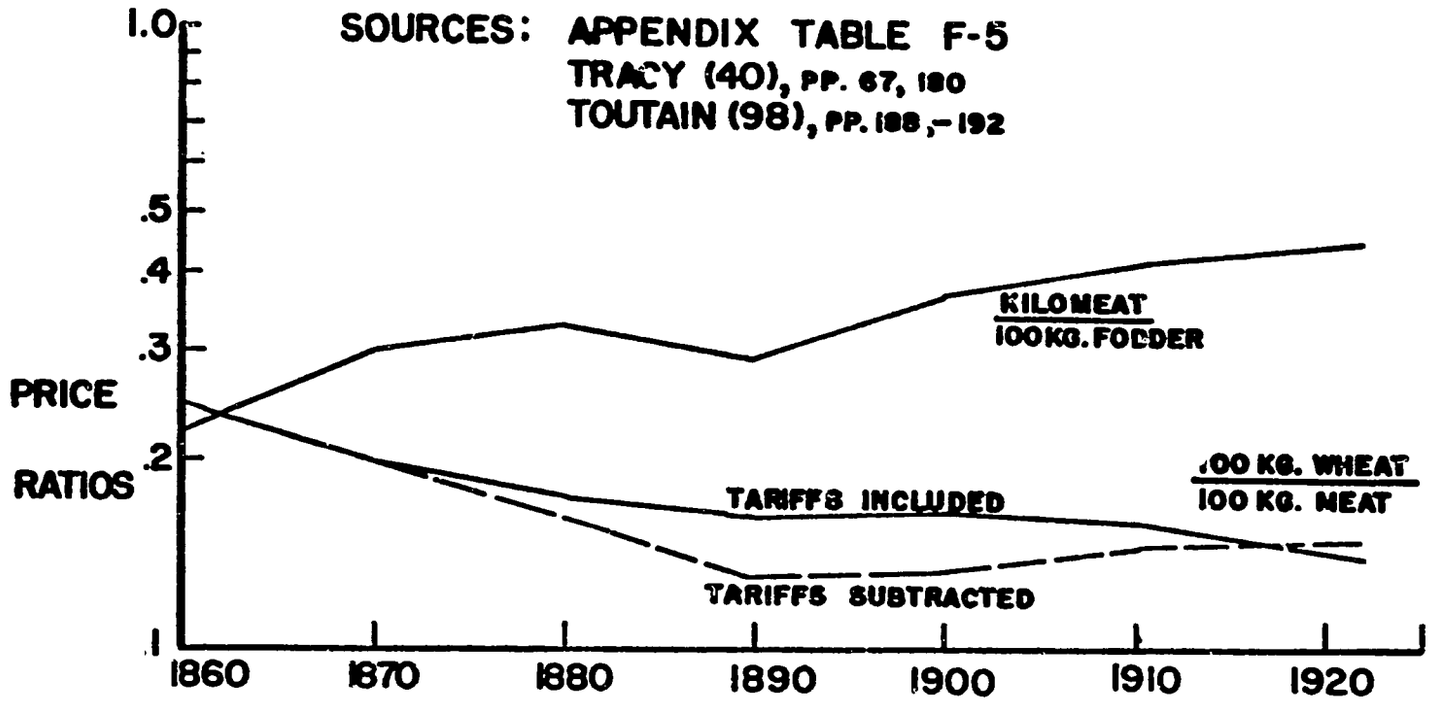


FIGURE 4-4: FRANCE: FACTOR-PRODUCT AND PRODUCT-PRODUCT PRICE RATES

wheat or total grain hectarage until after World War I. Thus, long after the product price ratio had changed to favor the expansion of the livestock sector and even after the introduction of imported grains in the last quarter of the 19th century, resources were not reallocated from food grain production. There was not even a shift to feed grains. It is hypothesized that in view of the spread of labor using crops and the increased urban demand for income elastic livestock products, the failure to shift resources out of wheat after 1870 was a missed opportunity to maximize the comparative advantages of manual polyculture in the production of livestock and fodder inputs to livestock.

Several facets of 19th century French agriculture must be understood to explain the continued allocation of land to wheat throughout the century. Previously, it was shown that interregional trade was difficult and expensive before 1850. Although the replacement of the exclusive grain rotations with the mixed cropping and livestock patterns of agriculture--polyculture--offered improved regional security within this autarchic situation, wheat, the main cash crop and source of subsistence, continued to dominate cropping plans. The expansion of the small farm sector throughout the 19th century, indicated by the expansion of small farms

in Figure 4-5, resulted, therefore, in the expansion of wheat as well as the other crops of polyculture. The continued expansion of wheat hectarage after 1850 concurrent with the growth in the number of farm units strongly suggests that wheat production remained a significant part of each of these peasant farms. In only ten of 87 departments did wheat occupy less than half of the arable land in 1882. Only in Corsica did the percentage fall below 40.[40]

The continued expansion of small farms and polyculture after 1850, clearly a result of the comparative advantage of labor intensive crops, just as clearly militated against efficient specialization into livestock production. Michael's analysis done in 1925 suggested that well into the 20th century the livestock raising industry was not specialized to any considerable degree; the animals in practically all cases were but one item in the system of diversified farming. The great majority of farms maintained at least two or three, but seldom more than a dozen head of cattle, some sheep and a few hogs. The animals were sold a few at a time "usually at a local fair or some periodic

---

[40]Golob (77), p. 81.

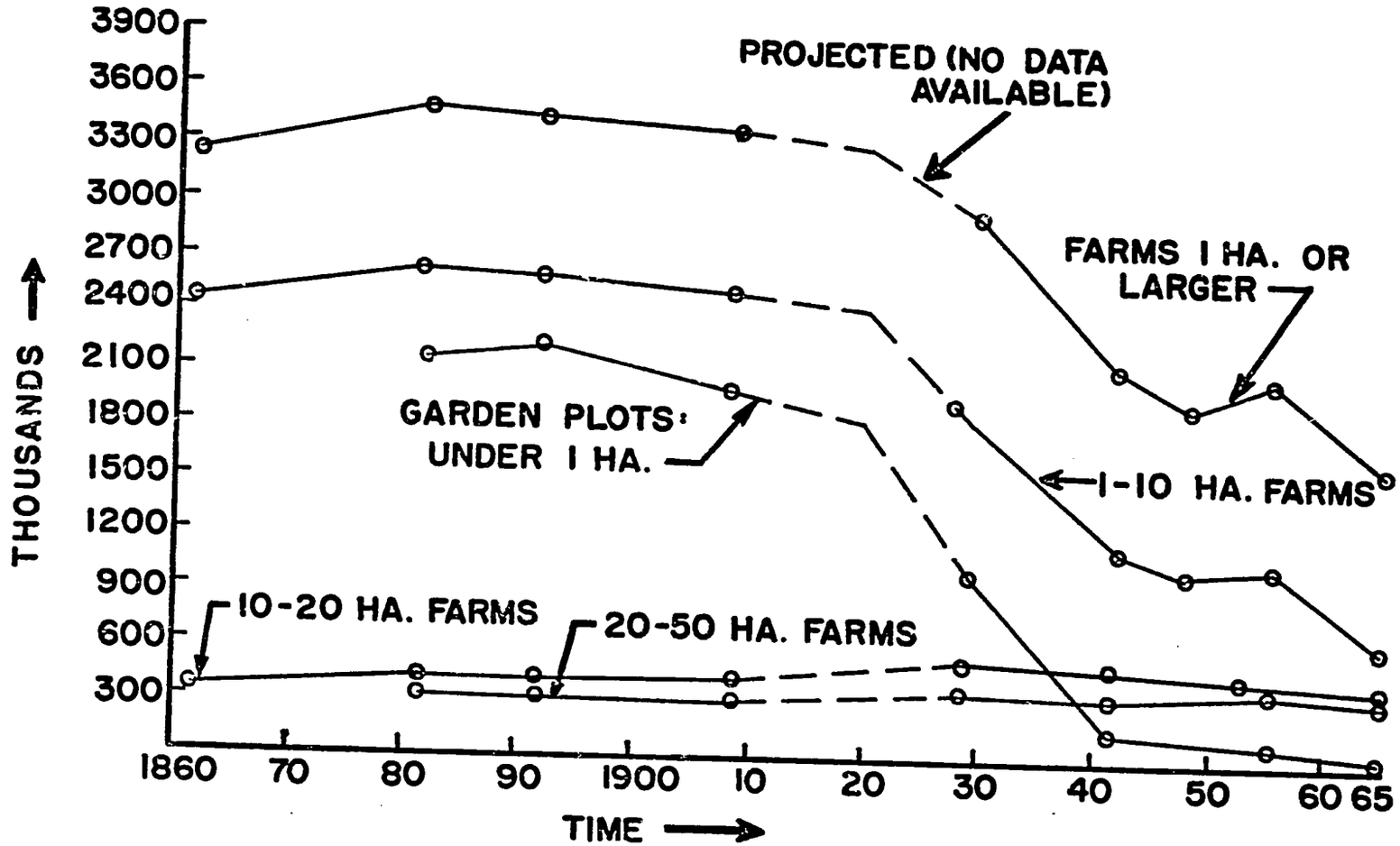


FIGURE 4-5: FRANCE: THE PREVANCE OF SMALL FARMS

market day."[41] The greater portion of all livestock was consumed in close proximity to the producing farm.

Another point that must be remembered in consideration of the resources allocated to wheat is that until imported North American grain began arriving in the late 1860's, reallocation of existing resources away from wheat was not feasible. As indicated, however, wheat production was strongly rooted to the polyculture system of agriculture. Figure 2-12 revealed that not until after World War I was there any significant reallocation of inputs away from food grain production.

The increase in grass pasture indicated in Figure 2-12 from 1900 to 1910, therefore, largely was accounted for by an expansion of total agricultural land and the continuing reduction of fallow, a trend that began over 100 years earlier. Some minor industrial crops, as well as rye, also declined in area adding to the grassland area.

Although aggregate draft power for the entire of France appears to have declined from 1860 to 1910, as previously indicated, this change may not have reflected the conditions in the large farm sector. The static horse population may have been redistributed

---

[41] Michael (89), p. 114.

in the direction of the large farm sector concurrent with the redistribution of labor resources to the small farm sector. Granthum's regional analysis supports such a hypothesis. His data show that from 1862 to 1882, small farms expanded in the south and west while farms over 30 hectares expanded in the northeast and east.[42] His research indicated that regional differences existed with respect to the relative productivity of capital-intensive and labor-intensive tillage. This lends support for the redistribution of the horse population. However, there is no clear evidence of the extent of mechanization in the large farm sector.

If technical progress did occur in the large farm sector, then its small impact on the aggregate land and labor productivity measures displayed in Figure 2-14 reveals an interesting observation. Farms over 40 hectares, while only 2.5% of farms in 1892, included 35% of arable land. Much of French cultivated land was, therefore, subject to capital-intensive farming practices. However, the nearly constant partial productivity measures shown in Figure 2-14 throughout the 19th century suggest that either actual progress

---

[42] Granthum (79), p. 30.

in the modern sector (again using Hohenberg's designation) was not extensive or the proportion of total output from this sector was insufficient to have an impact on aggregate output including the product of the polyculture sector. Furthermore, whatever mechanical advances did occur were insufficient to have any impact on the aggregate land/man ratio (see Table 2-5). In either case, attention is directed back to the traditional manual techniques of production maintained in the polyculture sector as the primary retardative influences of French agricultural growth after 1870.

A considerable proportion of marketed livestock was produced in the polyculture sector.[43] It will be instructive to take a closer look at the data of livestock and fodder production. It has been shown that these labor-intensive products were the economic basis for the expansion of the peasant sector. The data of these products of polyculture support the hypothesis that the agricultural revolution based on improved rotations which became evident sometime after the beginning of the 19th century, was still in an evolutionary state after the beginning of the 20th century. Table 4-7 shows the evolution of animal feeding patterns from

---

[43]Michael (89), p. 35.

Table 4-7: France: Animal Consumption of Crop Products

Year	Grains and Potatoes	Fodder	Straw
1850	10%	51%	39%
1880	8%	60%	32%
1910	7%	74%	19%
1937	7%	79%	14%

Source: Toutain (98), p. 52.
(Percentages calculated from physical quantities)

Composition of the Fodder Component

Year	Natural Grass	Cultivated Grass	Roots
	(million quintals)	(million quintals)	(million quintals)
1850	175 (55%)	95 (30%)	48 (15%)
1880	175 (40%)	193 (36%)	129 (24%)
1910	253 (26%)	351 (36%)	370 (38%)
1937	296 (25%)	343 (29%)	556 (46%)

Source: Toutain (98), p. 181
(Percentages calculated from physical quantities)

predominately grazed straw and natural grass at mid-century to predominately cultivated grasses and roots by 1910. These changes in feeding patterns go hand in hand with the adoption of the new husbandry regimens.

Nearly 70% of animal intake consisted of natural meadow grass and straw in 1850. By 1910 the mixture of products fed consisted of only 37% natural meadow grass and straw.[44] The percentage of feed grains in the ration declined from 1850-1910. The expansion of cultivated grasses and roots in the intervening 60 years represented not only a significant improvement in the nutritional quality of the diet but also a significant expansion of the improved rotations of the new husbandry techniques of production.

Throughout the 19th century, cultivated fodder crops along with natural pasture grass and straw were primary inputs to livestock production. Cultivated fodder crops also contributed important nutrients and beneficial effects to the soil in the new husbandry rotations. These competitive and complementary

---

[44]These data do not take account of animal feed products originating in industry. Toutain maintains that these expanded in an interesting fashion but he was unable to determine their part of the livestock diet (98), p. 178.

production relationships will be explicitly identified in order to describe the effects of the new husbandry rotations on production in the polyculture sector. Fixing the land area and family labor supply a model has been constructed to indicate the effects of root and leguminous fodder on grain production as well as the importance of these fodders in the livestock ration. Assuming that the small farm operator was a revenue maximizer, a simple model has been hypothesized to describe the polyculture sector (Appendix A).

This simplified model of the polyculture sector can be used to view the expansion of output in the small farm sector as a shift of resources from the old production methods to the new husbandry practices. This model explicitly assumes a set of production functions that describe the new husbandry techniques. It is hypothesized that this model is sufficient to account for output increases in the polyculture sector throughout the 19th century and well into the 20th. The larger implication of this hypothesis is that the agricultural revolution that began after the French Revolution was still in an evolutionary state after the turn of the 20th century. There was little diffusion of a newer technology based on purchased inputs.

The yield of wheat displayed in Figure 4-6 may

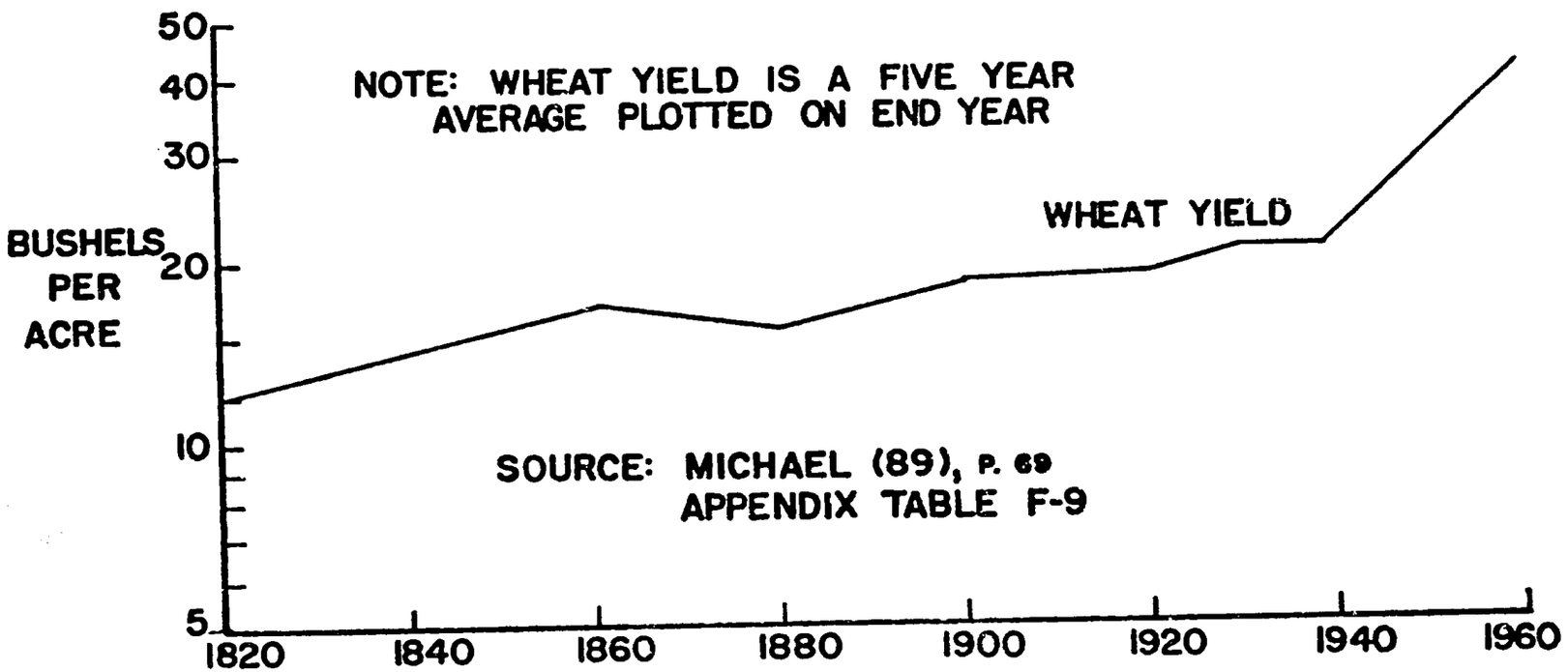


FIGURE 4-6: FRANCE: WHEAT YIELD 1820-1960

be interpreted to provide a useful indication of the time for diffusion of the new rotations of polyculture. The aggregate wheat yield of France grew steadily from the 1815-1820 period until 1860. Newell's interpretation[45] of Toutain's output data[46] in Appendix Table F-1 indicate that agricultural output and productivity growth rates from 1820-1870 were not surpassed until after World War II. The model for polyculture of Appendix A suggests that the sustained growth in wheat yield through 1860 was indicative that the production relationship between leguminous fodders and grains in the rotation was in the complementary range as late as 1860. Until the production relationships of grains and fodders became technically competitive, the yield of grain increased as the new production processes diffused throughout France. The static wheat yield for 20 years following 1860 suggests that during this period fodder production had diffused sufficiently to become competitive with wheat and other crops for resources. Figure 4-1 indicates that after 1880 the diffusion of grass and root fodder cultivated area was

---

[45] Newell (92), p. 4.

[46] Toutain's data is not given in wheat units. See notes to Table F-1 for the conversion process.

much slower. These data in conjunction with the model of Appendix A weakly supports a conclusion that polyculture practices, or the package of technology generally referred to as "new husbandry" had largely diffused across France by the last quarter of the 19th century. Furthermore, the very small rate of growth of wheat yield from 1860 to 1940 suggests the hypothesis that very little more advanced technology enjoyed wide diffusion over France from 1860 to 1940.

The polyculture model of Appendix A also indicates the effect of the diffusion of the new rotations on livestock production. The expansion of fodder crops shifted up the livestock isoquant. Strictly interpreted, however, the new rotations did not represent a new technology for the production of livestock. Rather, polyculture only provided a larger, more nutritious diet with increased year-around dependability.

The data of column 6 of Table 4-8 indicate that the increased percentage of fodder crops planted allowed the nutritional component of animal diet measured in aggregated feed units to increase nearly threefold from 1850 to 1910. The straight forward implication of this fact is that as more and more resources were devoted to the set of production functions that described the new husbandry rotations, livestock output

Table 4-8: France: Indexes of Livestock Output and Crops Fed to Animals Adjusted for Improved Nutrition Content

	(1) Index of Quantities of livestock products[1] Meat	(2) Milk	(3) Butter, Cheese	(4) Index of value of final livestock products, 1905-14 Francs[2]	(5) Index of aggregated quantities of crops fed to livestock[3]	(6) Index of crops fed adjusted for improved nutrition[4]	(7) Index of livestock output crop per feed unit input[5] (4)
1850	100	100	100	100	100	100	100
1880	152	123	120	137	143	163	88
1910	186	205	206	197	212	292	73
1937	211	302	293	276	241	333	72

Notes:

1. Sources: 1: Toutain (97), p. 14.
   2: Toutain (97), pp. 128-29.
   3: Toutain (97), p. 52.
   4: The composition of the animal diet was determined from Toutain's data on pp. 52 and 81. The components were converted to total digestible nutrients (TDN) based on Morrison's data. This assumes that (1) TDN in the volume of feed more accurately indicate nutrition units of the French 19th century animal diet than simple unweighted quantities, and (2) that TDN remained constant. Elements of the animal diet and their TDN were: red clover, 53.8%, natural pasture grass, 51.7%, wheat straw, 35.7%, rye straw, 41.2%, barley, 78.7% oats, 75.4%, potatoes, 17.3%. With the aggregated feed units, column 5 was adjusted to reflect increased nutrition units of the changing livestock diet. Column 5 shows the increased volume of diet. Column 6 shows the increased nutritional units of the diet.

   Source: Morrison (29) 1936, Appendix I.

   5. The index of value and final livestock products divided by the index of crops fed adjusted for improved nutrition.

increased commensurately. Column 7 of Table 4-8 indicates furthermore that from 1850 to 1910 livestock output showed diminishing returns to the feeding patterns of the improved ration. This is the expected result of movement along an existing normally shaped production function.

In view of the fact that the value of livestock products measured in constant francs doubled from 1850 to 1910 as shown in Table 4-8, it is noteworthy to compare the livestock carrying capacity of French land with that of other European agricultures. Table 4-9 shows that French agricultural land had the lowest livestock carrying capacity among six European countries. Furthermore, no significant growth in livestock carrying capacity developed from 1890 to 1930. Appendix Table F-6 shows that livestock units barely increased 10% from 1870 to 1910. This small increase in the livestock herd and the low comparative carrying capacity of French agricultural land make it difficult to argue other than that the improved feeding patterns provided by polyculture allowed livestock output to move out its existing production function.

This section has indicated that output increases for French agriculture throughout the 19th and into the 20th century associated with the diffusion of a set of

Table 4-9: Livestock Units per 1000 Acres,* Selected Countries

	1887-9	1909-13	1927-9
Denmark	254	384	532
Belgium	283	488	452
Netherlands	346	465	512
Germany	325	327	324
France	198	212	198
Great Britain	318	339	375

*Seven sheep or five pigs were considered as equivalent to one cattle or livestock unit. No allowance was made for horses, goats or poultry.

Source: World Agriculture (100), p. 136.

production functions that represented the production techniques of the new husbandry rotations. It was shown previously that these techniques placed heavy pressures on labor and resulted in an evolution of farm size to an area that could be worked with family labor. This reduction in farm size resulted in too many farms with too many people working for returns less than the opportunity value of their labor. This institutional constraint resulted in a missed opportunity for induced mechanical innovation. Instead, the polyculture sector evolved as a production system that could be worked with traditional manual techniques but with very low factor productivity. Within the polyculture sector the traditional preoccupation with self-sufficiency in wheat resulted in a missed opportunity to effectively organize resources in a manner to exploit livestock production. It was shown that the growth in livestock's share of aggregate output during the quarter century prior to World War I was largely accounted for by increased traditional inputs. Livestock were fed more and marketed earlier than they were earlier in the century.

Government Policy and Productivity

This section will examine the failure of

government policy to disrupt the low productivity of institutional arrangements of polyculture until after World War II.

Through 1940. The French tariff and quota response to the advent of cheap imported grains after 1870 has been well documented by the literature.[47] French trade policy through the early 20th century was always mercantilistic in its emphasis on national output and freedom from dependence on foreign sources. In agriculture, the focus of trade policy was the protection of wheat. Animal products were also protected but the main emphasis of the political oratory was directed to wheat. There was no tolerance by the government for the proposition that wheat might have been more cheaply imported so that some of the land then under wheat could have been devoted to other purposes. "Every reduction of the wheat area [was] regarded as a national disaster."[48]

A number of explanations have been offered for French tariff policies. Some seek to provide a rational

---

[47] See Tracy (40), Haight (80), or Golob (77) for additional information.

[48] World Agriculture (100), p. 139.

explanation for the agricultural protection as a policy of nationalism.[49] Surely it was. Some explain the tariff structure as designed to maintain the strength of a peasant agriculture in France. This argument asserts that it was the peasant who preserved that quality of independence for the individual which assured a nation founded on happiness and virtue.[50] Surely these sorts of generalizations are almost impossible to test or even to state with precision; still no study of French agriculture is completely without a tribute to the qualities which a viable peasantry contributed to national character.

This study will attempt to provide a more objective explanation for the trade policies. The large grain farmers, who marketed a larger share of their crop for cash than did the owners of small farms, were seriously threatened after 1880 by the incursion of lower-priced new continental grain. They actively organized the farm bloc and from this power base lobbied effectively for tariff protection. The growth of the agricultural syndicate movement in France closely paralleled the growth of imported foreign grains and

---

[49]Haight (80), p. 59.

[50]Griswold (17), pp. 113-14.

indicated the large farmers' desire to mobilize a rural mass movement as a political voice for equality with industry in the protection from imports. Wheat imports increased from 600,000 bushels average annually in the 1850's to 9 million in the 1860's, 28 million in the 1870's and 38.5 million in the 1880's.[51] The formation of syndicates required the repeal of laws dating from the Revolution which forbade free association based upon economic interest. These laws were modified in 1865 and repealed in 1884 in response to the pressure for agricultural syndicates.[52] Thus, as the economic interests of the large land holders were challenged, they began to organize the countryside to effectively defend their traditional agricultural practices. Although these syndicates became cooperatives for buying fertilizer, seeds and other inputs, their primary purpose was to preserve a bloc of voters committed to rally for what they were told and believed to be their economic interest: the elimination of foreign grain competition.[53]

---

[51]Michael (89), p. 52.

[52]Kindleberger (26), p. 33.

[53]There were other social and political considerations contained in the syndicate movement. Essentially, however, the main thrust of the movement

The inception of the agricultural syndicate movement was the type of institutional innovation which North and Thomas maintain must be considered endogenous to growth models.[54] By leading the movement, the large farmers were able to obtain the power to preserve through tariff barriers their existing grain enterprises. In the oratory leading to the passage of the various tariffs, the spokesmen for the agricultural sector always identified their interests with those of the peasantry. In fact, however, their vested interests were directly opposed to the peasantry. The large farmers were concentrated in the cash grain sector. The small farmers stood to profit from lower grain prices which would have encouraged the growth of livestock production and regional specialization into intensified crop production. The effect of the tariff was to distort prices in favor of wheat and discourage the polyculture sector from reallocating resources away from wheat. Figure 4-4 shows the magnitude of the distortion of the grain-livestock price ratio due to

---

appears to have been directed at insulating the peasantry to preserve traditional social and political attitudes as a power bloc from which to catapult the large farmers' viewpoints. See Wright (101) and Golob (77) for explication of these brief points I have taken from their treatments.

[54] North and Thomas (30), p. 5.

tariffs. Clearly, this distortion in the product prices had the effect of muting the shift of the iso-revenue function along the grain-livestock transformation function.

Students of French agriculture are in general agreement that the effect of the tariff barriers was to offset the stimuli towards greater regional specialization just at the time when changing world production patterns could have pushed the polyculture sector toward greater efficiency.[55]

Both the right and left elements of the political structure favored the maintenance of the small peasant. The peasants became pawns in the political power struggles as well as a welcome reservoir of votes.[56] Thus, the true effect of this tariff innovation was to shelter the agricultural sector from disruptive outside influences. This had the effect of preserving existing traditional production relationships constrained by the excessive fragmentation of the small holdings.

The tariffs were an institutional innovation actuated by the large grain farmers whose profitable grain operations were strained by the advent of imported

---

[55]Thompson (96), p. 127; Wright (101), pp. 17-18.

[56]Wright (101), p. 22; Muth (90), p. 23.

grains. Due to the poorly organized markets for the small and medium-sized farmers who controlled two-thirds of agricultural resources, it is hypothesized that they were unable to perceive the increased profitability of specialized livestock production. Furthermore, their strongly held traditions were rooted to polyculture. The peasants required no great oratory to believe their economic interests were best served by the tariffs.

Wright maintains that the result of tariff efforts aimed at isolation was to "petrify farming practices in their 19th century mold."[57] Thompson claims that the result was to shelter the rural sector so that "French agriculture persisted as a way of life rather than a commercial system until comparatively late in the nation's economic history."[58] The available data of parcelization show that the 5.6 million farms of 1882 located in 125 million separate parcels were reduced to 2.3 million farms by 1955 located in 76 million parcels.[59] The average number of parcels per

---

[57]Wright (101), p. 18.

[58]Thompson (96), p. 125.

[59]Data are from official sources reprinted in Michael (89), p. 32 and Muth (90), p. 21.

farm worsened from slightly more than 20 to slightly more than 30. These data confirm that the constraints imposed by the small farm system remained in existence well into the 20th century. Sargent called this fragmentation the greatest single factor limiting agricultural production.[60]

While the large grain farmers' response to the incursion of imported grain was essentially economic, the support given the tariff development by the peasant farmers appears to have sprung from behavior weighted in terms of preserving their existing and familiar organization of production. The polyculture system of farming was the result of the preference of rural people to work their own land at subsistence income rather than enter the labor market for higher wages. At the turn of the 20th century, using labor productivity as the measure, French agriculture had a labor surplus. The widening disparity between agricultural and non-agricultural wages and income per capita confirms that there was a surplus of agricultural labor. This surplus labor was obviously part of the polyculture sector, not the large-farm sector.[61]

---

[60]Sargent (95), p. 218.

[61]This apparent labor surplus in the aggregate

The labor surplus sector which resulted in low agricultural productivity was the basis for the wide range of hand-cultivated farm products which resulted in the excellence of turn-of-the-century French cuisine. As that behavior and those policies which resulted in the polyculture organization of agricultural resources are examined, it is important to recognize explicitly that well into the 20th century, government policy appears only to have been what the rural sector, particularly the large farmer spokesmen, asked for: to be protected and left alone. The peasant's support for the large farmers' claim that protection was required to protect agriculture was support for a policy that would not disturb the individual peasant's perception of the best organization of his resources. In the Schultzian framework, with his limited human resources, the peasant's farm organization was at a static utility and revenue maximizing equilibrium. He was anxious to preserve this.

The literature about French agriculture is filled with generalities describing the traditionalism in the rural sector. Such terminology, however descriptive, does not facilitate rigorous examination.

---

must be considered in conjunction with continued shortage in the hired labor market. Here wages continued to rise.

If, however, polyculture is understood in North and Thomas' terminology as an institutional arrangement between economic units which assured sustenance and revenue from the family plot of land, then traditionalism may be more clearly specified as opposition to those things which might alter this institutional arrangement. Willingness to change would come to the individual farmer when perceived returns were greater than costs of change. This would, of course, disturb the farmer's perception of his existing equilibrium and cause him to move in the direction of a new equilibrium.

To the extent that institutional structures, be they tariff barriers, poor education or others unnamed or unspecified, hampered or distorted the evaluation of actual--as opposed to perceived--costs and gains of change, these structures impeded movement to the new and presumed higher equilibrium. It is easy to see that the incursion of imported grain threatened to disrupt the polyculture farmer's perceived equilibrium. This increased supply lowered the price and reduced his revenue. Shifting output in response to new opportunities, however, required new and unlearned allocations with unknown results. So long as the gain from shifting cultivation practices remained unperceived, there was no force to alter the existing polyculture

structure. Therefore, there was a force to preserve his existing resource organization by supporting the tariff movement.

Perception of gain from altering practices was the important limitation of the polyculture sector. Resistance to change was the consequence. An examination of the adoption of fertilizer will illuminate the pervasive resistance to change in French agriculture.

In the last quarter of the century, land was clearly the short factor of production for the polyculture sector.[62] The average price of land compared to an average day's wage was very high before 1910. The data of Appendix Table F-4 measure average winter and summer wages. If the peasant operator imputed a lower opportunity cost to his labor, the relative cost of land was considerably higher. Furthermore, there is considerable evidence that land sold in small parcels was bid up far in excess of its cost in large units.[63] This had the effect of making the relative

---

[62]It is likely that those farms employing hired labor viewed the supply of labor as the constraining factor whereas the family-operated farms included many that were too small and required enlargement. Land was constraining.

[63]Griswold (17), p. 116.

cost of land still higher. Clearly the use of fertilizer as a land substitute was called for in the polyculture sector.

Paul Hohenberg in his 1967 study of the development of the chemical industry in western Europe indicated that there was "strong, presumably irrational, resistance"[64] to the use of fertilizers in France. Hohenberg indicated that only in the north and north central regions was there any extensive use. This was an area of large farming. Thus, the increased use of fertilizer through World War I indicated in Figure 2-5 was primarily applied in the large-farm sector. Hohenberg maintained that the main reason for the general non-use of fertilizers was that they "required greater changes in methods and management than farmers could or would make."[65]

The recent experience of peasant agriculture in the "Green Revolution" has shown that, contrary to Hohenberg's statement, the adoption of fertilizer requires no reorganization of the farm enterprise and is, thus, the easiest of the new inputs to adopt. Thus,

---

[64] Hohenberg (81), p. 48.

[65] *Ibid.*

what changes the French polyculturist "would" make was the crucial impediment to productivity growth. The small farmers--85 to 90 percent of farm operators--continued to operate free of purchased inputs. The apparent growth in use of fertilizer shown in Figure 2-5 must be compared with those countries which were fertilizer adopters to emphasize the low rate of usage in France. In 1914, French usage was only one-third that of German usage and one-fifth that of Belgian usage.[66]

Government action could have been taken to encourage the adoption of chemical fertilizers and thus raise the level of productivity. Agriculturalists could have been shown the techniques of using fertilizers. This, however, would have required a large and trained extension force. While the literature makes occasional reference to government interest in the introduction of improved methods,[67] no effective research or extension efforts were implemented in the 19th or early 20th centuries. Therefore, there was no way of efficiently spreading the knowledge of chemical

---

[66] Ibid., p. 49.

[67] Knowles (85), p. 58.

fertilizers, no way of changing the agriculturalists' perception of cost and gain. The Ministry of Agriculture was only created in 1881. In the period through 1914, there were 42 different governments with 19 different Ministers of Agriculture. Most of these were lawyers and doctors. Only a few had expert knowledge of agriculture.[68] It is not surprising that research and training activities, necessary to adjust to the changing world agricultural situation, did not take hold during this period. Tariff protection was the only feasible government policy, as well as the action desired by the rural sector.

To some extent the syndicates were active in popularizing new techniques and providing agricultural education. Some of the syndicates employed agricultural researchers and established experimental fields in the closing decades of the 19th century.[69] The Societe des Agriculteurs also made efforts to encourage technical improvements.[70] These various efforts, however, were local in impact. No national policy was pursued until after World War I and no concerted policy

---

[68] Tracy (40), p. 81.

[69] Golob (77), p. 92.

[70] Ibid., pp. 41-42.

aimed at providing a scientific basis to agriculture was implemented until the First Plan after World War II.[71]

Wright indicates that government efforts after the First World War to establish in each department a state agency for furthering technical experimentation were abolished in 1935 as an economy measure. In 1927, the Minister of Agriculture proposed to establish technical aid through research and education in each canton with a trained agronomist and subsidized experimentation. The plan had a one billion franc price tag. "Although everyone paid lip service to the proposal, the appropriation was cut out of the 1928 budget. . . . Most politicians doubted the usefulness of so costly an investment in the future."[72] This same legislative body which voted down research and extension money had previously approved the various tariff bills of the preceding 40 years. Tariff legislation protected the rural sector from change. Research and education were agents for change. To the politicians as well as the agriculturalists, the perception of gain through change remained clouded behind the complex polyculture

---

[71]Thompson (96), p. 144.

[72]Wright (101), p. 34.

relationships of man to land and man to family. Not until after World War II was there sufficient pressure to increase productivity to change the weights of the various elements of cost and gain and recalculate the results from reorganizing agricultural production.

At the time of the late 19th century tariff bills, government policy was concerned with industrial development. To secure their commercial policies, "it was clear that . . . success (for) the protectionists depended on alliance between landowners and industrialists."[73] The rural sector asked only for equality under the protective umbrella of the tariff. This, the politicians readily provided. Convinced then "that agriculture had received its just due from the state . . . over the next quarter century, no cabinet proposed a serious agricultural program."[74] This policy was obviously biased toward maintaining existing production arrangements. A policy weighted by a different set of values might have allowed the disequilibrating forces of imported grains to impinge fully on the agricultural sector in the hope that resources would be efficiently reorganized. Kindleberger

---

[73]Golob (77), p. 53.

[74]Wright (101), p. 18.

Reproduced from best available copy.

maintained that "French governments were concerned less with economic than with social stability"[75] until after World War II. The abrupt spurt in agricultural productivity associated with the dramatic take-off of reconsolidation after the war appears to affirm Kindleberger's statement.

After World War II. The productivity measures in Figure 2-14 show the results of agricultural changes after 1945. Land and labor productivity dramatically accelerated after 1945. Output has grown since 1945 at 4.5 percent per annum. Labor productivity has increased in excess of 7.5 percent per annum since the war.

Between 1945 and 1965 the male agricultural labor force was nearly halved. Simultaneously, there was a sharp increase in mechanization. Thirty-seven thousand tractors in 1945 quadrupled by 1950 and grew to over a million by 1965.[76] Figure 2-7 shows the effect of this rapid tractorization on horsepower available for each male worker. Horsepower per male

---

[75] Kindleberger (25), p. 190.

[76] These data are taken from Wright (101), p. 145, and the 1966 Annuaire Statistique, p. 179.

worker, which had varied only between 0.7 and 1.0 horsepower from 1862 through 1940, grew 14-fold from 1940 to 1965. Overwhelmingly, this increased use of tractors and the out-migration of male labor after 1945 was the result not so much of new economic forces, but of newly felt economic forces as a result of institutional reforms. The reconsolidation of fragmented land parcels was foremost among these institutional changes. The emergence of an identifiable corps of peasant leaders was another important institutional change.[77]

The emergence of an activist peasantry in the years during and after World War II was similar to the sort of political reforms that occurred 100 years earlier in Denmark.[78] The Danish reforms had the result of an economic and social awakening which increased farmer awareness to changes in his economic environment. So, too, the French peasant awakening to their ability to share a voice and influence with the large farmers had the effect of creating an awareness to their changing economic environment.

---

[77]Wright (101), p. 87, confirms that one of the important changes in the rural countryside in the early 1940's was peasant activism.

[78]Tracy (40), Chapter 5.

Surely the success of the reconsolidation program after the war was associated with a changed view of perceived costs and perceived gains. Le Remembrement was not a new concept although the data of Figure 2-14 indicate it was only seriously pursued after World War II. Previous attempts at reconsolidation had been made both in the 19th and early 20th centuries. Previous attempts, however, had failed largely due to the "peasant's fear of being worsted."[79] Perceived costs of giving up the smallest part of a family holding were greater than perceived gains from the improved production possibilities of reconsolidated land in those earlier periods. Social stability was regarded more highly than economic gain.

Sargent maintained that the success of the post-war remembrement program was due not only to improvements in the enabling law and its implementations but primarily to a "profound revolution in the basic institutions and ideas of French rural life."[80]

The concept of ownership rights in land was changed with the remembrement. "Ownership no longer [referred] to exclusive rights over a specific area of

---

[79] Sargent (95), p. 220.

[80] Ibid., p. 225.

land but to limited and socially compatible rights, over a certain quantity of the productive factor: land . . . production . . . superseded ownership as the prime value governing the legal status of land."[81] It is important to recognize that neither the remembrement nor this new view of property rights in the productive possibilities of land was autocratically imposed by the law. Sargent emphasizes that neither was imposed and that each evolved from obviously changing peasant attitudes and behavior. The pervasive resistance to change which had foredoomed earlier attempts to reconsolidate land suddenly gave way to a more enlightened approach to the perceptions of costs and gains from altering practices. Certainly, government policies to guarantee prices both during and after the war and policies to boost production after the war were instrumental in enhancing the peasant vision of opportunities for gain from adopting new practices.[82]

Opportunities for gain from wage employment also became recognized after the second World War. Out-

---

[81] Ibid., pp. 225-26.

[82] Tracy (40), Chapter 13, and Wright (101), Chapters 5-7, provide useful accounts of post-war policies aimed at exportable surpluses.

migration from the family farm, so long resisted, finally accelerated. The perception of the true opportunity cost of rural subsistence family employment finally became apparent. With the progress of remembrement and the out-migration of labor, new institutional arrangements replaced the traditional practices handed down in the polyculture sector. The conservation model of agriculture based solely on farm resources was replaced by a new purchased-inputs technology. Fertilizer usage and mechanized farming diffused rapidly. Productivity zoomed.

Summary and Implications for the Induced Innovation Hypothesis

French agriculture emerged during the 19th century as a system fully capable of providing an adequate diet for its citizenry. The landless laborer of the 18th century who spent nearly 60 percent of his annual income just to buy rye bread in the years before the Revolution was well fed from the diverse products of polyculture by the beginning of the 20th century. If freedom from hunger and diversity of diet were the criteria for success, then French agriculture achieved its goal. Considering, however, the low rate of population increase over this period, the achievement of diet sufficiency was no great feat of productivity.

This paper has argued that French agricultural production continued well into the 20th century largely without a technology associated with purchased inputs of the sort which found their way into other European agricultural sectors. Aside from improved hand implements, French agricultural production well into the 20th century was closely associated with a technology developed in the 18th century--the new husbandry rotations. Furthermore, the French response to increased labor requirements of new rotations was predicated on an institutionally distorted valuation of labor services. The French peasant with a view to the history of occasional crop failure and extreme privation valued his relationship to the land and his family more highly than the economic opportunity of labor force participation. As a result, market labor was in short supply while labor in the polyculture sector was in surplus. Agricultural wages rose throughout the last half of the 19th century. At the same time, the disparity between agricultural and non-agricultural wages and per capita income widened. Labor resources were neither moving in sufficient numbers into the agricultural labor market nor into the urban labor market.

This preference not to offer labor services had the effect of decreasing farm size to an area that

could be worked without hired labor. Land beyond this size was sold or rented and farm numbers increased in the 19th century. The polyculture sector expanded throughout the century with the attendant evil of parcellization. By 1892, 90 percent of farms were less than 20 hectares in size; 85 percent were less than 10 hectares. These 90 percent occupied 55 percent of the agricultural area. The disproportionate number of people accepting less than their opportunity value to remain on their small farms caused a distortion in the inducement mechanism. The shortage of labor in the large farm sector was not effectively signalled to the industrial sector. Even on the largest farms, the available evidence shows that as late as the end of the century many of the crop evolutions were not done with horsedrawn technology but by hand implements. Manual technology clearly prevailed well into the 20th century in both the large-farm and polyculture sectors.

As French agriculture evolved into its polyculture mold, it solved its problem of providing an adequate diet for its citizenry but only at the expense of poorly organized resource use in the agricultural sector and low factor productivity. If one were to judge by the actions of Meline, the Minister of Agriculture at the end of the 19th century, this cost was

willingly paid. The tariff barriers which carried his name protected agriculture from disruptive economic forces that might have caused a significant reorganization of resources. Tariff protection supplemented by strict quotas in 1929 remained the essential agricultural policy until after World War II. By these quota and tariff barriers, the manual cultivation techniques of polyculture were, thus, preserved along with the other maladies of polyculture. The low private cost organization of polyculture was maintained with a high social cost in terms of economic efficiency. No effective government policy was brought forth to significantly alter the institutional arrangements of agriculture which locked it into low productivity until the implementation of the 1941 Remembrement legislation with the First Plan after World War II. No significant technological innovation occurred in the agricultural production functions of polyculture until after World War II. After the war, the institutional structures of polyculture began to give way as the peasant vision of perceived costs and gains became influenced by economic influences rather than traditional values. Only after these institutional modifications were made was productivity able to grow.

The smooth and dynamic operation of the inducement

mechanism implicitly assumes that people perceive the true economic relationships of factor prices. Agricultural producers must perceive these actions and take steps to manufacture factor substitutes. Government policy must be focused as a catalyst to the inducement procedure. In the French case, the perception of factor costs was distorted by an institutional bias against labor market participation. The polyculture organization that ensued assumed a fixed and trapped family labor supply.

Government policy was shaped by government perception not of the economic relationships but by the perception of rural behavior which was determined by institutionally distorted relationships. Layer after government layer of institutional distortions were built up to reinforce the initial distorted values. Not until after World War II did these institutional distortions begin to give way to a more enlightened view of economic forces. Only then did new inputs and new production functions clearly replace the manual techniques handed down from the 19th century.

APPENDIX A:

A Simplified Model of the Polyculture Sector

Let: Grain (G) be some function of land (L_1), labor (N_1), and fodder (F); natural grass be some function of land (L_2); straw (C) be a joint product with grain in a fixed proportion; Fodder be some function of land (L_3) and labor (N_2); livestock (S) be some function of grass, fodder, straw and labor (N_3). Grass is considered to be pasture grass land suitable for alternative uses, including also grass on fallow. Fodder is considered to be cultivated grasses and roots. Feed grains will not be explicitly recognized in the model since (1) they were less than 10% of animal diet and (2) the changes in feed grain area in production paralleled food grains. Thus, these functional relationships may be restated:

$$
\begin{aligned}
G &= f(L_1, N_1, F) \\
g &= h(L_2) \\
F &= i(L_3, N_2) \\
C &= KG \\
S &= j(g, F, C, N_3) \\
\underline{L} &= L_1 + L_2 + L_3 \\
\underline{N} &= N_1 + N_2 + N_3 \qquad (1)
\end{aligned}
$$

The assumed objective of the small farm operator was to

maximize revenue from livestock and grain.[1] This may be stated as the objective function:

$$\text{MAX } R = P_G G + P_s S + u(\underline{L}-L_1-L_2-L_3) + v(\underline{N}-N_1-N_2-N_3) \tag{2}$$

Substituting to express all variables in terms of the functional relationships of land and labor and taking the partial derivatives, the first order conditions are:

$$P_G \frac{\partial G}{\partial L_1} + P_S (K \frac{\partial S}{\partial G} \frac{\partial G}{\partial L_1}) = u \tag{3}$$

$$P_S (\frac{\partial S}{\partial g} \frac{\partial g}{\partial L_2}) = u \tag{4}$$

$$P_G (\frac{\partial G}{\partial F} \frac{\partial F}{\partial L_3}) + P_S (\frac{\partial S}{\partial F} \frac{\partial F}{\partial L_3} + K \frac{\partial S}{\partial G} \frac{\partial G}{\partial F} \frac{\partial F}{\partial L_3}) = u \tag{5}$$

$$P_G \frac{\partial G}{\partial N_1} + P_S (K \frac{\partial S}{\partial G} \frac{\partial G}{\partial N_1}) = v \tag{6}$$

$$P_G (\frac{\partial G}{\partial F} \frac{\partial F}{\partial N_2}) + P_S (\frac{\partial S}{\partial F} \frac{\partial F}{\partial N_2} + K \frac{\partial S}{\partial G} \frac{\partial G}{\partial F} \frac{\partial F}{\partial N_2}) = v \tag{7}$$

$$P_S \frac{\partial S}{\partial N_3} = v \tag{8}$$

$$\underline{L} - L_1 - L_2 - L_3 \tag{9}$$

$$\underline{N} - N_1 - N_2 - N_3 \tag{10}$$

---

[1] It is more correct to postulate that small farm operators were utility and revenue maximizers. A similar model is described for Japanese small farmers

With six unknown allocations to solve and six equations, the values for the allocations of land and labor to maximize revenue may be determined. u and v are interpreted as the value of the marginal unit of land and labor. Thus, equilibrium conditions require that the value of the marginal allocations of land be equal in alternative uses and the value of the marginal allocations of labor be equal in alternative uses. Any pair from equations 3-5 may be chosen to formulate product transformation curves in land space, or from equations 6-8 to formulate the same in labor space. In each case, production mix should occur such that the iso-revenue plane is tangent to the transformation curve. Selecting equations 4 and 5, as well as 7 and 8, and rearranging terms, the following product transformations functions may be derived:

$$\frac{P_g}{P_S} = \frac{\frac{\partial S}{\partial g}\frac{\partial g}{\partial L_2} - \frac{\partial S}{\partial F}\frac{\partial F}{\partial L_3} - K\frac{\partial S}{\partial G}\frac{\partial G}{\partial F}\frac{\partial F}{\partial L_3}}{\frac{\partial G}{\partial F}\frac{\partial F}{\partial L_3}} \tag{11}$$

$$\frac{P_G}{P_S} = \frac{\frac{\partial S}{\partial N_3}\frac{\partial S}{\partial F}\frac{\partial F}{\partial N_2} - K\frac{\partial S}{\partial G}\frac{\partial G}{\partial F}\frac{\partial F}{\partial N_2}}{\frac{\partial G}{\partial F}\frac{\partial F}{\partial N_2}} \tag{12}$$

---

by Keizo Tsuchiya (41) where he postulates that the farm household maximizes utility subject to money income. Since the purpose of the model of this appendix is to derive the production relationships, not confirm a behavioristic assumption, the assumption of revenue maximizing is sufficient to proceed.

These particular product transformation functions were chosen because they contain the expression $\frac{\partial G}{\partial F}$ in the denominator. Rationality requires this expression to be negative. Since the output of grain could be increased by increasing the output of cultivated fodders in the rotation over a certain range, the practical man should include at least this amount of fodder in his rotation. Beyond this level, fodder competes with grain for resources. This competitive relationship is the rational region of production. All other marginal products are assumed positive. For equation (11) to be positive, the numerator must also be negative which implies:

$$\left|\frac{\partial S}{\partial F}\frac{\partial F}{\partial L_3}\right| > \left|\frac{\partial S}{\partial g}\frac{\partial g}{\partial L_2}\right| + \left|K\frac{\partial S}{\partial G}\frac{\partial G}{\partial F}\frac{\partial F}{\partial L_3}\right| \tag{13}$$

$K\frac{\partial S}{\partial G}\frac{\partial G}{\partial F}\frac{\partial F}{\partial L_3}$ is the marginal output of livestock due to the increase of straw caused by an incremental change of fodder land in the rotation. $\frac{\partial S}{\partial g}\frac{\partial g}{\partial L_2}$ is the marginal output of livestock from an incremental unit of grass land and $\frac{\partial S}{\partial F}\frac{\partial F}{\partial L_3}$ is the marginal output of livestock that would result from the feed of an incremental unit of leguminous grass of root fodder land. Equation (13) essentially implies that the marginal nutrition from a unit of fodder land is greater than the sum of the

marginal nutrition from units of grass and straw land. This is correct.

Likewise, for equation (12) to be positive:

$$\left|\frac{\partial S}{\partial F}\frac{\partial F}{\partial N_2}\right| > \left|\frac{\partial S}{\partial N_3}\right| + \left|K\frac{\partial S}{\partial G}\frac{\partial G}{\partial F}\frac{\partial F}{\partial N_2}\right| \qquad (14)$$

Again, the first term is the marginal output of livestock due to the incremental unit of labor employed growing and feeding the fodder crops. The last term is the marginal output of livestock due to the rotation effect on the output of straw resulting from an incremental unit of labor to producing fodder. The middle term is the marginal output of livestock from an incremental unit of labor directly caring for the livestock. Direct care of the animals was a very small part of the day's work in 19th century French polyculture. Livestock output was largely a result of diet and nutrition. Therefore, equation (14) is correct.

If we consider $\frac{\partial G}{\partial F}$ to be positive, this implies that so few resources are allocated to fodder crops that grain output can be increased by increasing resources allocated to the leguminous fodders in the rotation. Implicitly, this indicates that much grain production is taking place not on the new production function of polyculture but on the old production function. Equations (11) and (12) show that the rate of product transformation

of grains for livestock is negative in this case. The slope of the transformation curve is positive so that grain and livestock both can be increased by increasing fodder. As previously indicated, when fodder output reaches a sufficiently high level, the rate of product transformation becomes positive. The following diagram will illustrate two dimensions of the multi-dimensional effects of increasing the amount of fodder crops in the rotation and in the ration fed to livestock. The transformation curves in the diagram initially assume the land area fixed and then show the land area expanded.

Panel A shows the fodder-grain transformation function. Until fodder output reaches F_2, the slope of the function is positive; this is the range of technical complementarity in the production process. Panel B displays the livestock product-grain transformation function. It, too, is positive over a certain range due largely to the joint effect on grain of fodder in the ration. That combination of outputs which allows a tangency at E_o of transformation function U_o and iso-revenue P_o is shown to be the maximum revenue organization of final products. Iso-revenue P_o intersecting the transformation function at A is the less than optimal solution resulting from too little fodder in the rotation and feed ration.

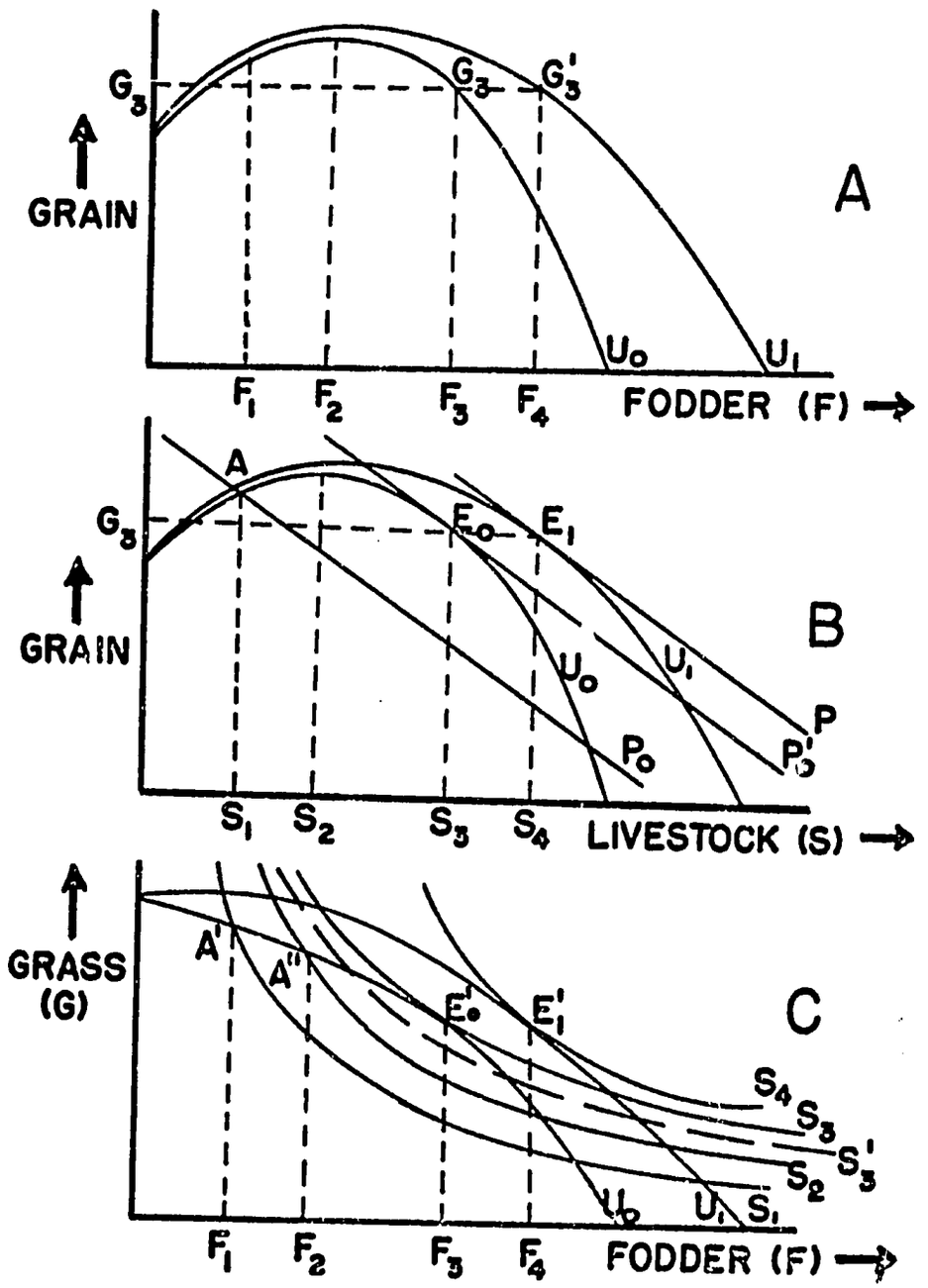


FIGURE A-1: PRODUCT TRANSFORMATION CURVES FOR FRENCH POLYCULTURE

Panel C displays the grass-fodder transformation function as well as livestock iso-quants S_1 through S_3. To maximize output on a given land base, panel C indicates that fodder should be increased until the rate of transformation of fodder for grass is equal to the rate of substitution of fodder for grass in the ration--position E_o'. Thus, due to the higher total nutrition level per unit of land, livestock may be increased by increasing fodder in the ration. Equilibrium condition E_o' is only a result of construction. Without prices allocating resources and assuming all produced is fed, equilibrium truly implies E_o'. However, the behavioral assumption of the model is that the tangent of the product transformation function and the iso-revenue P_o in panel B determines the optimal level livestock to be S_3. The isoquant for this livestock level may not be on the frontier of panel C. It may intersect with the transformation function as drawn by S_3'. The solution levels of fodder and grass are determined simultaneously with grain and livestock output in panel B.

Transformation functions U_1 show the effect on livestock production of expanding the area of fodder without reducing the area allocated to grain. In panel C, the livestock isoquant is shown to shift up. Again, apparent equilibrium E_1 is drawn only by construction.

S_4 may intersect U_1. The new solution levels of fodder and grass are determined simultaneously with grain and livestock in panel B.

CHAPTER V

SUMMARY: IMPLICATIONS FOR POLICY AND CONTINUED RESEARCH

Introduction

The stated objectives of this dissertation are three:

(1) To test the factor price induced innovation hypothesis with data from the agricultural sectors of Denmark, Great Britain and France. The two-fold purpose of this testing is: (1) to see if the hypothesis can be affirmed under conditions of less extreme factor endowments than have prevailed within previous empirical agricultural studies; and (2) to see if the hypothesis offers a significant explanation for agricultural development that has been less spectacular than the Japanese and United States cases which previous studies investigated.[1] The goal of this objective is to look at each country's historical growth pattern and see if

---

[1]Hayami and Ruttan (19), Yeung and Roe (47), Binswanger (3).

the ability or inability to achieve rapid productivity growth is related to the successful or unsuccessful operation of a factor price inducement mechanism.

(2) To determine to what extent the differential productivity acceleration periods and growth patterns of the three countries were determined by interacting institutional and economic forces. The purpose of this investigation is to see if slow productivity growth in conjunction with statistical evidence of a non-operational inducement mechanism can be attributed to the failure of institutions to convey economic forces in lieu of the non-existence of economic forces. The goal of this objective is to infer that there were economic forces that offered incentives to increase output and could have resulted in technical innovation to increase productivity. Since rapid productivity growth did not occur in Great Britain and France until relatively late, the goal of this objective is to associate with their periods of slow productivity growth specific institutional arrangements which acted as constraints to the development process.

(3) To analyze the formation of French institutional forces in the early 19th century to see what effect these forces had on French agricultural productivity growth after 1870. The two-fold purpose of

this analysis is: (1) to see if specific institutional arrangements can be associated with the lack of any statistical evidence that there were biases to induce advanced technology specific to French agro-climatic conditions; and (2) to examine government actions to see how policy shaped to favor the vested interests of the smallest minority of farmers acted as an additional institution constraint that impeded agricultural progress. The goal of this objective is to associate the very late productivity take-off of French agriculture with rigid institutional forces that constrained induced technical change and productivity growth until after World War II.

Summary: Estimation Procedures

The estimation procedure employed in this dissertation offers an improved method that is econometrically convenient for estimating the biases of technical change. The usual problems encountered in empirical efforts to determine the direction of biases are two: (1) sorting out the proportion of observed factor share change due to ordinary factor substitution resulting from factor price changes; and (2) determining the proportion of technical change truly induced by biases from that which Hicks labels autonomous technical change.[2]

---

[2]Hicks (20).

Estimated equations (17) and (18) of Chapter III which are derived from the marginal products of the CES production function (equation (10)) contain estimators for each of the changes occurring in the production function which are necessary to determine in order to isolate the existence of bias: ordinary factor substitution, neutral, or autonomous, efficiency growth, and biased augmentation. The discussion of Chapter III will be graphically expanced to show how these estimated equations deal with the usual empirical problems indicated above.

Figure 5-1 demonstrates the different components of historically observed factor share changes that must be determined to isolate the existence of biased technical change. Displayed as U_o is the land-labor isoquant for a unit of production. If neutral efficiency growth occurs, the isoquant shifts homothetically inward to U' which is proportionately land and labor saving. If we know the constant elasticity of substitution and prices change to $(r/w)_1$ then we observe ordinary factor substitution on U' from y to z. This movement reduces labor employed by the amount $L_o' - L_1$. If biased technical change occurs, the isoquant may shift to U''. This further reduces the labor employed from L_1 to L_1'. Of the historically observed labor reduction, $L_o - L_1'$,

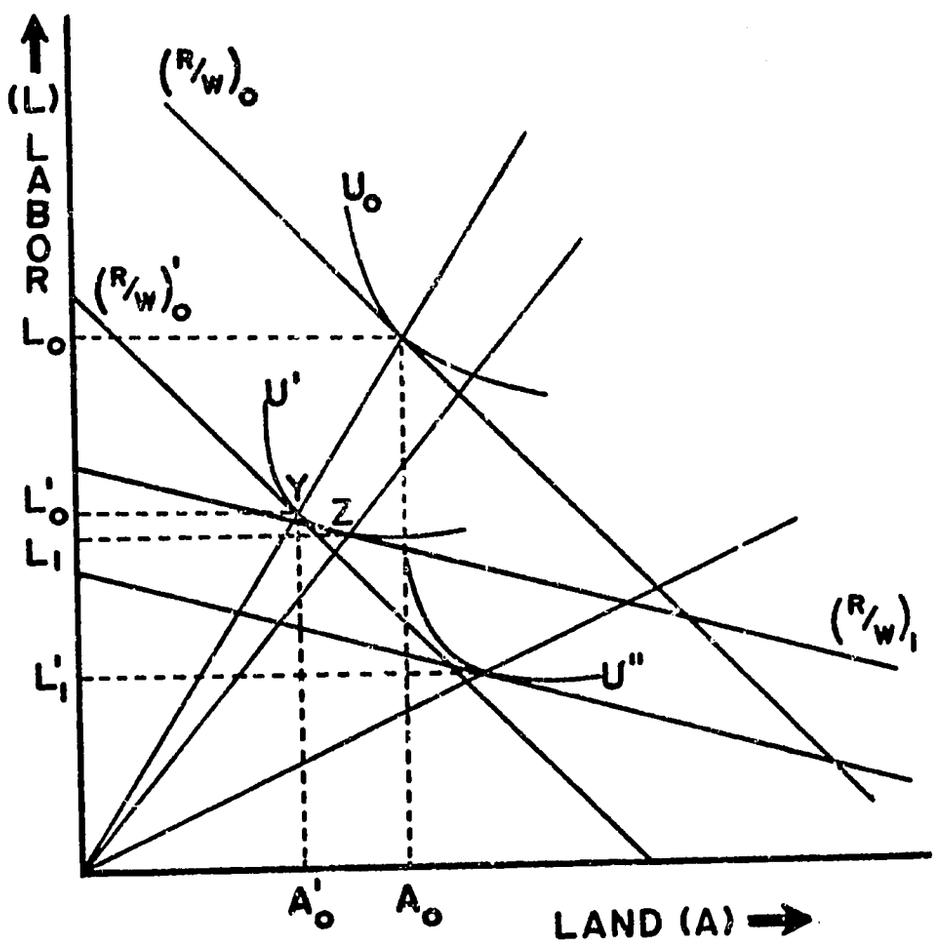


FIGURE 5-1: THE EFFECTS OF ORDINARY FACTOR SUBSTITUTION, NEUTRAL AND BIASED TECHNICAL CHANGE ON FACTOR PROPORTIONS

only that part $L_1 - L_1'$ is attributed to biased labor saving technical change.

Equations (10) and (11) of Chapter III show how the components of factor augmentation can be separated into neutral, or autonomous, efficiency growth and biased factor augmentation. These separate components are estimated in equations (17) and (18). Figure 5-2 shows how observed labor augmentation can be divided into neutral efficiency growth at the rate γ and factor price biased labor augmentation at the rate $\lambda \partial I / \partial t$.

The major shortcomings of the estimation procedure are two:

(1) The elasticity of substitution and the parameters of growth rates are considered to be constant over the long time period;

(2) The CES function is econometrically convenient for use with only two factors of production.

To consider the first problem, the French and British data are estimated over two time periods where growth rates are observed to have radically differed and the plausibility of the assumption of constant growth rate parameters is extremely questionable. The elasticity of substitution is not allowed to vary between periods, however, and this remains a weak but useful assumption.

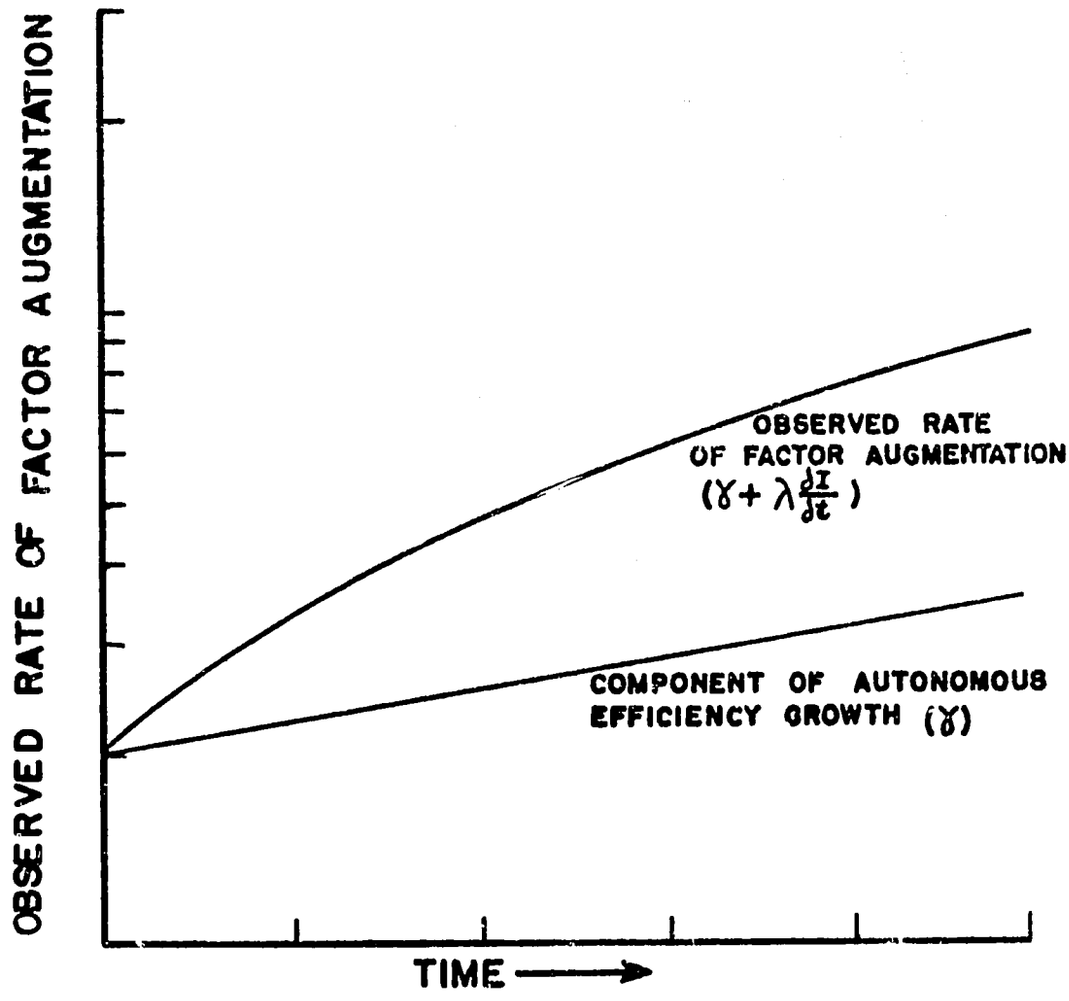


FIGURE 5-2: COMPONENTS OF OBSERVED FACTOR (LABOR) AUGMENTATION

To consider the second problem, the Hayami-Ruttan demand type equations which consider four factors of production are estimated and compared with the results from the CES model.

Summary: Empirical Findings

As a first step to summarize the empirical findings, consider the annualized rates of growth of neutral efficiency and factor augmentation in Table 5-1. These calculated growth rates overestimate the British and French actual values in the first half of the study and under-estimate the actual values in the second half because there was a sharp change in the underlying production function between the periods. For this reason the British and French data are divided and estimated separately over two periods. The French results yield a non-acceptable negative elasticity of substitution that precludes evaluation. The British estimated values are indicated in Table 5-2. Again, the neutral growth rate apparently is over-estimated in the first period.

The overriding conclusion that can be drawn from these annualized growth rates is that the neutral component of observed technical change is, by far, the most important. In view of the position of the European

Table 5-1: Comparison of Annualized Growth Rates of the Components of Observed Factor Augmentation, 1870-1965[1]

		Denmark	France	United Kingdom
Neutral Efficiency Growth	(γ)	.94%	.71%	.23%
Land Augmentation	(δ)	.04%	0.0%	.01%
Labor Augmentation	(λ)	.38%	0.0%	- .008%

[1]These values are computed from parameter estimates in Tables 3-4, 3-7 and 3-13. Observed estimates determined from quinquential observations were divided by five to annualize.

Table 5-2: United Kingdom: Comparison of Annualized Growth Rates of the Components of Observed Factor Augmentation Between Two Periods, Restricted Model III[1]

		1870-1925	1925-1965
Neutral Efficiency Growth	(γ)	1.14%	2.04%
Land Augmentation	(δ)	.001%	.03%
Labor Augmentation	(λ)	-.14%	-.009%

[1]The estimation procedure for restricted model III did not yield variance estimates. Therefore, while these are BLUE estimates, their significance remains unknown.

historical growth paths in the middle of Figure 1-3, this result is not surprising.

Before commenting further on the relative size of the growth parameters, consider the direction and size of the Hicks bias. Drandakis and Phelps have shown that if the production function is CES and technical change is factor augmenting, the Hicks bias, defined in terms of a change in the rate of substitution at constant prices. should be weighted by the substitution parameter and can be measured as follows:[3]

$$\text{BIAS} = \frac{1-\sigma}{\sigma}(\lambda - \delta) \gtreqless 0 \quad \begin{array}{l}\text{Labor saving}\\ \text{Labor neutral}\\ \text{Labor using}\end{array}$$

where $1 - \sigma/\sigma$ is the substitution parameter and $(\lambda - \delta)$ is the net labor or land augmentation effect.

Utilizing the values of the parameters from Model II and British restricted Model III, Table 5-3 is constructed.

The overriding conclusions to be drawn from these bias measures is that Danish agriculture experienced a strong bias for labor saving technical change while British agriculture experienced only a weak bias for land saving technical change. Table 5-1 showed

---

[3]Drandakis and Phelps (12), p. 831.

Table 5-3: Denmark and United Kingdom: Direction of Bias

	Substitution Parameter $(1-\sigma^{-}/\sigma)$	Net Effect of Augmentation $(\lambda-\delta)$	Bias	Result
Denmark, 1870-1965	26.027	.0138	.3592	Labor saving
United Kingdom, 1870-1965	3.591	-.00109	-.0039	Land saving
United Kingdom, 1870-1925	.7292	-.00687	-.0050	Land saving
United Kingdom, 1925-1965	.7292	-.00173	-.00126	Land saving

that French estimates indicate no bias.

Danish agriculture has shown the most consistent historical productivity growth and the Danish estimates of neutral and biased factor augmentation are the strongest. British agriculture evidenced a 50-year period of productivity stagnation and the British estimates of neutral and biased factor augmentation are the smallest. French agriculture evidenced continued sluggish productivity growth until after World War II and the French estimates of factor augmentation show no biased augmentation, only a neutral component.

Chapter III suggested that the most simplistic interpretation of the induced innovation hypothesis allows the conclusion that the differential productivity growth patterns between the three countries can be attributed directly to the performance of the inducement mechanism.

Danish agriculture experienced induced innovation which on balance favored labor augmentation. British agriculture experienced only a very small induced bias for land augmentation and little productivity growth resulted until after 1925. French agriculture exhibited no induced bias and only sluggish autonomous growth occurred.

Chapter III also suggested that to consider the

success or failure of a country to achieve productivity growth exclusively in terms of the measured economic variables is a myopic view of the total bundle of forces that act to determine productivity growth. Specifically, such a view excludes from consideration those extra-market forces which govern both behavior patterns and the organization of economic units as they meet in the marketplace to create economic forces.

Thus, the failure to achieve productivity growth has been seen in Chapter III to be consistent with either the non-existence of economic forces or with the non-existence of proper extra-market forces to communicate the economic forces. In the latter case, it has been argued that specifically needed institutional changes do not take place. In this case, the failure to induce needed technical innovations and achieve rapid productivity growth has been seen to be the fault not so much of a non-operative inducement mechanism as due to the non-occurrence of needed institutional changes.

Chapter IV examined the French history of agricultural development. The objective was to examine the fabric of the institutional arrangements of polyculture to see why there were no induced biases. Behavioristic patterns were revealed during the 19th century which had the effect of isolating most of the

agricultural sector from participating in the labor market. With the diffusion of new husbandry techniques in the 19th century, this non-availability of market labor had the effect of distributing production to small farms. These farms were seen to enjoy a horizontal labor supply function up to the capacity output of the family. The number of smaller farms grew throughout the 19th century and the proportion of output from these farms expanded and bulked large in comparison with the output of the large farm sector.

The polyculture sector was seen to be comprised mostly of illiterate peasants. The large farm sector contained the aristocratic element of farming. They were mostly cash grain producers. With the arrival of new continental grains in the last quarter of the 19th century, their vested interests were challenged. Possessed of the education and closely connected to government the aristocratic farmers rallied for tariff protection. Uneducated, and unable to perceive the changing product demand to favor the livestock products that were the peasants' comparative advantage, the peasants accepted the aristocratic argument for grain protection as important for preservation of peasant interests.

At the beginning of the 20th century, French

farming was locked into the rigid institutional arrangements of labor intensive polyculture and largely divorced from economic forces--particularly in the factor market. Government policy shaped by the vested interests to preserve the status quo allowed the institutional arrangements of polyculture to prevail until World War II.

The institutional rigidity of polyculture reinforced by government policy rendered the inducement mechanism inoperative. French productivity growth was sluggish not because of a failure of the inducement process but because of a prior failure to innovate necessary institutional reforms conducive to a reorganization of resources around a more productive technology.

Policy Implications and Directions for Needed Research

The contrasting growth experiences of the three countries studied in this dissertation afford several insights into the nature of problems facing many nations of the world today. Many nations today are concerned with achieving rapid agricultural progress but are constrained by rigid institutional structures.

The significant distinguishing characteristic of Denmark's successful achievement of continued rapid productivity growth has been the flexibility of Denmark's

institutional structure. The necessary institutional innovations to allow the transition from crop to livestock production and marketing occurred very rapidly during the 1880's. The accelerating rate of Danish productivity growth suggests that any subsequent necessary institutional innovations have occurred with equal smoothness.

The analysis of Chapter III suggests that under conditions of a flexible institutional structure, the response of an agricultural sector to economic forces clearly is revealed in the usual framework of economic analysis. Specifically, the induced innovation hypothesis is strongly supported by the analysis of the Danish data. Similar results have been obtained in other tests of the inducement model of productivity growth that dealt with countries that have achieved rapid productivity growth.[4] However, the successful cases do not, on balance, appear to offer a generalized model of agricultural development in those countries that have not achieved successful rapid growth.

The causes of failure are, at least, as many as there are countries that have not succeeded. The study

---

[4]The Hayami and Ruttan (19) analysis of Japanese and United States productivity growth was the seminal study providing empirical verification for induced innovation in agricultural productivity growth.

of French and British sluggish productivity growth suggests that the failure to have achieved a productivity take-off sooner than each did was due to institutional rigidity. The necessary institutional innovations to allow internalization of new profitable opportunities came only with very long time lags.

Both France and Great Britain had specific institutional impediments to adopting new technical opportunities. It appears reasonable to hypothesize that institutional impediments to new technical opportunities are specific both to countries and even to regions within countries.

The statistical analysis of the British and French data of economic variables suggests that biased technical innovation was not induced and that productivity acceleration occurred only after long time lags. Missing from the analysis is the answer to the question of why biased technical innovation did not occur. Other arguments of this dissertation have identified specific probable institutional constraints that answer the question. However, no formal argument to suggest how needed institutional reforms could have been achieved has been attempted. It is suggested that this is the direction for needed research.

One direction for additional research suggested

by the comparative growth patterns of Denmark, France and Great Britain is the impact of the development of human capital on institutional innovation.

In spite of the apparent specificity of institutional constraints, the rural populations of Denmark, France and Great Britain appear to have shared similar characteristics that are distinguishable both during the periods of slow growth and during the periods of rapid growth.

The agricultural populations of France and the United Kingdom in the last quarter of the 19th century were divided largely between a small group of educated aristocratic landowners and a large group of largely uneducated farmers. There was sharp class distinction and the larger element was not a visibly cohesive group. In the terminology of Kindleberger's 1951 study, there was no "social cohesion"[5] among the larger group.

As the human capital of the larger group was developed in the 20th century, a greater sense of group awareness was developed; spokesmen emerged and a larger awareness of democracy emerged. The British tenant farmers began to acquire land. The French peasant farmer acquired group awareness and took to the village

---

[5]Kindleberger (26), p. 45.

Reproduced from best available copy.

square to protest the conditions of agriculture. In both cases, the larger group gained a voice with government and began to influence government policy favorable to their conditions. Each group acquired "social cohesiveness."

The Danish farmer of the 19th century was already an educated member of a cohesive democratic society by the last quarter of the 19th century. Equal social status and a tradition for group organization were especially important to the establishment of the cooperative movement. "Social cohesiveness" was clearly evident.

One element, therefore, that needs to be considered in additional research to discover the policy tools to modify institutional structures is the impact of human capital on "social cohesiveness" and, in turn, the impact of "social cohesiveness" on institutional innovation. It is apparent that institutional innovation, like technical innovation, allows the sub-sector of the economy affected to produce greater output and larger income flows. It appears reasonable to suggest that economic studies that have estimated the increased value of production and income to a society from the development of human capital have missed the impact of human capital on the formation of "social cohesiveness" and, therefore, institutional innovation.

APPENDIX TABLES

Appendix B: British Data

Appendix D: Danish Data

Appendix F: French Data

Data and sources are described in the notes to individual tables. Aggregation procedures for much of the data are described with more detail in an earlier publication by the author: Hayami, *et al*. (19).

Table B-1:
United Kingdom: Time Series Data of Output, Agricultural Land, Male Labor and Productivity: 1870-1965[5]

	Agricultural output in wheat units[1] Y	Agricultural land[2] A	Males economically active in agriculture L	Land productivity Y/A	Labor productivity Y/L	Land per male worker A/L
1870	21657	18852	1385	1.1	15.6	13.1
1875	21232	18900	1325	1.1	16.0	14.3
1880	20847	18949	1288	1.1	15.7	14.7
1885	21271	19139	1263	1.1	16.4	15.2
1890	21696	19331	1235	1.1	17.0	15.7
1895	21464	19466	1210	1.1	17.2	16.1
1900	21040	19602	1178	1.1	17.4	16.6
1905	21464	19547	1198	1.1	17.5	16.3
1910	21696	19484	1221	1.1	17.3	16.0
1915	21696	19395	1203	1.1	17.6	16.1
1920	21696	19121	1154	1.1	18.3	16.6
1925	21889	19798	1199	1.1	17.8	16.5
1930	23163	19611	1151	1.2	19.7	17.0
1935	25016	19571	1131	1.3	21.6	17.3
1940	27332	19453	1079	1.4	24.7	18.0
1945	29417	19539	1034	1.5	27.7	18.9
1950	31502	19518	985	1.6	31.2	19.8
1955	32969	19405	928	1.7	34.5	20.9
1960	38605	19894	853	1.9	44.0	23.3
1965	45728	19624	771	2.3	59.3	25.5

Table B-1:
United Kingdom: Time Series Data of Output, Agricultural Land, Male Labor and Productivity (continued)

	Index: 1870 = 100						Percent of male workers in non-agriculture[4]
	Y	A	L	Y/A	Y/L	A/L	
1870	100	100	100	100	100	100	.81
1875	98	100	96	100	103	104	
1880	96	101	93	100	104	108	.84
1885	98	102	91	100	108	112	
1890	100	103	89	100	113	115	.86
1895	99	103	87	100	113	118	
1900	97	104	85	100	115	122	.88
1905	99	104	86	100	115	120	
1910	100	103	88	100	114	118	.88
1915	100	103	87	100	115	118	
1920	100	101	83	100	121	122	.89
1925	101	105	87	100	117	121	
1930	107	104	83	109	129	125	.90
1935	116	104	82	118	142	127	
1940	126	103	78	127	162	132	
1945	136	104	75	136	182	139	
1950	145	104	71	145	205	146	.91
1955	152	103	67	155	228	154	.92
1960	178	106	62	173	290	171	.94
1965	211	104	56	209	380	188	.96

Table B-1:
United Kingdom: Time Series Data of Output, Agricultural Land, Male Labor and Productivity (continued)

Notes:

1. Output in 1000 wheat units. Clark's series of gross agricultural output less seed and feed in 1911-13 prices was spliced to the series from A Century, deflated to 1911-13 prices. The resultant series was then converted to wheat units employing Hayami's computation for 1957-62. Southern Ireland is excluded.

   Sources: Clark, (7), p. 269.
   A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), pp. 76-77.
   Hayami, (18), p. 21.

2. Agricultural land in 1000 hectares includes temporary fallow and grass plus permanent pasture.

   Source: Great Britain: Annual Abstract of Statistics, various issues.

3. Economically active males in agriculture in 1000 males exclude fishing, hunting and forestry.

   Sources: Clark, (7), p. 264.
   FAO, Production Yearbooks, various issues.

4. Economically active males engaged in non-agricultural occupations.

   Sources: Ojala, (33), p. 85.
   Deane and Cole, (112), p. 142.

5. Data are five year centered averages about the tabulated year.

Table B-2: United Kingdom: Final Agricultural Output of Crop and Livestock Products

	Crop Products (Million Pounds)	Livestock Products (Million Pounds)	Ratio of Crop to Animal Products	Index: 1867-69 = 100	
				Crop Products	Livestock Products
1867-69	70.4	128.1	.55	100	100
1870-76	69.9	136.1	.51	99	106
1877-85	63.7	136.9	.47	90	107
1886-93	60.1	148.1	.41	85	116
1894-1903	57.2	154.5	.37	81	121
1904-10	57.5	161.6	.36	82	126
1911-13	56.2	165.9	.34	80	130
1920-22	57.8	153.3	.38	82	120
1924-29	47.6	132.4	.36	68	103
1930-34	45.2	142.0	.32	64	111
1935-39	46.8	138.9	.34	66	108

Notes:

1. Final agricultural output equals sales off farms plus consumption in farm homes; seed and feed are subtracted. Southern Ireland is excluded after 1922. Output is measured in 1911-13 deflated prices.

Source: Ojala (33), p. 209.

Table B-3: United Kingdom: Agricultural Land Utilization[6]

	Permanent Grass[1] (1000 ha.)	Temporary Grass[2] (1000 ha.)	Feed Grains[3] (1000 ha.)	Wheat[4] (1000 ha.)	Root Fodder Crops[5] (1000 ha.)
1866	4513	1196	2023	1356	976
1870	4887	1823	2078	1417	1019
1875	5389	1762	2094	1353	1014
1880	5840	1795	2131	1178	958
1885	6211	1884	2104	1003	960
1890	6485	1954	2030	966	923
1895	6725	1924	2211	574	911
1900	6772	1942	2030	747	851
1905	6963	1834	1929	728	807
1910	7063	1707	1923	732	813
1915	7117	1570	1802	910	716
1920	6415	1591	2083	781	730
1925	6700	1672	1726	627	632
1930	6930	1604	1525	567	540
1935	6953	1543	1260	758	447
1940	6435	1380	1746	728	391
1945	4410	1944	2229	920	451
1950	4730	2024	1836	1002	353
1955	4973	2302	1870	788	303
1960	4728	2546	2058	850	238
1965	4501	2412	2481	1025	160

Table B-3: United Kingdom: Agricultural Land Utilization[6] (continued)

Notes:

1. Permanent grass includes excellent pastures as well as remote, hilly or poorly drained land. About 25 to 30 percent of permanent grass is cut for hay; the balance is grazed.

2. Temporary grass includes clover, sainfoin and other grasses under rotation. About 50 percent of temporary grass is cut for hay; the balance is grazed.

3. Feed grains are barley and oats.

4. Wheat is considered the only food grain; rye is insignificant in the British diet.

5. Root fodder crops are turnips, swedes and mangolds.

6. Data are for single years.

Source: A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), Appendix 1.

Table B-4: United Kingdom: Prices of Arable Land, Wages, Fertilizer and Wheat: 1870-1965[5]

	Daily wages[1] (Shillings)	Price per ha. agricultural land[1] (Shillings)	Number of days work to buy 1 ha.[2]	Price of 100 kg avg. fertilizer[3] (Shillings)	Price per quintal wheat[4] (Shillings)	Quintals of wheat to buy 100 kg.
1870	2.5	2781	1112	16.9	25.6	.7
1875	2.4	2865	1193	15.1	24.2	.6
1880	2.6	2588	995	12.7	21.0	.6
1885	2.6	2286	879	11.3	16.0	.7
1890	2.5	2174	870	10.0	15.0	.7
1895	2.6	2100	808	9.5	11.8	.8
1900	2.6	2065	794	8.9	13.2	.7
1905	2.7	2046	758	9.0	13.2	.7
1910	2.8	2065	738	9.0	12.8	.7
1915	3.1	1448	467	11.8	23.6	.5
1920	7.9	1720	217	18.5	32.0	.6
1925	5.5	1512	274	14.7	23.0	.6
1930	5.8	1096	189	11.8	15.8	.7
1935	5.7	1210	212	11.5	12.6	.9
1940	7.2	1730	240	12.5	21.0	.6
1945	12.4	2306	186	13.4	31.0	.4
1950	17.1	4051	237	14.4	51.6	.3
1955	22.6	3952	175	19.6	51.8	.4
1960	28.8	6076	211	21.3	42.0	.5
1965	39.8	9337	235	22.5	43.8	.5

Notes:

1. Wages are average daily wages to ordinary farm laborers receiving no payment in kind. They were determined from data of weekly minimum wage rates for a 48-hour week by dividing the week's work into five days. Dividing by five days biases the daily wage up. However, the data are minimum, not necessarily actual wages. This biases the true average down. The opposing direction of the biases are assumed offsetting.

   Sources: Ernle (114), p. 524 following.
   A Century of Agricultural Statistics, Great Britain, 1866-1966 (132), p. 65.

2. Farm land price is the price of land without buildings. These data were constructed by splicing Clark's data to Britton's. Clark's series begins with the 1877-1885 average price. The Rhee rental index was found to move in a pattern similar to given land prices and therefore land prices back to 1870 were extrapolated with the Rhee rental index. Prices given are average prices for a non-uniform group of years about the date shown.

   Sources: Clark (7), p. 264; Britton (108); Ashworth (103), p. 61.

3. The price of fertilizer is the unweighted average of the prices of fertilizer compounds on the market. Prices are the average of a non-uniform group of years about the given year.

   Sources: Ojala (33), pp. 212, 213; FAO, Production Yearbooks, various issues.

4. Wheat price is the average price in England and Wales. Data are tabulated in A Century in imperial hundredweights. Those prices were doubled to give the price per quintal.

   Source: A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), p. 80.

5. Data are five-year centered averages unless otherwise noted.

Table B-4A: United Kingdom: Agricultural Land Rents, and Proportion of Farms Owner Occupied

	Rent per hectare of agricultural land[1]	Number od days work to rent 1 hectare agricultural land[2]	Percent of owner occupied farms[3]
1851	57.3	31.8	
1860	64.2	27.9	
1870	67.2	26.9	10
1875	71.1	29.6	11
1880	64.2	24.7	12
1885	56.8	21.8	13
1890	53.9	21.6	15
1895	50.4	19.4	15
1900	49.2	18.9	14
1905	49.9	18.5	13
1910	50.4	18.0	13
1915	51.1	16.5	12
1920	60.8	7.7	22
1925	60.8	11.1	25
1930	54.6	9.4	37
1935	63.0	11.1	37
1940	67.9	9.4	35
1945	70.6	5.7	37
1950	78.1	4.6	39
1955	116.8	5.2	56
1960	140.5	4.9	56
1965	209.9	5.3	60

Notes:

1. Agricultural land rent refers to farm land in England and Wales. The bulk of the data series was calculated from the rhee rental index (28 shillings per acre = 100). Data refer to average rents for non-uniform groups of years about the year tabulated.

Table B-4A: United Kingdom: Agricultural Land Rents, and Proportion of Farms Owner Occupied (continued)

(notes)

Sources: Ojala (33), p. 216.
Ward (135), p. 5.
R.F. Thompson (131), p.82.
FAO, Production Yearbook, various issues.

2. Farm labor wages divided into rent. Wage data from Table B-4. 1851 wages were 1.8 shillings a day and 1860 wages were 2.3 shillings a day. Ernle (114), p. 542.

3. Owner occupied farms includes farms in-hand; thus the increase to 15% in 1890 and 1895 was accounted for by farms in hand during the period of low grain prices.

Sources: Sturmey, "Owner-Occupied Farming in England and Wales," (129)
Dowring, (11), pp. 168-169.

Table B-5: United Kingdom: Product Prices and Price Ratios

	Wheat[1] (Shillings per cwt)	Average price of fat cattle lightweight[2] (Shillings per cwt)	Milk Shillings per gallon	Wheat / Fat cattle (cwt/cwt)	Wheat / Milk (cwt/gallon)	Index of Price Rat Wheat / Cattle (1870=100)	Index of Price Rat Wheat / Milk (1870=100)
1850	9.9	29.1		.34		103	
1855	15.2	25.3		.43		130	
1860	11.7	35.5		.33		100	
1865	11.2	37.1		.30		91	
1870	12.8	39.3	.572	.33	22.4	100	100
1875	12.1	43.1	.613	.28	19.7	85	88
1880	10.5	40.8	.578	.26	18.2	79	81
1885	8.0	36.9		.22		67	
1890	7.5	33.8	.496	.22	15.1	67	67
1895	5.8	32.2		.18		55	
1900	6.6	34.2	.473	.19	14.0	58	63
1905	6.7	33.0	.531	.20	12.6	61	56
1910	6.4	35.5	.583	.18	11.0	55	49
1915	11.8	54.2		.22		67	
1920	16.0	80.1	1.45	.20	11.0	61	49
1925	11.5	57.1	.974	.16	11.8	48	53
1930	7.9	50.3	.828	.16	9.5	48	42
1935	6.3	38.9	.875	.16	7.2	48	32
1940	10.6	55.3	1.25	.19	8.5	58	38
1945	15.5	75.9	1.84	.20	8.4	61	38
1950	25.8	109.5	2.45	.24	10.5	72	47
1955	25.9	133.5	2.68	.19	9.7	58	43
1960	21.0	144.6	2.58	.15	8.1	45	36
1965	21.9	160.1	2.79	.14	7.8	42	35

Notes:

1. Wheat price is the five-year centered average price of wheat per hundredweight in England and Wales.

   Source: A Century of Agricultural Statistics, Great Britain, 1866-1966 (132), pp. 81-2.

2. The price of fat cattle per live hundredweight is an average market price from 1899 on. These prices relate only to England to 1914, to England and Wales, 1915 to 1960 and the the United Kingdom from 1961 on. Official prices are not available prior to 1899. To construct fat cattle prices back to 1850, the Sauerbeck-Statist price index for animal products was spliced to the cattle price data. The Sauerbeck-Statist price index includes prime beef, middling beef, prime and middling mutton, pork, bacon, and butter. Therefore, these prices prior to 1900 are not exclusively reflective of beef price movements. Data are five-year centered averages.

   Sources: A Century of Agricultural Statistics, Great Britain, 1866-1966 (132), p. 84.
   Mitchell (124), p. 474.

3. The price of milk is an average price for a non-uniform group of years about the tabulated date.

   Sources: Ojala (33), p. 205; Great Britain, Agricultural Statistics, various issues.

Table B-6: United Kingdom: Cattle and Livestock Numbers

	Cattle (1000)	Index 1870 = 100	Aggregate Livestock (1000)	Index 1870 = 100	Cattle / Male labor	Livestock / Male labor	Livestock / Agricultural land (animals per 10 hectares)
1870	4337	100	8644	100	3.9	6.2	4.6
1875	4744	109	9078	105	4.5	6.8	4.8
1880	4676	108	8743	101	4.5	6.8	4.6
1885	5107	118	10386	120	5.1	8.2	5.4
1890	5212	120	10968	127	5.3	8.9	5.7
1895	5183	120	11237	130	5.4	9.3	5.8
1900	5367	124	11794	136	5.7	10.1	6.0
1905	5516	127	12401	143	5.8	10.4	6.3
1910	5617	130	13215	153	5.8	10.8	6.8
1915	5796	134	12669	147	6.0	10.5	6.5
1920	5612	129	11986	139	6.1	10.4	6.3
1925	5818	134	13761	159	6.1	11.5	7.0
1930	5821	134	15125	175	6.3	13.1	7.7
1935	6322	146	16839	195	7.0	14.9	8.6
1940	6546	151	15493	179	7.6	14.4	8.0
1945	6866	158	13555	157	8.3	13.1	6.9
1950	7448	172	17131	198	9.5	17.4	8.8
1955	7831	181	18984	220	10.5	20.5	9.8
1960	8430	194	21347	247	12.4	25.0	10.7
1965	8593	198	22854	264	14.0	29.6	11.7

Notes:

1. Livestock are aggregated using the standard FAO weights: Horses, 1.0; cattle, 0.8; pigs 0.2; sheep, 0.1; fowl, 0.01. Cattle are weighted numbers. To arrive at actual number of cattle, divide by 0.8. Date are

Table B-6: United Kingdom: Cattle and Livestock Numbers (continued)

(notes)

five year centered averages. Land and labor data are from Table B-1.

Source: A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), p. 122 following.

Table B-7: United Kingdom: Horsepower and Fertilizer Inputs

	Horsepower[1] (1000 HP)	Fertilizer[2] (1000 kg)	Horsepower per[3] male worker	Fertilizer per ha.[4] of agricultural land
1870	966	100	.7	5.3
1875	951	141	.7	7.5
1880	980	129	.8	6.8
1885	976	125	.8	6.5
1890	1039	125	.8	6.5
1895	1085	158	.9	8.1
1900	1078	179	.9	9.1
1905	1122	196	.9	10.0
1910	1137	221	.9	11.3
1915	858	261	.7	13.5
1920	1267	286	1.1	15.0
1925	1393	267	1.2	13.5
1930	1483	243	1.3	12.4
1935	1731	254	1.5	13.0
1940	2616	351	2.4	18.0
1945	5289	483	5.1	24.6
1950	9117	755	9.3	38.7
1955	12352	824	13.3	42.5
1960	12776	1233	15.0	62.0
1965	12933	1464	16.8	74.6

Notes:

1. Horsepower refers only to the number of horses through 1915. Beginning with 1920 horsepower is the sum of tractor horsepower and horses. Data refer to England, Wales and Scotland. Tractor Horsepower were estimated employing OECD data of average size of tractor as 20 horsepower prior to 1940 and 25 horsepower

Table B-7: United Kingdom: Horsepower and Fertilizer Inputs (continued)

after 1940. Data are five year centered averages.

Sources: OECD, Evolution de LaMotorization de l'agriculture et de la consommation et des Prix des Carberants dans les pays membres, Paris: Juin, 1963.

A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), pp. 61, 71, 129.

FAO, Production Yearbook, various issues.

2. Fertilizer data refer to the sum of the nutrients in commercial fertilizer compounds. ($N + P_2O_5 + K_2O$). However, Ojala's data refer to the compounds so that the nutrients had to be computed. USDA data suggest that pre-war consumption of fertilizer was comprised of 16.4% nitrogen, 59% phosphate and 24.6% potash. These percentages were assumed constant for the pre-war data. Of the commercial compounds nitrogen was 20.6% of ammonium sulfate; phosphate was an average of 15% of the combination of slag and super phosphate; potash was 55% of potassium chloride. Therefore, if N, P, & K are the compounds and N, P, & K are the nutrients then $N + P + K = \frac{N + P + K}{.164/.206 + .590/.150 + .246/.550} = \frac{N + P + K}{5.175}$

Sources: USDA, "Pre-War World Production and Consumption of Plant Foods in Fertilizers," Miscellaneous Publication 593, April, 1946, Washington, D.C., pp. 6, 43.
Ojala, (33), p. 212.
FAO, Production Yearbook, various issues.

3. Male labor and land data are taken from Table B-1.

Table B-8: United Kingdom: Agricultural Input Price Indexes: 1870 = 100[5]

	Land price[1]	Land rent[2]	Wages[1]	Fertilizer[1]	Farm machinery[3]	Concentrated feeds[4]
1870	100	100	100	100	100	100
1875	103	106	98	89	100	108
1880	93	96	104	75	82	95
1885	82	85	104	67	76	
1890	78	80	102	59	72	73
1895	76	75	103	56	65	
1900	74	73	104	52	76	65
1905	74	74	107	53	84	66
1910	74	75	111	53	87	74
1915	52	76	126	70	144	
1920	62	90	317	110	291	146
1925	54	90	220	87	172	106
1930	39	81	232	70	105	68
1935	44	93	231	68	111	78
1940	62	101	290	74	162	
1945	83	105	498	79	192	
1950	146	116	691	85	274	
1955	142	174	904	116	387	
1960	218	209	1163	126	506	
1965	336	313	1461	133	569	

Notes:

1. Data of land prices, wages and fertilizer are taken from table B-4.

2. Data of land rents are taken from table B-4a.

3. The farm machinery price index is a composite of three indexes which are comprised of industrial and mechanical products: (1) The Rousseaux price index of principal industrial products; (2) the board of trade wholesale price index of metals and minerals; and (3) the price index of transported vehicles.

Sources: Mitchell [124], Chapter 16.
Great Britain, Annual Abstract of Statistics, various issues.

Table B-8: United Kingdom: Agricultural Input Price Indexes: 1870 = 100[5] (continued)

	Indexes of Price Ratios:		
	Fertilizer / Land Rent	Concentrates / Land Rent	Machinery / Wages
1870	100	100	100
1875	84	102	102
1880	78	99	79
1885	79		73
1890	74	91	71
1895	75		63
1900	71	89	73
1905	72	89	79
1910	71	98	78
1915	92		114
1920	122	161	92
1925	97	118	78
1930	86	83	45
1935	73	82	48
1940	73		56
1945	75		59
1950	73		40
1955	67		43
1960	60		44
1965	43		39

Notes:

4. Data of concentrated feed prices are taken from table B-9.

5. Data are primarily five year centered averages; where such data are not available, these data are averages of some non-uniform group of years.

Table B-9: United Kingdom: Prices and Quantities of Concentrated Feeds

	Concentrated feed[1] (1000 tons)	Price of concentrates[2] (shillings per ton)	Concentrates: per ha. of agricultural land[3] (kg/HA)	Concentrates: Per head of livestock[4] (kg/head)	Price Ratios: Conc. Land rent[5] (Ton/HA)	Price Ratios: Cattle conc.[6] (cwt/Ton)	Price Ratios: Milk conc.[6] (Gal/Ton)
1870	2492	160	13.2	28.8	2.38	.25	.0036
1875	3062	172	16.2	33.7	2.42	.25	.0036
1880	3795	152	20.0	43.4	2.37	.27	.0038
1885							
1890	3876	116	20.1	35.3	2.15	.29	.0043
1895							
1900	4931	104	25.2	41.8	2.11	.33	.0045
1905	5031	106	25.7	40.6	2.12	.31	.005
1910	5257	118	27.0	39.8	2.34	.30	.005
1915							
1920	4511	234	23.6	37.6	3.85	.34	.0062
1925	4883	170	24.7	35.5	2.80	.34	.0057
1930	5529	108	28.2	36.6	1.98	.47	.0077
1935	6248	124	31.9	37.1	1.97	.31	.0071

Notes:

1. Concentrated feeds are oil cakes, wheat bran and maize. This does not include all feeding products shown by Ojala but these components are comparable to those of Danish feeds.

Source: Ojala (33), p. 212.

2. The price of concentrates is the unweighted average of the prices of home and imported oil cakes, maize and wheat bran. The prices were computed by dividing quantity data into value data of the components of the concentrates.

   Source: Ojala (33), p. 213.

3. Agricultural land data are taken from Table B-1.

4. Livestock data are taken from Table B-6.

5. Agricultural land rent data are taken from Table B-4A.

6. Cattle and milk price data are taken from Table B-5.

Table B-9: United Kingdom: Prices and Quantities of Concentrated Feeds (continued)

	Index: 1870=100		
	Concentrate Land Rent	Cattle Concentrate	Milk Concentrate
1870	100	100	100
1875	102	100	100
1880	100	108	106
1885			
1890	90	116	119
1895			
1900	89	138	125
1905	89	124	139
1910	98	120	139
1915			
1920	162	136	172
1925	118	136	158
1930	83	188	214
1935	83	124	197

Table B-10: United Kingdom: Wheat and Milk Yield

	Wheat Yield[1] Quintals per hectare	Milk Yield[2] kg. per cow	Milk Yield[2] kg. per cow
1870	18.8	1545	
1875	17.4	1592	
1880	17.8	1649	
1885	20.5	1684	
1890	20.0	1727	
1895	19.9	1779	
1900	21.9	1812	
1905	21.5	1870	
1910	21.5	1910	
1915	21.1	1938	
1920	21.5	1938	
1925	21.6	1985	
1930	21.5	1975	
1935	22.4	1943	2527
1940	23.6	1737	2260
1945	23.0	1734	2321
1950	26.8	2046	2574
1955	30.5	2205	2869
1960	35.8	2327	3028
1965	39.5	2448	3188

Notes:

1. The yield of wheat is the five year centered average for England, Wales and Scotland.

Source: Ojala (33), p. 193.
A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), pp. 108-109.

Table B-10: United Kingdom:. Wheat and Milk Yield (continued)

(notes)

2. The yield of milk is an average of a non-uniform group of years about the tabulated date. British data for the United Kingdom was converted from gallons to kilograms assuming the weight of the imperial gallon constant at 10.32 lbs. throughout the period. The American gallon weighs 8.6 lbs; the imperial gallon is 20% larger. The entire series was constructed by splicing the data shown from 1935 to 1965 to Ojala's data at the 1935 average. Ojala argues that his data from 1870 to World War I are the best available. However, there is a wide difference between Ojala's data about 1935 and the official data. To yield a complete series the recent data was spliced to Ojala's. However, the available data is that the earlier period is good data as is the more recent data. But there remains some unknown discontinuity in the middle which precludes a good linkage.

Sources: Ojala (33), p. 205.

A Century of Agricultural Statistics, Great Britain, 1866-1966, (132), p. 58.

Table D-1: Denmark: Agricultural Output, Agricultural Land, Male Labor and Productivity: 1870-1965

	Agricultural output in wheat Units[1]	Agricultural land[2]	Males economically active in agriculture[3]	Land productivity	Labor productivity	Land per Male worker
	Y	A	L	Y/A	Y/L	A/L
1870	3310	2595	309	1.3	10.7	8.4
1875	3364	2667	318	1.3	10.6	8.4
1880	3408	2859	321	1.2	10.6	8.9
1885	3551	2889	325	1.2	10.9	8.9
1890	3882	2913	326	1.3	11.9	8.9
1895	4126	2907	327	1.4	12.6	8.9
1900	4428	2912	312	1.5	14.2	9.3
1905	4975	2918	336	1.7	14.8	8.7
1910	5837	2883	346	2.0	16.9	8.3
1915	6111	2875	358	2.1	17.1	8.0
1920	6341	3172	395	2.0	16.1	8.0
1925	6830	3217	404	2.1	16.9	8.0
1930	9518	3229	398	2.9	23.9	8.1
1935	9863	3242	390	3.0	25.3	8.3
1940	9015	3218	391	2.8	23.1	8.2
1945	8670	3180	371	2.7	23.4	8.6
1950	10956	3141	342	3.5	32.0	9.2
1955	12940	3117	336	4.2	38.5	9.3
1960	14378	3094	303	4.6	47.5	10.2
1965	15792	3033	272	5.2	58.1	11.2

Notes:

1. Output in 1000 wheat units, five year centered averages: Bjerke and Ussing's series of net agricultural output in 1929 prices is spliced to the USDA index of Danish production. The resultant series was then converted to wheat units employing Hayami's computation for 1957-62.

Table D-1: Denmark: Agricultural Output, Agricultural Land, Male Labor and Productivity: 1870-1965 (con't)

	Index: 1870 = 100						Percent of male workers in non-agriculture[4]
	Y	A	L	Y/A	Y/L	A/L	
1870	100	100	100	100	100	100	
1875	102	103	103	100	99	100	45
1880	103	110	104	92	99	106	46
1885	107	111	105	92	102	106	
1890	117	112	105	100	111	106	49
1895	125	112	105	108	118	106	
1900	134	112	101	115	132	111	53
1905	150	112	109	130	108	104	
1910	176	111	112	154	158	99	55
1915	185	111	116	162	160	95	
1920	192	122	128	154	150	95	58
1925	206	124	131	162	158	95	
1930	288	124	129	223	223	96	62
1935	298	125	125	231	236	99	
1940	272	124	127	215	216	98	67
1945	262	122	120	208	215	102	
1950	330	121	111	269	299	110	77
1955	391	120	109	323	360	111	
1960	434	119	98	354	444	121	74
1965	477	117	88	400	543	133	77

Notes (con't):

Sources: Bjerke and Ussing, (49), p. 144.
USDA, (43), pp. 25-26.
Hayami, (18), p. 21.

Table D-1: Denmark: Agricultural Output, Agricultural Land, Male Labor and Productivity: 1870-1965 (con't)

Notes (con't):

2. Agricultural land in 100 hectares includes temporary fallow and grass plus permanent pasture. Data are for single years.

   Sources: Jensen, (59), p. 389.
   Denmark: Landbrugstatistik, 1900-1965, (51), pp. 8-9.

3. Economically active males in 1000 males in agriculture exclude fishing, hunting and forestry. Males in agriculture are estimated as a percentage of the total agricultural labor force given by Bjerke and Ussing with data from Dovring of males in agriculture for 1900, 1930 and 1950. Data are for single years.

   Sources: Bjerke and Ussing, (49), p. 192.
   Dovring, (11), p. 63.

4. Percentage of males economically active in non-agriculture is estimated from the percentage of labor force in non-agriculture given by Bjerke and Ussing by splicing ILO data of males in non-agriculture at 1950, 1955 average.

   Sources: Bjerke and Ussing, (49), p. 142.
   ILO , Labor Yearbooks, various issues.

Table D-2: Denmark: Value of Major Agricultural Products in Final Consumption (million kroner) (con't)

	Skim milk and butter milk	Eggs	Total milk, butter, eggs	Total livestock products	Ratio of value of: Grains / Meat	Ratio of value of: Grains / Dairy and eggs
1871	48.1	22.6	228.1	492.0		
1876	54.2	23.7	261.5	544.2	.040	.044
1881	65.4	25.9	305.5	598.6	.042	.040
1893	91.4	41.2	460.5	835.7	.038	.031
1903	122.8	82.2	672.8	1231.8	.026	.022
1914	162.4	132.4	920.0	1756.7	.013	.012
1924	173.1	169.4	1028.9	1880.1	.013	.010

Table D-2: Denmark: Value of Major Agricultural Products in Final Consumption[1] (million kroner)

	Beef	Pork	Mutton	Poultry	Total meat	Wheat plus rye	Butter
1871	106.6	93.6	58.6	5.1	263.9	-	157.4
1876	115.9	106.7	54.7	5.4	282.7	11.4	183.6
1881	126.4	111.6	49.3	5.8	293.1	12.3	214.2
1893	145.8	175.7	45.4	8.3	375.2	14.4	327.9
1903	197.8	309.0	35.9	16.3	559.0	14.6	467.8
1914	264.9	529.3	21.1	21.4	836.7	11.1	625.2
1924	261.9	550.5	11.6	27.2	851.2	10.7	686.4

Notes:

1. Most of Danish crop production is fed to animals. Even in the earliest available data this is true. Therefore, wheat and rye are the bulk of crop products in final consumption. Prices employed are the three year average wholesale prices at Copenhagen for 1921-23. The actual prices employed in the computation for 100 kg units are: Skim milk, 4.7 kr.; eggs, 278.7 kr.; beef, 215 kr.; butter, 437.2 kr.; pork, 243.7 kr.; wheat and rye, 25.1 kr.; poultry, 223 kr. The prices of wheat and rye were nearly identical so that their quantities were lumped together. The production of rye has varied from two to four-fold that of wheat. There was no price series available for mutton. Mutton price is computed as the average of beef, pork and poultry prices. Data are for single years. The values computed do not take account of imported feeds which increased dramatically during the period. Therefore, this series is not strictly comparable to the value of final output in table D-1.

Sources: Jensen, (59), Appendix I, prices; Appendix II, production.
Denmark, Landbrugets Priser, 1900-1957,(52), pp. 60, 75, 94.

Reproduced from best available copy.

Table D-2a: Denmark: Index of Final Agricultural Output of Crop and Livestock Products

	Index: 1871 = 100	
	Crop Products	Livestock Products
1871	100	100
1876	100	110
1881	108	122
1893	126	171
1903	128	251
1914	97	359
1924	94	383

Notes: Final output is measured in 1921-23 constant prices.

Wheat and rye are considered a proxy for changes in final crop products. They are the major components of final crop production. Most of the changes in Danish crop production were directed to animal feeding stuffs. These are measured in livestock final products. Data of crop products output for 1871 is not available. 1876 output is assumed to be within 5% of 1876 output. To make the Danish series comparable to French and British series and to focus attention on livestock changes after 1870, the 1876 value of crop output is used as base.

Source: Table D-2.

Table D-2b: Denmark: Livestock and Crop Sales from a Representative Farm

	Crop sales (Kroner)	Livestock product sales (Kroner)	Ratio: Crop Sales / Livestock sales	Index: 871=100 Crop sales	Index: 871=100 Livestock sales
1871	1795	1676	107	100	100
1881	1613	1793	89	89	106
1891	1033	3140	32	57	187
1901	711	4401	16	39	262
1912	1327	6661	19	73	397
1929	2820	14580	19	157	869

Source: Jensen, (59), Appendix III.

Table D-3: Denmark: Agricultural Land Utilization (6)

	Food Grains[1] (1000HA)	Feed Grains[2] (1000HA)	Root Fodder[3] (1000HA)	Hay and Pasture in Rotation[4] (1000HA)	Meadows and Permanent Pasture[5] (1000HA)
1861	271	679	33	792	409
1866	282	691	40	803	396
1871	305	708	49	837	390
1881	324	738	64	946	416
1888	330	817	105	959	382
1896	325	739	140	999	377
1901	314	832	212	889	410
1907	317	807	309	799	431
1912	300	849	356	743	411
1920	277	831	407	748	435
1925	295	973	482	760	559
1930	252	1077	529	739	559
1935	267	1076	521	739	543
1940	257	1074	518	744	539
1945	252	1050	545	743	460
1950	239	1048	584	710	450
1955	172	1172	570	692	383
1960	245	1225	567	639	347
1965	217	1364	410	562	326

Notes:
1. Food grains are wheat and rye.
2. Feed grains are barley, oats and mixed grains.
3. Root fodder crops are potatoes and sugar beets before 1875. After 1875 mangels, rutabagas are added and grow to become the most important root fodders.

Table D-3: Denmark: Agricultural Land Utilization (6) (continued)

Notes: (continued)

4. Hay and pasture in rotation is clover and mixed grasses.
5. Meadows and permanent pasture are those grass areas not in the rotation.
6. Data are for single years.

Sources: Jensen, (59), p. 389a.
Denmark, Landbrugsstatistik, 1900-1965, (51), pp. 30-31, 112-113, 180-181.

Table D-4: Denmark: Prices of Arable Land, Wages, Fertilizer and Wheat: 1870-1965[6]

	Daily wages[1] (Kroner)	Price per hectare of arable land[2] (Kroner)	Number of days work to buy 1 ha.	Price of 100 kg avg. fertilizer[3] (Kroner)	Price per quintal wheat[4] (Kroner)	Quintals of wheat to buy 100 kg.
1870	1.3	198	152		20.9	
1875	1.4				20.0	
1880	1.6	264	165	6.0	18.4	.3
1885	1.7				14.1	
1890	1.7	251	148	6.0	13.6	.4
1895	1.9				10.9	
1900	2.1	225	107	9.5	11.9	.8
1905	2.3	250	109	11.9	12.3	1.0
1910	2.8	304	109	12.0	14.1	.9
1915	3.4	414	122	17.3	16.4	1.0
1920	5.9	681	115	39.3	32.8	1.2
1925	6.2	651	105	16.5	26.3	.6
1930	5.2	537	103	12.0	15.3	.8
1935	5.3	497	94	11.7	14.0	.8
1940	7.8	628	81	15.4	20.9	.7
1945	15.3	908	59	21.8	31.5	.7
1950	21.5	1171	54	24.8	44.8	.6
1955	28.5	1455	51	27.6	49.7	.6
1960	35.6	2517	71	28.1	52.8	.5
1965	67.4	3361	50	32.1	58.6	.6

Notes:

1. Wages are daily wages paid to day laborers not boarded.

Notes:

1. Wages are daily wages paid to day laborers not boarded. The basic data of wages comes from: Denmark, Landbrugets Priser (52), pp. 104-5; Denmark, Landbrugsstatistik, 1967, p. 237. Linkages were made to yield the full data series with indexes contained in: Denmark Agriculture (50), Table 58; Report to FAO (54), p. 57.
2. Arable land prices are the prices of land without buildings. Such data are sparse in Denmark because most farms are sold with buildings. The index of prices paid for agricultural holdings with buildings was spliced to the price of average land in 1955 to yield 1905-1955 prices. Earlier prices were estimated from data of land prices in Jensen. Later data were taken from official sources. To the extent that buildings to support the enlarging livestock sector of agriculture increased the value of farm land from 1905 to 1955, the value of land is biased up.

   Sources: Technical and Economic Changes in Danish Farming (58), p. 55; Denmark, Landbrugets Priser (52), p. 357; Denmark, Landokonomisk Oversigt (53), p. 117.

3. Fertilizer prices are the prices paid by farmers for the average fertilizer purchased. Fertilizers were Chile Nitre, calcium nitrate, super phosphate and potash. The average price is unweighted. Little or no purchased fertilizer was used prior to 1880. The prices for 1880, 1890 and 1900, taken from Jensen, are questionable.
   Sources: Jensen (59), Appendix III; Denmark, Landbrugets Priser, 1900-1957 (57), p. 100; Denmark, Landbrugsstatistik, 1967, p. 250.
4. Wheat prices are the wholesale prices at Copenhagen.
   Sources: Jensen (59), p. 382; Denmark, Landbrugets Priser (52), p. 32; Report to FAO, 1962, (54), p. 56; Denmark, Landbrugsstatistik, 1967, p. 112.
5. Due to better availability of data for prices of land with buildings, there is greater reliability attached to these data than to the data of column two. Data are converted from Tonde Hardcorn to hectares according to Jensen's calculation that 1 Tonde Hardcorn equals 9.8 hectares.
   Sources: Denmark, Landbrugets Priser, 1900-1957 (52), p. 107; Jensen (59), p. 126; Denmark, Landokonomisk Oversigt, 1968 (53), p. 117.
6. Prices are five-year centered averages in most cases, or averages of some group of years about the tabulated date when centered averages are not available. In some cases, only single years are available.

Table D-4: Denmark: Prices of Arable Land, Wages, Fertilizer and Wheat: 1870-1965 [6] (continued)

	Price per hectare of agricultural holdings with buildings[5] (Kroner)	Number of days work to buy 1 ha. of land and buildings
1870	457	351
1875	611	382
1880	536	315
1885	536	255
1890	701	250
1895	1413	239
1900	1186	228
1905	1233	158
1910	2459	114
1915	3414	120
1920	5908	166
1925	7886	117
1930		
1935		
1940		
1945		
1950		
1955		
1960		
1965		

Table D-5: Denmark: Product Prices and Price Ratios[4]

	Butter[1] (kr/100 kg)	Pig Meat[2] (kr/100 kg)	Wheat[3] (kr/100 kg)	Price Ratios of: Wheat/Pork	Price Ratios of: Wheat/Butter	Indexes of Price Ratios: Wheat/Pork (1870=100)	Indexes of Price Ratios: Wheat/Butter
1870	204	85	20.9	.25	.10	100	100
1875	231	87	20.0	.23	.09	92	90
1880	227	86	18.4	.21	.08	84	80
1885	209	83	14.1	.17	.07	68	70
1890	194	73	13.6	.19	.07	76	70
1895	184	75	10.9	.15	.06	60	60
1900	190	70	11.9	.17	.06	68	60
1905	192	77	12.3	.16	.06	64	60
1910	204	86	14.1	.16	.07	64	70
1915	225	107	16.4	.15	.07	60	70
1920	465	236	32.8	.14	.07	56	70
1925	467	235	26.3	.11	.06	44	60
1930	304	148	15.3	.10	.05	40	50
1935	192	119	14.0	.12	.07	48	70
1940	247	177	20.9	.12	.08	48	80
1945	454	258	31.5	.12	.07	48	70
1950	558	355	44.8	.13	.08	52	80
1955	635	418	49.7	.12	.08	48	80
1960	608	405	52.8	.13	.09	52	90
1965	630	453	58.6	.13	.09	52	90

Notes:

1. Butter prices are the data of manor and creamery butter wholesale prices at Copenhagen. Before 1890 farm butter sold at a 20-30% discount from manor butter. After the invention of the separator and the innovation of co-op creameries, there remained only one series of prices, creamery butter.
   Sources: Jensen (59), p. 373; Denmark, Landbrugets Priser (52), p. 65; Denmark, Landbrugsstatistik, 1967, p. 164.

2. Pig meat prices are the wholesale prices of slaughtered and dressed hog at Copenhagen.
   Sources: Jensen (59), p. 377; Denmark, Landbrugets Priser (52), p. 78; Denmark, Report to FAO (54), p. 56; Denmark, Landbrugsstatistik, 1967, p. 192.

3. Wheat prices taken from Table D-4.

4. Prices are five-year centered averages unless such data is not available. In such cases, some group of years about the tabulated date or a single year is employed.

Table D-6: Denmark: Cattle and Livestock Numbers[1]

	Cattle (1000)	Index 1870=100	Aggregate Livestock (1000)	Index	Cattle / Male Labor	Livestock / Male Labor	Livestock / Agricultural land (Animals/10 hectares)
1870	1126	100	1753	100	3.6	5.7	6.8
1875	1221	108	1858	106	3.8	5.8	7.0
1880	1310	116	1959	112	4.1	6.1	6.9
1885	1376	122	2100	120	4.2	6.5	7.3
1890	1442	128	2211	126	4.4	6.8	7.6
1895	1508	134	2343	134	4.8	7.2	8.1
1900	1571	140	2494	142	5.0	8.0	8.6
1905	1645	146	2682	153	4.9	8.0	9.2
1910	1891	168	3083	176	5.4	8.9	10.7
1915	2174	193	3530	201	6.1	9.9	12.3
1920	1985	176	3050	174	5.0	7.7	9.6
1925	2192	195	3566	203	5.4	8.8	11.1
1930	2460	218	4071	232	6.2	9.0	12.6
1935	2551	227	4141	236	6.5	10.6	12.8
1940	2638	234	4239	242	6.7	10.8	13.2
1945	2558	227	4042	231	6.9	10.9	12.7
1950	2470	219	3903	223	7.2	11.4	12.4
1955	2594	230	4146	237	7.7	12.3	13.3
1960	2796	248	4548	259	9.2	15.0	14.7
1965	2658	236	4563	260	9.8	16.8	15.0

Notes:

1. Livestock are aggregated using the standard FAO weights: Horses, 1.0; Cattle, 0.8; Pigs, 0.2; Sheep, 0.1; Fowl, 0.01; Goats, 0.1. Cattle data are weighted numbers. To arrive at the actual number of cattle, divide by 0.8. Data are for single year closest to given year. Land and labor data are from Table D-1.
   Sources: Jensen (59), p. 394; Denmark, Report to FAO (54), p. 26; Denmark, Landbrugsstatistik, 1967, pp. 76-7.

Table D-7: Denmark: Horsepower and Fertilizer Inputs

	Horsepower[1] (1000 HP)	Fertilizer[2] (1000 kg)	Horsepower per male worker[3]	Fertilizer per ha. of agricultural land[3] (kg/HA)
1870	341	--	1.1	--
1875	360	--	1.1	--
1880	375	4	1.2	1.4
1885	400	5	1.2	1.7
1890	440	7	1.3	2.4
1895	475	10	1.5	3.4
1900	519	14	1.7	4.8
1905	535	18	1.6	6.2
1910	585	32	1.7	11.1
1915	605	49	1.7	17.0
1920	602	45	1.5	14.2
1925	578	65	1.4	20.2
1930	566	121	1.4	37.5
1935	609	119	1.6	36.7
1940	708	138	1.8	42.9
1945	771	99	2.1	31.1
1950	1018	222	3.0	70.6
1955	2061	334	6.1	107.2
1960	3733	395	12.3	127.7
1965	6037	463	22.2	152.7

Notes:

1. Horsepower refers to the number of horses before 1920 in the area which coincides with present-day Denmark. Beginning with 1925, horsepower is the sum of tractor horsepower and horses. The number of horses only began to significantly decline after 1950. Tractor horsepower is estimated as 5 hp per garden tractor, 30 hp per standard tractor.
   Sources: Horse data: Jensen (59), p. 394; Denmark, Landbrugsstatistik, 1900-1965, Vol. I, (51), p. 30; Tractor data: Denmark, Landbrusstatistik, various issues; data provided by Professor P. E. Stryg of the Royal Veterinary and Agricultural College, Denmark.

2. Fertilizer data refer to the sum of the nutrients ($\Sigma N + P_2O_5 + K_2O$) in commercial fertilizers averaged for groups of years about the tabulated data.
   Sources: Denmark Agriculture (50), p. 87; Denmark, Landbrugsstatistik 1900-1965 (51), pp. 240-41.

3. Land and labor data from Table D-1.

Table D-8: Denmark: Indexes of Input Prices and Price Ratios: 1910 = 100

	Land[1]	Wages[2]	Fertilizer[3]	Concentrated Feeds[4]	Machinery	Indexes of Price Ratios: Fertilizer/Land	Conc./Land	Machinery/Wages
1870	65	47						
1875		50						
1880	87	57	50			58		
1885		61		106				
1890	83	61	50	86		60	103	
1895		68		91				
1900	74	75	79	85		107	115	
1905	82	82	99	89		121	109	
1910	100	100	100	100	100	100	100	100
1915	136	122	144	118	154	106	87	126
1920	224	211	328	273	269	146	122	127
1925	214	222	138	201	216	65	94	97
1930	177	186	100	135	175	56	77	94
1935	163	190	98	99	185	60	61	97
1940	207	279	128	135	256	62	66	92
1945	299	547	182	--	366	61	--	67
1950	385	770	207	387	432	54	101	56
1955	479	1020	230	502	552	48	98	54
1960	708	1273	234	--	623	33	--	49
1965	938	2412	268	--	740	29	--	31

Notes:

1. Land price data in Table D-4.

2. Wages data in Table D-4.

3. Fertilizer price data in Table D-4.

4. Concentrate price data in Table D-9.

5. Machinery price index was constructed by splicing recent FAO data of farm machinery prices to the machinery and implements index given in Technical.

   Sources: Technical and Economic Changes in Danish Farming (58), p. 28; FAO, Production Yearbooks, various issues.

Table D-9: Denmark: Imports and Prices of Concentrated Feeds: 1880-1925

	Net import of concentrates[1] (1000 tons)	Price of concentrates[3] (kr/ton)	Conc. per hectare of agricultural land[4] (kg/HA)	Conc./head of livestock[5] (kg/Head)	Price Ratios[6] Conc. / Ag. Land (Ton/Ha)	Price Ratios[6] Butter / Conc. (Ton/HA)
1870						
1875						
1880	73	140.4	2.6	3.7	.532	16.2
1885	120	123	4.2	5.7	.466	14.6
1890	208	99	7.2	9.4		18.0
1895	255	105	8.8	10.9	.418	17.9
1900	607	98	20.8	24.3	.436	19.4
1905	663	103	22.7	24.7	.412	18.6
1910	836	115	29.0	27.1	.378	17.7
1915	1063	136	37.0	30.1	.329	17.6
1920[2]	534	315	16.8	17.3	.463	14.8
1925	1176	232	36.6	33.0	.350	20.1
1930		156			.291	19.5
1935		114			.229	16.8
1940		156			.248	15.8
1945						
1950		446			.381	12.5
1955		578			.377	11.0
1960						
1965						

Notes:

1. Concentrates are maize, bran, oil cake.

   Source: Jensen (59), p. 398.

2. In 1918 Denmark only imported three tons of concentrates. The pig herd was halved in the 1918-1922 period from its 1913-17 level.

3. The price for concentrates is the unweighted average of prices for cottonseed oil cake, sunflower oil cake, palm oil cake, wheat bran, molasses and maize. Before 1901 and after 1934, the price for molasses fourage is not included.

   Sources: Denmark Agriculture (50), Table 57; Denmark, Landbrugets Priser (52), p. 96.

4. Agricultural land data are taken from Table D-1.

5. Livestock data are taken from Table D-6.

6. Land prices and butter prices are taken from Tables D-4 and D-5.

Table D-9: Denmark: Imports and Prices of Concentrated Feeds: 1880-1925 (continued)

	Index of Price Ratios	
	Concentrate / Ag. Land	Butter / Concentrate
	(1910=100)	
1870		
1875		
1880	141	109
1885		82
1890	103	101
1895		101
1900	115	110
1905	109	105
1910	100	100
1915	87	99
1920	122	84
1925	94	114
1930	77	110
1935	61	95
1940	66	89
1945		
1950	101	71
1955	98	62
1960		
1965		

Table D-10: Denmark: Wheat and Milk Yields

	Wheat Yield[1] Quin/HA	Milk Yield[2] kg per cow
1870		1350
1875	22.5	
1880	23.5	1600
1885	28.5	
1890	27.0	1925
1895	29.3	
1900	29.3	2275
1905	29.0	
1910	29.5	2750
1915	29.5	
1920	30.8	2620
1925	27.5	
1930	30.1	3341
1935	30.1	3429
1940	28.6	2725
1945	32.2	3077
1950	37.2	3648
1955	39.5	3517
1960	40.7	3611
1965	42.2	3725

Notes:

1. Wheat yield is a five-year centered average. Source: Jensen (59), p. 390; Denmark, Land Brusstatistik, 1900-1965 (51), pp. 54-55; Denmark, Landbrugsstatistik, 1967, p. 66.

2. Milk yield is tabulated as a single year nearest to date. Data in Technical and Report were spliced to Jensen to yield the series in kilograms per cow.
Sources: Jensen (59), p. 396; Technical and Economic Changes in Danish Farming (58), p. 33; Denmark, Report to FAO (54), pp. 26, 28.

Table F-1: France: Time Series Data of Output, Agricultural Land, Male Labor and Productivity: 1820-1965[5]

	Output in wheat units[1] Y	Agricultural land[2] A	Males economically active in agriculture[3] L	Land productivity Y/A	Labor productivity Y/L	Land per worker A/L
1820	19,995	34,106	4,100	.6	5.0	8.3
1840	26,071	31,379	4,500	.8	5.8	7.3
1850	29,000	33,688	4,800	.9	6.0	7.0
1870	36,159	34,514	4,800	1.1	7.5	7.1
1875	36,417	34,554	5,230	1.1	7.0	6.6
1880	36,589	34,594	4,970	1.1	7.4	7.0
1885	37,364	34,514	4,720	1.1	8.0	7.3
1890	38,139	34,429	4,580	1.1	8.3	7.5
1895	39,172	34,800	5,160	1.1	7.6	6.7
1900	40,636	35,200	5,020	1.2	8.1	7.0
1905	43,219	35,950	4,960	1.2	8.7	7.2
1910	45,457	36,799	4,910	1.2	9.3	7.5
1915	45,801	36,500	4,720	1.3	9.7	7.7
1920	46,146	36,219	4,540	1.3	10.2	8.0
1925	49,848	36,294	4,290	1.4	11.6	8.5
1930	53,464	35,566	4,040	1.5	13.2	8.8
1935	53,119	34,883	3,870	1.5	13.7	9.0
1940	48,657	33,488	3,860	1.5	12.6	8.7
1945	44,682	32,328	3,840	1.4	11.6	8.4
1950	51,311	33,562	3,300	1.5	15.5	10.2
1955	60,782	33,706	2,970	1.8	20.5	11.3
1960	86,093	34,681	2,580	2.5	33.4	13.4
1965	108,271	34,211	2,210	3.2	49.0	15.5

Table F-1: France: Time Series Data of Output, Agricultural Land, Male Labor and Productivity: 1820-1965[5] (continued)

	Index: 1870 = 100						Percent of Males Economically Active in Non-agriculture[4]
	Y	A	L	Y/A	Y/L	A/L	
1820	55	98	85	55	67	117	
1840	72	91	94	73	77	102	
1850	80	98	100	82	80	99	48
1870	100	100	100	100	100	100	49
1875	101	100	109	100	93	93	
1880	101	100	104	100	99	99	51
1885	103	100	98	100	107	103	
1890	105	100	95	100	111	106	55
1895	108	101	107	100	101	94	
1900	112	102	105	109	108	99	56
1905	120	104	103	109	116	101	
1910	126	107	102	109	124	106	60
1915	127	106	98	118	129	108	
1920	128	105	95	118	136	113	60
1925	138	105	89	127	155	120	
1930	148	103	84	136	176	124	67
1935	147	101	81	136	183	127	
1940	135	97	80	136	168	122	67
1945	124	94	80	127	155	118	
1950	142	97	69	136	207	143	70
1955	168	98	62	164	273	158	75
1960	238	100	54	227	445	188	80
1965	29	99	46	291	653	218	

Table F-1: France: Time Series Data of Output, Agricultural Land, Male Labor and Productivity: 1820-1965 (continued)

Notes:

1. Output in 1000 wheat units: The Toutain series of agricultural output net of seeds and feed (current price series deflated by the 1905-14 weight price index) is spliced to the EEC's 1958 constant price output series. The Toutain series, presented in 10 year averages, is interpolated to a quinquennial series. Splice is made at 1950-54. The resultant series was then converted to wheat units employing Hayami's computation for 1957-62. Alsace-Lorraine is excluded 1870-1920.

   Sources: J.C. Toutain, (97), pp. 6, 128-129. (Lumber deducted from table 10,pp.128-129).
   EEC, Agarstatistik, ( ), pp. 26-27.
   Hayami, (18), p. 21.

2. Land in 1000 hectares: Agricultural land is comprised of arable land including temporary fallow and grass plus permanent pastures. Alsace-Lorraine is excluded 1882-1919 and 1939-1944.

   Source: France: Annuaire Statistique, 1966, p. 177; 1951, p. 104.

3. Labor in 1000 males: Data are economically active males in agriculture excluding forestry, fishing and hunting occupations. Alsace-Lorraine is excluded 1870-1920.

   Sources: Toutain, (97), pp. 200-201.
   FAO, Production Yearbook, various issues.

4. Economically active males in non-agricultural occupations.

   Source: Toutain, (97), p. 201.

5. Land data are for single years; output and labor are interpolations from Toutain's ten year average data, or five year centered averages.

Table F-2: France: Final Agricultural Output of Crop and Livestock Products

	1 Crop products (1000 Francs)[1]	2 Livestock products[1]	3 Ratio of crop to animal products	Index: 1865-74=100 Crop products	Livestock products
1781-90	2,972	1,510	1.97	48	47
1815-24	3,481	1,671	2.08	57	53
1845-54	4,943	2,532	1.95	81	80
1855-64	5,678	2,908	1.95	93	91
1865-74	6,130	3,182	1.93	100	100
1875-84	5,798	3,469	1.67	95	109
1885-94	5,566	4,031	1.38	91	127
95-1904	6,272	4,185	1.50	102	132
05-1914	6,671	4,996	1.34	109	157
1920-24	5,965	5,634	1.06	97	177
1925-34	6,806	6,773	1.01	111	213
1935-38	7,044	7,002	1.01	115	220

[1] Final agricultural product in deflated 1905-14 francs, seed and feed deducted.

Source: Toutain (97), pp. 128-29.

Table F-3: France: Agricultural Land Utilization

	Food Grains[1] (1000 ha.)	Of Which, Wheat (1000 ha.)	Feed Grains[2] (1000 ha.)	Permanent Grass[3] (1000 ha.)	Cultivated Grass & Root Fodder[4] (1000 ha.)
1870	8907	6979	5378	6905	3095
1875	8675	6801	4890		
1880	8720	6900	5132	6089	4497
1885	8719	6991	5252		
1890	8335	7000	5398	6457	4793
1895	8385	6762	5369		
1900	8118	6844	5159	6633	4667
1905	7795	6575	5059		
1910	7739	6539	5188	10072	5097
1915	5777	4971	3988		
1920	5963	5094	4350	10930	5242
1925	6200	5357	4538		
1930	6192	5218	4499	11216	5401
1935	5887	5085	4362		
1940	4764	4312	3323	11589	6107
1945	4342	3885	3319	12356	5929
1950	4751	4133	3654	12279	6734
1955	4512	4419	4052	12340	7146
1960	4624	4358	4402	13062	7599
1965	4608	4388	4382	13281	7525

Notes:
1. Food grains are wheat and rye.
2. Feed grains are oats, barley and corn.

Table F-3: France: Agricultural Land Utilization (continued)

(notes)

Sources for food and feed grains: Farnsworth (71), pp. 270-271.
France, Annuaire Statistique, 1951, p. 105; 1966, p. 182.

3. Permanent grass are natural pastures and meadows not in rotation.

4. Cultivated grasses are trefle, luzerne, sainfoin, mixed grasses and green fodders. Root fodders are beets, rutabagas, navets and cabbages. The separate areas of roots and grasses is not available.

Sources for grass and fodder: Toutain (97), pp. 214-215.
France, Annuaire Statistique, 1966, p. 185.

Table F-4: France: Prices of Arable Land, Wages, Fertilizer and Wheat: 1852-1965[5]

	Daily Wages[1] (O.F.)	Price per ha. arable land[2] (O.F.)	Number of days work to buy 1 ha.	Price of 100 kg Avg. fertilizer[3]	Price per Quintal wheat[4]	Quintals of wheat to buy 100 kg. F.
1852	1.76	1,500	852.0			
1870	2.31	1,673	724.2	49.7	25.9	1.9
1875	2.37	1,724	727.4	37.3	29.5	1.3
1880	2.28	1,778	779.8	39.8	28.8	1.4
1885	2.19	1,759	803.2	24.9	22.6	1.1
1890	2.43	1,674	688.9	24.9	24.6	1.1
1895	2.69	1,638	608.9	24.9	20.3	1.2
1900	2.69	1,584	588.8	24.9	20.8	1.2
1905	2.80	1,530	546.4	24.9	22.6	1.1
1910	3.0	1,583	527.7	24.9	24.8	1.1
1915	5.0	1,964	392.8	49.7	34.0	1.5
1920	11.5	2,831	246.2	114.4	79.1	1.4
1925	14.9	4,055	272.9	131.8	132.0	1.0
1930	20.6	5,4 5	264.3	116.9	141.6	.8
1935	20.4	5,170	253.4	74.6	110.4	.7
1940	33.1	5,200	157.1	92.0	258.9	.4
1945	149.2	35,000	234.6	248.7	884.6	.3
1950	479.4	125,000	260.7	1044.4	2911.8	.4
1955	888.4	140,000	157.6	1775.4	3492.1	.5
1960	1508.9	250,000	165.7	2163.3	3750.8	.6
1965	2547.7	600,000	235.0	2486.6	4435.2	.6

Table F-4: France: Prices of Arable Land, Wages, Fertilizer and Wheat: 1852-1965 (continued)

Notes:

1. Wages are a simple average of daily winter and summer wages to men neither fed nor housed. Adequate data for farm wages exist for the period 1852-1892 and after 1928. To link these two periods a splice was made to an index of daily wages of laborers in the provinces assuming one day was equivalent to ten hours.

   Sources: France, Statistique Agricole, 1892, p. 244.
   France, Annuaire Statistique, 1915, p. 253.
   ILO, Yearbook, various issues.

2. Land prices are the mean value per hectare of arable land.

   Source: France, Un Certain Malthusianisme, (74).

3. Fertilizer prices. The only available long time series of fertilizer prices is for muriate of potash. Prices for other nitrogenous and phosphate fertilizers were only available after 1950. Before 1934 nitrate of soda was assumed to be representative of fertilizer prices. Indexes were constructed for the nitrate product and the potash and then spliced to give a complete index of five year centered prices. The data of ammonium nitrate, super phosphate and muriate of potash wholesale prices for 1950-1965 were averaged to yield an average fertilizer price. The index previously computed was then spliced to these actual price data to establish approximate fertilizer prices.

   Sources: FAO, Yearbook, 1966.
   France, Annuaire Statistique, 1951, p. 213.

4. Wheat price is the price of wheat at Paris.

   Sources: Michael, (89), pp. 55-57.

Table F-4: France: Prices of Arable Land, Wages, Fertilizer and Wheat: 1852-1965 (continued)

France, Annuaire Statistique, 1966, p. 182.

5. Where available, data are five year centered averages. Otherwise, data are for single years or for averages over some non-uniform group of years about the tabulated year.

Table F-5: France: Product Prices and Price Ratios (2)

	Wheat (1) Francs per 100 kg	Meat (1) Francs per 100 kg	Butter (1) Cheese Francs per 100 kg	Price Ratios of: Wheat/Meat	Price Ratios of: Wheat/Butter	Indexes of Price Ratios: Wheat/Meat	Indexes of Price Ratios: Wheat/Butter
						1865-74=100	
1855-64	28.8	118	222	.244	.129	124	109
1865-74	30.2	154	255	.196	.118	100	100
1875-84	27.3	159	232	.172	.118	88	100
1885-94	22.8	144	164	.158	.139	81	118
1895-1904	20.8	129	178	.161	.117	82	99
1905-14	24.8	158	193	.157	.128	80	109
1920-24	88.9	635	772	.140	.115	71	97
1925-34	139.6	1170	1146	.119	.122	61	103
1935-38	157.3	745	1153	.211	.136	108	115

Notes:

(1) Prices are the prices to producers.

Source: Toutain, (97), pp. 188-192.

(2) Beginning with 1885, French products were protected by tariffs which had the net effect of biasing the price ratios in favor of wheat.

Table F-6: France: Cattle and Livestock Numbers

	Cattle (1000)	Index 1870=100	Aggregate[1] livestock (1000)	Index 1870=100	Cattle / male labor	Livestock / male labor	Livestock / agricultural land (animals per 10 hectares)
1870	9,658	100	17,113	100	2.5	3.6	5.0
1875	9,922	103	17,211	101	2.4	3.3	5.0
1880	10,065	104	17,220	101	2.5	3.5	5.0
1885	10,239	106	17,237	101	2.7	3.7	5.0
1890	10,865	112	17,880	104	3.0	3.9	5.2
1895	10,519	109	17,465	102	2.5	3.4	5.0
1900	11,399	118	18,477	108	2.8	3.7	5.2
1905	11,312	117	18,530	108	2.9	3.7	5.2
1910	11,538	119	18,695	109	2.9	3.8	5.1
1915	10,008	104	15,172	89	2.7	3.2	4.2
1920	10,382	107	15,622	91	1.9	3.4	4.3
1925	11,434	118	17,336	101	3.3	4.0	4.8
1930	12,409	128	18,543	108	3.8	4.6	5.2
1935	12,570	130	18,655	109	4.1	4.8	5.3
1940	11,756	122	16,694	98	3.0	4.3	5.0
1945	11,427	118	16,110	94	3.7	4.2	5.0
1950	12,638	131	18,105	106	4.8	5.5	5.4
1955	14,023	145	19,555	114	5.9	6.6	5.8
1960	15,685	162	21,074	123	7.6	8.2	6.1
1965	16,114	167	21,097	123	7.3	9.5	6.2

Notes:

1. Livestock are aggregated using the standard FAO weights: horses, 1.0; cattle, 0.8; pigs, 0.2; sheep, 0.1; fowl, 0.01; goats, 0.1. Cattle data are weighted numbers. To arrive at the actual number of cattle divide

Table F-6: France: Cattle and Livestock Numbers (continued)

(notes)

by 0.8. Data are three year centered averages. Labor and land data are taken from Table F-1.

Source: France, Annuaire Statistique, 1951, pp. 119-120 and 1966, pp. 180-181.

Table F-7: France: Fertilizer and Horsepower Inputs

	Fertilizer[1] ($N + P205 + K_2O$) (1000 kg.)[2]	Horsepower[2] (horses plus tractor H.P.) (1000 H.P.)	Fertilizer[3] per ha. of agricultural land (kg./ha.)	Horsepower[4] per male farm worker
1870	55	3500	1.6	.7
1875	65	3500	1.9	.7
1880	75	3500	2.2	.7
1885	78	3537	2.3	.7
1890	113	3465	3.3	.8
1895	184	3381	5.3	.7
1900	235	3464	6.7	.7
1905	298	3733	8.3	.8
1910	396	3752	10.8	.8
1915	222	2677	6.1	.6
1920	371	3114	10.2	.7
1925	668	3341	18.4	.8
1930	786	4134	22.1	1.0
1935	697	4205	20.0	1.1
1940	662	3780	19.8	1.0
1945	443	4343	13.7	1.1
1950	1046	6880	31.2	2.1
1955	1440	11777	42.7	4.0
1960	2267	22874	65.4	8.9
1965	3088	30850	90.3	14.0

Notes:

[1]Fertilizer: Data refer to the sum of the nutrients in commercial fertilizers, ($N + P_2O_5 + K_2O$). Data are available beginning with 1886. To arrive at the values before 1886 a rate of growth was computed.

Table F-7: France: Fertilizer and Horsepower Inputs (continued)

With this, the values were extrapolated. Data are five year centered averages.

Source: France, Annuaire Statistique, 1966, p. 178.

[2]Horsepower: Data are the sum of tractor horsepower and horses, mules and asses beginning in 1930. Before 1930 only animal power is counted. Tractor horsepower were computed on the basis of 30 horsepower per standard sized tractor and 5 horsepower per garden tractor. Data are five year centered averages.

Sources: France, Annuaire Statistique, 1966, p. 179.
France, Annuaire Statistique, 1951, p. 19; 1961, p. 101; 1966, p. 180.

[3]Fertilizer per hectare of agricultural land employs land as defined and tabulated in Table F-1.

[4]Horsepower per male farm worker employs the data of males from Table F-1.

Table F-8: France: Input Price Indexes 1905-13 = 100

					Indexes of Price Ratios	
					Fertilizer	Machinery
	Wages[1]	Machinery[2]	Fertilizer[1]	Land[1]	Land	Wages
1870	80	119	192	105	183	149
1875	82	113	146	108	135	138
1880	79	108	158	111	142	137
1885	76	103	96	110	87	136
1890	84	99	92	105	88	118
1895	93	99	88	102	86	106
1900	93	98	88	99	89	105
1905	97	99	104	96	108	102
1910	103	100	100	99	101	97
1915	79	201	213	123	173	254
1920	52	405	446	177	252	779
1925	67	450	513	253	203	672
1930	94	463	458	340	135	493
1935	92	479	292	323	90	521
1940	151	748	358	325	110	495
1945	692	2,263	958	2,188	44	327
1950	2,441	12,519	4,075	7,813	52	513
1955	4,326	17,669	6,958	8,750	80	408
1960	7,109	22,982	8,521	15,625	55	323
1965	9,896	26,097	9,750	37,500	26	264

Table F-8: France: Input Price Indexes 1905-13 = 100 (continued)

Notes:

1. Wages, fertilizer prices, and land price data are taken from table F-4.

2. The machinery price index was constructed from two overlapping indexes. An index for farm machinery prices exists for 1938 to the present. Before 1938 the price index for metal manufacutring was employed as a proxy for farm machinery. These were linked at the overlapping period around 1938.

Source: FAO, Production Yearbook, various issues.
Markovitch (87), table 5 of the appendix.

Table F-9 : France: Wheat and Milk Yields

	Wheat Yield[1] Quintals per Ha.	Milk Yield[2] kg per cow
1870	11.2	
1875	11.1	
1880	10.9	
1885	11.8	1550
1890	11.5	
1895	12.2	1650
1900	13.5	
1905	14.4	
1910	13.2	
1915	11.4	
1920	13.2	
1925	13.9	
1930	14.7	
1935	15.3	
1940	14.6	1780
1945	13.5	
1950	18.2	
1955	22.4	1870
1960	25.3	
1965	29.1	

Notes:

1. Wheat yield is a 5 year centered average.

Source: France, Anniuaire Statistic, 1966, p. 152; 1951, p. 105.

Table F-9 : France: Wheat and Milk Yields (continued)

2. Milk yield is an average of a non-uniform group of years about the tabulated date. These data are taken from Clark with Clark's caveat that there was a conflict in his sources. One official source indicated the 1902 milk yield as only slightly over 1000 kg.

Source: Clark, (7) p. 291.

BIBLIOGRAPHY

General

1. Ahmad, Syed. "On the Theory of Induced Invention," Economic Journal, 76, 302 (June, 1966), pp. 344-357.

2. Allen, R.G.D. Macro-Economic Theory. New York: St. Martin's Press, 1967.

3. Binswanger, Hans. "The Measurement of Biased Efficiency Gains in U.S. and Japanese Agriculture to Test the Induced Hypothesis," Ann Arbor, Michigan, University Microfilms, 1973.

4. _____. "The Measurement of Biased Technical Change in the Many Factors Case: U.S. and Japanese Agriculture," Staff Paper, Series P72-28, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul, December 1972.

5. Brown, Lester R. Increasing World Food Output, Foreign Agricultural Economic Report No. 25, USDA, Washington, D.C., 1965.

6. Brown, Murry. On the Theory and Measurement of Technical Change. Cambridge: University Press, 1966.

7. Clark, Colin. The Conditions of Economic Progress. Third Edition. London: Mac Millan and Co., Ltd., 1957.

8. David, Paul A. and Klundert, Th. van de. "Biased Efficiency Growth and Capital-Labor Substitution in the United States, 1899-1960," American Economics Review, 55, 3 (June 1965), pp. 357-394.

9. Davis, Lance E. Institutional Change and American Economic Growth. Cambridge: University Press, 1971.

10. Dovring, Folke. "Eighteenth-Century Changes in European Agriculture: A Comment," Agriculture History, 93, 1 (January 1969), pp. 181-186.

11. _____. Land and Labor in Europe in the Twentieth Century. Third Edition. The Hague: Martines Nijhoff, 1965.

12. Drandakis, E. M. and E. S. Phelps. "A Model of Induced Innovation." Economic Journal, 76, 282, pp. 823-840.

13. FAO. Production Yearbook. Various issues.

14. Fellner, W. "Two Propositions in the Theory of Induced Innovations." Economic Journal, 71, 282 (June 1961), pp. 305-308.

15. Griliches, Zvi. "Research Expenditures, Education, and the Aggregate Production Function." American Economic Review, 54 (December 1964).

16. _____. "Research Costs and Social Returns: Hybrid Corn and Related Innovations." Journal Political Economy, LXVI (October 1958), pp. 419-431.

17. Griswold, A. Whitney. Farming and Democracy. New Haven: Yale University Press, 1952.

18. Hayami, Yujiro in association with Barbara Miller, William Wade and Sachiko Yamashita. "An International Comparison of Agricultural Production and Productivities, Technical Bulletin 277, University of Minnesota: Agricultural Experiment Station, forthcoming.

19. Hayami, Yujiro and V. W. Ruttan. Agricultural Development--An International Perspective, forthcoming Baltimore, John Hopkins Press, 1971.

20. Hicks, J. R. The Theory of Wages. Cambridge: Mac Millan, 1932; reprinted Glouchester, Mass., Peter Smith, 1957.

21. ILO. Yearbook of Labor Statistics. Various issues.

22. Johnson, Glen. "The Labor Utilization Problem in European and American Agriculture." Journal of Agricultural Economics, 14, 1 (June 1960), pp. 73-87.

23. Johnston, J. Econometric Methods. Second Edition. New York: McGraw-Hill, 1972.

24. Kennedy, C. "Induced Bias in Innovation and the Theory of Distribution." Econometric Journal, 74 (September 1964), pp. 541-547.

25. Kindleberger, Charles P. Economic Growth in France and Britain, 1851-1950. Cambridge: Harvard University Press, 1964.

26. _____. "Group Behavior and International Trade," Journal of Political Economy, 50, 1 (February 1951), pp. 30-46.

27. Kmenta, Jan. Elements of Econometrics. New York: Mac Millan Company, 1971.

28. Kotowitz, Yehuda. "On the Estimation of a Non-neutral CES Production Function." Canadian Journal of Economics, I, 2 (May 1968), pp. 429-439.

29. Morrison, F. B. Feeds and Feeding. Twentieth Edition. Ithaca: Morrison Publishing Co., 1936.

30. North, Douglas C. and Thomas, Robert P. "An Economic Theory of the Growth of the Western World." Economic History Review, 23, 1 (April 1970), pp. 1-17.

31. _____. "Institutional Change and American Economic Growth: A First Step Towards a Theory of Institutional Innovation." Journal Economic History, 30, 1 (March 1970), pp. 131-149.

32. OECD. Evolution de La Motorization de l'Agriculture et la Consummation et des Prix des Carberants dans les Pays Membres. Paris: June 1963.

33. Ojala, E. M. Agriculture and Economic Progress. Cambridge: University Press, 1959.

34. Rosenberg, Nathan. "The Direction of Technical Change: Inducement Mechanism and Focusing Devices." Economic Development and Cultural Change, 18 (October 1969), pp. 1-24.

35. Ruttan, Vernon W. and Yujiro Hayami. "Strategies for Agricultural Development." FRI Studies in Agricultural Economics, Trade, and Development, XI, 2 (1972), 129-148.

36. Salter, W.E.G. Productivity and Technical Change, Second Edition. Cambridge: University Press, 1966.

37. Schultz, T. W. "Institutions and the Rising Economic Value of Man." American Journal Agricultural Economics, 50, 4 (December 1968), pp. 1113-1122.

38. Stroud, A., A. Zellner and L. C. Chau. "Program for Computing Two- and Three-Stage Least Square Estimates and Associated Statistics." Revised by H. Thornber and A. Zellner, Chicago: University of Chicago Graduate School of Business, July 1965.

39. Theil, Henri. Principles of Econometrics. New York: John Wiley and Sons, 1971.

40. Tracy, Michael. Agriculture in Western Europe. London: Jonathan Cape, 1964.

41. Tsuchiya, Keizo. "Economics of Mechanization in Small-Scale Agriculture." Agriculture and Economic Growth: Japan's Experience. Bruce Johnston and Hiromitsu Kaneda, editors. Tokyo: University of Tokyo Press, 1969.

42. USDA. "Prewar World Production and Consumption of Plant Foods in Fertilizers." USDA: Miscellaneous Publication, 593, Washington, D.C., April 1946.

43. USDA. "Indices of Agricultural Production in Western Europe, 1950-1968." ERS-Foreign 266, July 1969.

44. Van Bath, B. H. Slicher. The Agrarian History of Western Europe A.D. 500-1850. London: Edward Arnold, Ltd, 1963.

45. Walker, Ronald. From Economic Theory to Policy. Chicago: University of Chicago Press, 1943.

46. Weber, Adolf. "Distinctive Characteristics in the Agricultural Development of Germany from 1800 to 1970." Unpublished mimeograph, University of Minnesota, 1972.

47. Yeung, Patrick and Terry Roe. "Induced Innovation: A CES-Type Meta-Production Function." Staff Paper, P 71-27. Department of Agricultural and Applied Economics, University of Minnesota, December 1971.

48. Youngson, A. J. Possibilities of Economic Progress. Cambridge: University Press, 1959.

Denmark

49. Bjerke, Kjeld and Ussing, Niels. Studies Over Danmarks Produkt, 1870-1950. Copengagen, 1958.

50. Denmark, Agriculture, Copenhagen: The Agricultural Council. 1935.

51. Denmark, Landbrugs Statistik, 1900-1965. Bind I, Copenhagen: Danmarks Statistik, 1968.

52. Denmark, Landbrugets Priser, 1900-1957. Copenhagen: Statistical Department. 1958.

53. Denmark, Landkonomisk Oversigt, 1968. Copenhagen: Danske Land Bo Foreninger. 1968.

54. Denmark, Report to FAO. Copenhagen: Danish National FAO Committee, 1962.

55. Hertel, H. Cooperation in Danish Agriculture. New York: Longmans, Green and Co. 1918.

56. Howe, Frederic C. Denmark: A Cooperative Commonwealth. New York: Harcourt, Brace and Company. 1921.

57. _____. "The Most Complete Ag Recovery in History: The Example of Denmark." The Annuals of the American Academy. March 1934.

58. Institute of Farm Management and Agricultural Economics. Technical and Economic Changes in Danish Farming: 1917-1957. Copenhagen: Landhusholdingsselskabets Forlag. 1959.

59. Jensen, Einar. Danish Agriculture. Copenhagen: J. H. Schultz Forlag. 1937.

60. Knudsen, P. H., ed. Agriculture in Denmark. Copenhagen: Agricultural Council of Denmark. 1967.

61. Manniche, Peter. Rural Development and the Changing Countries of the World. New York: Pergamon Press. 1969.

62. Nash, E. F. and E. A. Attwood. The Agricultural Policies of Britain and Denmark. London: Land Books, Ltd. 1961.

63. Skrubbeltrang, F. Ag Development and Rural Reform in Denmark. (FAO, Agricultural Studies, No. 22, April 1953), Rome.

France

64. Auge-Laribe, Michel. La Politique Agricole de La France de 1880 A 1940. Paris: Presses Universitaires de France, 1950.

65. Cameron, Rondo E. "Economic Growth and Stagnation in France, 1815-1914." The Experience of Economic Growth. Barry E. Supple, ed. New York: Random House. 1963.

66. _____. France and the Economic Development of Europe, 1800-1914. Princeton, New Jersey: Princeton University Press. 1961.

67. Clapham, J. H. Economic Development of France and Germany, 1815-1914. Fourth Edition. Cambridge: University Press, 1966.

68. Collins, E.J.T. "Labour Supply and Demand in European Agriculture 1800-1880." Agricultural Change and Economic Development. E. L. Jones and S. J. Woolf, editors. London: Methuen and Company, Ltd. 1960.

69. EEC. Statistique Agricole. 10 (October 1960).

70. EEC. Statistique Agricole. 4, 1968.

71. Farnsworth, Helen C. "Determinants of French Grain Production, Past and Prospective." Food Research Institute Reprint, Stanford, 1964. (Reprinted from FRI Studies, IV, 3, 1964).

72. France. Annuaire Statistique: Resume Retrospectif. 1951. Paris: Institut National de La Statistique et des Etudes Economiques. 1952.

73. France. Annuaire Statistique: Resume Retrospectif. 1966. Paris: Institut National de La Statistique et Des Etudes Economics. 1966.

74. France. Ministere de L'Agriculture. Un Certain Malthusianisme. Etude No. 299. September 1966.

75. France. Statistique Agricole. 1892.

76. France. Statistique Agricole. 1968.

77. Golob, Eugene Owen. The Meline Tariff: French Ag. and Nationalist Economic Policy. New York: Columbia University Press. 1944.

78. Granthum, George W. Technology and Organizational Change in French Agriculture, 1840-1880. Ann Arbor, Michigan: University Micro Films. 1972.

79. _____. "The Demand for Labor and Factor Substitution in French Agriculture, 1840-1880," paper given at Annual Cliometric's Conference, Madison, Wisconsin, April 1972.

80. Haight, Frank Arnold. A History of French Commercial Policies. New York: Mac Millan Company, 1944.

81. Hohenberg, Paul M. Chemicals in Western Europe, 1850-1914. Chicago: Rand McNally and Co., 1967.

82. _____. "Change in Rural France in the Period of Industrialization, 1830-1914." Journal of Economic History, 23 (March 1972).

83. Hunter, Neil. Peasantry and Crisis in France. London: Victor Gollancz, Ltd. 1938.

84. _____. "The Postwar Resurgence of the French Economy." In Search of France. Stanley Hoffman, Editor. Cambridge: Harvard University Press. 1963.

85. Knowles, L.C.A. Economic Development in the Nineteenth Century. New York: Augustus M. Kelly, 1967. (Reprinted from 1932 publication).

86. Marczewski, J. Le Product Physiquede L'economie francaise de 1789 a 1913. Paris: Institute de Science Economique Appliquee, 1965.

87. Markovitch, T. J. L'Industrie Francaise de 1789 a 1964--Analyse desfaits. Paris: ISEA, 1966.

88. Mendras, Henri. The Vanishing Peasant: Innovation and Change in French Agriculture. Jean Lerner, translator. Cambridge: MIT Press, 1970.

89. Michael, Louis G. Agricultural Survey of Europe: France. USDA, Technical Bulletin #37, Feb. 1928.

90. Muth, Hanns Peter. French Agriculture and the Political Integration of Western Europe. Ceyden, Netherlands. A. W. Sijthoff, 1970.

91. Newell, William. Population Change and Agricultural Development in Nineteenth Century France. Ann Arbor, Michigan: University Micro Films, 1971.

92. _____. "The Agricultural Revolution in Nineteenth Century France." Unpublished paper, St. Olaf College, Northfield, Minnesota, October 1972.

93. OCED. Capital and Finance in Agriculture, Vol. II, Country Studies, "France." Paris, 1970.

94. Palmade, Guy P. French Capitalism in the Nineteenth Century. Trans. by Graeme M. Holmes, Devon, England: David and Charles, 1972.

95. Sargent, Frederic O. "Fragmentation of French Farm Land." Land Economics, 283 (August 1952), pp. 218-229.

96. Thompson, Jan B. Modern France, A Social and Economic Geography. London: Butterworths, 1970.

97. Toutain, J. C. Le Produit de l'Agriculture Francaise, de 1700 a 1958: Estimation de produit av XVII, Siecle. Paris: LiInstitut de Science Economique Appliquee, 1961.

98. _____. Le Produit de l'Agriculture Francaise, de 1700 a 1958: La Croissance. Paris: L'Institut de Science Economique Appliequee, 1961.

99. _____. La Population de La France de 1700 a 1959. Paris: L'Institut de Science Economique Appliquee, 1963.

100. World Agriculture. A report by a study group of members of the Royal Institute of International Affairs. Oxford University Press: London: Humphrey Milford, 1932.

101. Wright, Gordon. Rural Revolution in France. Stanford University Press, 1964.

United Kingdom:

102. Aldcroft, Derek H. and Harry W. Richardson. The British Economy, 1870-1939. London: Mac Millan and Co., 1969.

103. Ashworth, William. An Economic History of England, 1870-1937. London: Methuen and Co., Ltd., 1960.

104. Astor, Viscount and Rowntree See Bohm. British Agriculture. London: Longsmans, Green and Co., 1938.

105. Bellerby, J. R. "The Distribution of Farm Income in the United Kingdom, 1867-1938." Essays in Agrarian History, Vol. II. W. E. Michinton, Ed. London: David Charles, 1968.

106. _____. "National and Agricultural Income." Economic Journal. 69 (March 1959), pp. 95-104.

107. Bowley, Arthur L. Wages in the United Kingdom in the Nineteenth Century. Cambridge: University Press, 1900.

108. Britton, D. K. "The Sale Value of Farm Land Between the Wars." Farm Economist, VI, 5, 1949.

109. Chambers, J. D. and G. E. Mingay. The Agricultural Revolution, 1750-1880. New York: Schocken Books, 1966.

110. Clapham, John H. An Economic History of Modern Britain. Cambridge: University Press, 1938.

111. Collins, E.J.T. and E. G. Jones. "Sectoral Advances in English Agriculture, 1850-80." Agricultural History Review, XV, Part II, 1967, pp. 65-81.

112. Deane, Phyllis and W. A. Cole. British Economic Growth, 1688-1959. Cambridge: University Press, 1967.

113. Ensor, R.C.K. England, 1870-1914. Oxford: Claredon Press, 1936.

114. Ernle, Lord. English Farming, Past and Present. Sixth Edition. Chicago: Quadrangle Books, 1961.

115. Fletcher, T. W. "The Great Depression of English Agriculture, 1873-1896." Essays in Agrarian History, Vol. II. W. E. Minchinton, Ed. London: David and Charles, 1968.

116. _____. "Lancasshire Livestock Farming During the Great Depression." Agricultural History Review, IX, Part I, 1961, pp. 17-42.

117. Hall, A. D. Agriculture After the War. London: John Murray, 1916.

118. Jones, E. L. "The Changing Basis of Agricultural Prosperity, 1853-1873." Essays in Agrarian History, Vol. II. W. E. Minchinton, Ed. London: David and Charles, 1968.

119. _____. "English Farming Before and During the Nineteenth Century." Economic History Review, XV, 1 (August 1962), pp. 145-152.

120. Kerridge, Eric. The Agricultural Revolution. London: George Allen and Unwin, Ltd., 1967.

121. Martin, E. W. The Secret People, English Village Life After 1750. London: Phoenix, 1954.

122. Menzies-Kitchen, A. W. The Future of British Farming. London: Pilot Press, 1945.

123. Mingay, G. E. "The Agricultural Revolution in English History: A Reconsideration." Essays in Agrarian History, Vol. II. W. E. Minchinton, Ed. London: David and Charles, 1968.

124. Mitchell, B. R. and Phyllis Deane. Abstract of British Historical Statistics. Cambridge University Press, 1962.

125. Orwin, C. S. The Future of Farming. Oxford: Clarendon Press, 1930.

126. Sayers, R. S. "The Springs of Technical Progress in Britain, 1919-1939." Economic Journal, 60, 23 (June 1950), pp. 275-291.

127. Slater, Sir William. "The Revolution in Agriculture." Agriculture, V, 68 (October 1961), pp. 341-45, 398-403.

128. Stearns, Raymond Phineas. "Agricultural Adaptation in England, 1875-1900." Agriculture History, VI, 1 and 2, pp. 84-154.

129. Sturmey, S. G. "Owner-Farming in England and Wales, 1900-1950." Essays in Agrarian History, Vol. II. W. E. Minchinton, Ed. London: David and Charles, 1968.

130. Thompson, F.M.L. English Landed Society in the Nineteenth Century. London: Routledge and Kegan Paul, 1963.

131. Thompson, R. J. "An Enquiry into the Rent of Agricultural Land in England and Wales During the Nineteenth Century." Essays in Agrarian History, Vol. II. W. E. Minchinton, Ed. London: David and Charles, 1968.

132. United Kingdom, Ministry of Agriculture, Fisheries and Food. A Century of Agricultural Statistics, 1866-1966. London: HMSO, 1968.

133. United Kingdom. Annual Abstract of Statistics. London: HMSO, various issues.

134. United Kingdom, Ministry of Agriculture, Fisheries and Food. Agricultural Statistics. London: HMSO, various issues.

135. Ward, J. T. "Farm Rents and Tenure." Reprint No. 104, Wye College, new series. Reprinted from Journal of the Land Agent's Society, November 1957.