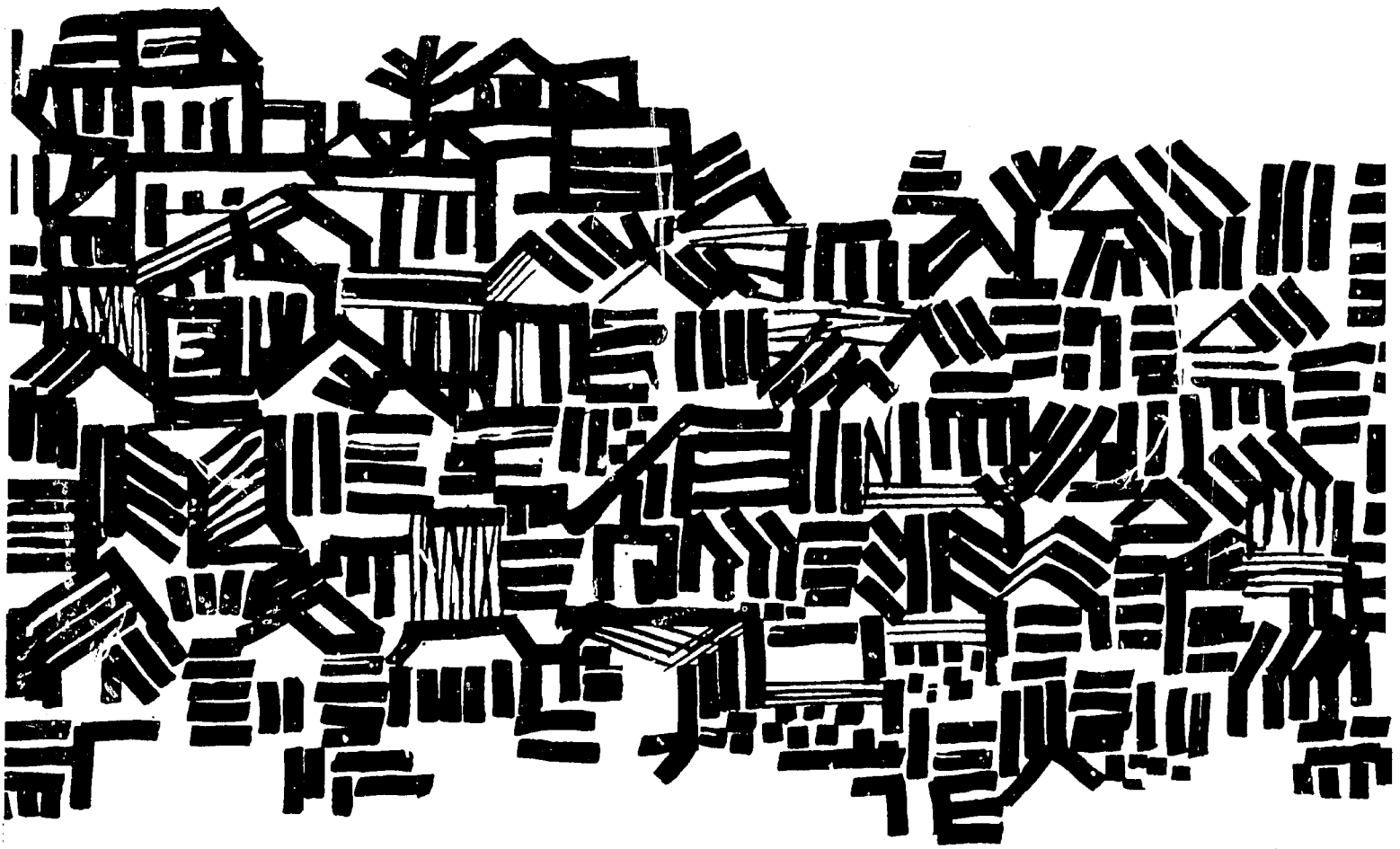
NTERNATIONAL HOUSING PRODUCTIVITY STUDY



GRADUATE SCHOOL OF BUSINESS ADMINISTRATION • UNIVERSITY OF CALIFORNIA, LOS ANGELES

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REPORT ON PRODUCTIVITY IN RELATION TO HOUSING CONDITIONS IN MONTERREY, MEXICO

by
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PRELIMINARY

INTERNATIONAL HOUSING PRODUCTIVITY STUDY
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The International Housing Productivity Study is a major research effort which seeks to articulate the position of housing in economic development programs. International studies are supported by a research contract with the Agency for International Development, U. S. Department of State; domestic studies are supported by a research grant from the National Center for Urban and Industrial Health, U. S. Public Health Service. Papers and reports dealing with various aspects of the research will be published periodically.

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PREFACE

This report, the second in a series of case studies constituting one phase of the International Housing Productivity Study, describes research undertaken in Monterrey, Mexico. The general purpose of the Study is to articulate an economic framework for analyzing the position of housing in development programs.

For a host of reasons, research often produces end-products at variance with those initially anticipated. The research reported here is one example. The set of carefully specified hypotheses are neither supported nor rejected by the evidence of this particular case. This is by no means sufficient proof that the positive associations linking the quality of housing with productivity, health, and education do not exist. However, assessing the associations and measuring their magnitude is a task fraught with booby-traps, as this Report illustrates. In the selection of test sites for studying these associations, we have applied a rigid set of criteria which approximate insofar as possible ideal experimental conditions. Hopefully too, the criteria list obviated those perverse conditions which would frustrate valid measurement.

In this particular case, a variety of conditions, totally irrelevant to the interaction we sought to evaluate, interfered. The conditions included the nature of work organization, payment for work, promotion schemes, and bias inherent in the sample. Consequently, it was all but impossible to identify the fragile thread tying improvement in housing quality to measurable benefits. It should be repeated, however, that our evidence is insufficient for either rejecting or accepting the hypotheses.

The Monterrey site was identified with the assistance of personnel from the Instituto de Investigaciones Industriales. Ings. Avelino Guerra, Antonio Guerra, and Raul Reyna were particularly helpful in assisting the

authors during their visits to Monterrey and in directing the chores of sample design and data collection. Personnel of the Fundidora de Fierro y Acero de Monterrey, S.A., provided access to data. The data were processed at the Western Data Processing Center, UCLA, with the programming assistance of Joyce Chamberlain. James Short and Robert Healy provided many helpful suggestions. Technical review of the materials in Appendix C was given by Glen Graves. Paul Matheson provided valuable research assistance. Jill Nichols and Mary Chapman typed the final report. The authors are grateful to these persons and institutions.

Leland S. Burns
Project Director

1. RESUME

This report describes efforts to analyze the effects on productivity, health, and education of changes in the quality of housing. Specifically, three major questions are addressed:

1. Does an improvement in housing quality lead to an improvement in labor productivity?

2. Does an improvement in housing quality lead to an improvement in health as measured by reductions in absenteeism due to illness?

3. Does an improvement in housing quality lead to the increased likelihood that children will extend their education?

The persons in the sample analyzed are employees, and their families, of a major steel mill in Monterrey, Mexico. The time interval encompassed by the study covers the 15-year period extending from 1949, two years prior to the relocation of a portion of the labor force in improved housing, to 1964. The extended time span provided the unique opportunity of testing the long-run effects of qualitative improvements in housing.

Substantial quantities of data were amassed in order to empirically test each of the three hypotheses. While some evidence supported the first and third hypotheses, the results were below the acceptable level of statistical significance.

During some intervals within the total time period embraced by the analysis, rehoused persons outperformed the non-rehoused in terms of productivity betterment; in other intervals, the reverse was true. In sum, the evidence failed to support the allegation that housing quality leads to improvements in productivity -- similarly, for the remaining two hypotheses.

Wild swings in the data used to measure health changes over the test period prevented identifying any association with housing quality. Other factors so powerfully determined levels of health that the influence of improved housing, if any, was obscured.

Survey revealed that the better housed were more likely to continue their schooling. The results, however, were statistically non-significant.

Several factors unique to this case -- sample bias, or conditions of promotion and payment -- are plausible reasons for the non-significant results.

In sum, the weight of evidence neither supports nor rejects any of the three hypotheses.

2. INTRODUCTION

This report consists of an analysis of the benefits of qualitatively superior housing provided to workers in a Monterrey, Mexico, steel plant. A company-sponsored residential development, completed and occupied in 1951, made possible an improvement in the housing quality of 37 workers and their families. As a measure of productivity differences generated by the improvement, the wages of this rehoused (test) group of workers over the 1949 to 1964 period are compared to the wages of a comparable (control) group of workers who did not receive improved housing. If a significant increase in wages was exhibited by the rehoused group over and above the non-rehoused after rehousing took place, then one could conclude that improved housing had increased the productivity of the rehoused group, assuming that wages reflect productivity.

Two related benefits are also considered. The association between improved housing and health is analyzed by comparing the secular changes in rates of absence from work due to illness of the rehoused and non-rehoused. The degree to which the illness rate of the rehoused declines faster than the non-rehoused is attributed to improved housing. Similarly, we will test the accuracy of the hypothesis that the quality of housing is associated with the motivation of school age children to continue their educations.

Conclusions from such comparisons can be reached only given certain carefully controlled experimental conditions. The necessary criteria and the degree to which they are met in the Monterrey, Mexico, case are discussed in the next section of this report. Measurements of the impact of the housing improvement on productivity, health, and education are considered in the following sections. Background information on the Mexico test site prefaces our discussion of the research.

2.1. The City of Monterrey

Monterrey is located in northeast Mexico approximately 150 miles south of the Texas border and 200 miles inland from the Gulf of Mexico. The City is situated on a level plain roughly 1,800 feet above sea level.[1] To the north and east lies level land; to the south and west are the east-west aligned mountains and foothills of the Sierra Madre Oriental.

With a population of 601,085 in 1960, Monterrey is surpassed in size only by Mexico City (4,870,876) and Guadalajara (740,394).[2] The largest absolute as well as relative gains in Monterrey's population have occurred since 1940 (Table 1). The current annual rate of increase is approximately six percent compared to the national rate of three percent. The entire differential is attributed to inmigration, primarily from the rural areas.[3]

Perhaps the most striking feature of Monterrey is the predominance of manufacturing industry. Of the 1960 working force, 43 percent were employed in manufacturing compared to 38 percent in Mexico City and 19 percent in the nation, on average. About nine percent of Monterrey's employment was classified as agricultural contrasted to less than three percent for Mexico City and 54 percent for all Mexico (Table 2). Among the industries important to the local economy are primary and fabricated metals, chemicals, paper, building materials, textiles, printing, glass and ceramics, beverages, and food.

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[1]Mary Catherine Megee, Monterrey, Mexico -- Internal Patterns and External Relations (Chicago: University of Chicago, 1958), p. 5.

[2]Direccion General de Estadistica, VIII Censo General de Poblacion, 1960, Resumen General (Mexico: Secretaria de Industria y Comercio, Direccion General de Estadistica, 1962), Table 3, pp. 11-51.

[3]Direccion General de Estadistica, Annuario Estadistico de los Estados Unidos Mexicanos, 1962-63 (Mexico: Secretaria de Industria y Comercio, Direccion General de Estadistica, 1965), Table 2.24, pp. 47-48.

TABLE 1. POPULATION, MONTERREY, MEXICO, 1900-1960

Census Year	Population	Numerical Increase During Decade	Percentage Increase During Decade
1900	72,250		
1910	86,294	14,044	19.4
1921	98,305	12,011	13.9
1930	137,388	39,083	39.7
1940	184,871	47,483	34.4
1950	339,282	154,411	83.5
1960	601,085	261,803	77.1

Source: Mary Catherine Megee, Monterrey, Mexico - Internal Patterns and External Relations (Chicago: University of Chicago, 1958), Table 1, p.27; Direccion General de Estadistica, VIII Censo General de Poblacion, 1960, Resumen General (Mexico: Secretaria de Industria y Comercio, Direccion General de Estadistica, 1962), Table 3 pp. 11-51.

TABLE 2. PERCENTAGE DISTRIBUTION OF THE WORKING FORCE BY TYPE OF ACTIVITY, SELECTED METROPOLITAN AREAS AND ALL MEXICO, 1960

Type of Activity	Monterrey	Mexico City	Guadalajara	All Mexico
Agriculture	9.2	2.7	7.2	54.2
Manufacturing	43.0	37.8	39.8	18.6
Commerce	17.6	17.4	20.9	9.5
Transportation	6.0	5.8	6.3	3.1
Services	22.8	33.7	24.1	13.5
Utilities	0.6	0.9	0.6	0.4
Other	0.8	1.7	1.1	0.7
Percentage of Population in work force	33.6	34.7	32.9	32.4

Source: Direccion General de Estadistica, VIII Censo General de Poblacion, 1960 (Mexico: Secretaria de Industria y Comercio, Direccion General de Estadistica, 1962).

The early rise of industry in Monterrey may be accounted for largely by the City's proximity to raw materials and markets in the United States and Mexico, an early lead in rail and road transportation, and the ingenuity of its leaders. By 1900, several ferrous and non-ferrous metal smelting and refining companies, as well as a large brewery, had located in the area. From many of these very early plants have sprung vast industrial complexes that remain largely in the control of the founders' families. As an illustration of the vertical expansion process, the management of the original brewery built a paper factory in order to make boxes and labels, a glass factory for manufacturing bottles for beer, a tin plate factory to produce bottle caps, a malt plant, and several other less closely related operations. Today, each division operates as an autonomous unit enjoying wide markets for its products.

Personal income in Monterrey is high relative to most parts of Mexico. The 1960 median monthly family income was 1,470 pesos compared to 1,450 pesos for Mexico City and 1,060 pesos for Guadalajara (Table 3). In an absolute

TABLE 3. MEDIAN MONTHLY FAMILY INCOME, SELECTED MAJOR METROPOLITAN AREAS, MEXICO, 1960

City	Median Monthly Family Income (in pesos)
Ciudad Juarez	1,270
Guadalajara	1,060
Mexicali	1,220
Mexico City	1,450
Monterrey	1,470
Puebla	890
Tijuana	2,140
Veracruz	1,280

Source: Derived from Direccion General de Estadistica, VIII Censo General de Poblacion, 1960 (Mexico: Secretaria de Industria y Comercio, Direccion General de Estadistica, 1962).

sense, however, the economic benefits of Monterrey's industrialization are not broadly shared. Poor sanitary conditions and overcrowding prevail in many sections of the city. In 1964 there were 160,800 families in metropolitan Monterrey occupying 129,500 housing units.[4] Thus, assuming no more than two families per dwelling, 24 percent of all units housed more than a single family. The average number of persons per room was two, and 30 percent of all dwellings had three or more persons per room.[5]

Until recently, water was in critical shortage. The completion of a large reservior and water purification plant, however, has allieviated the shortage. Although some general improvements have been made in sanitary facilities, 26 percent of all housing units still depend on exterior toilet facilities. Ninety-one percent of all dwellings are supplied with electricity, however, and 45 percent have piped natural gas, while most of the remaining use bottled gas.[6] Substantial improvements have been made in city services. For example, garbage is regularly collected in most parts of the city and inexpensive public transportation serves most areas.

Due to the shortage of good structural wood, the most commonly used building material is concrete. The better homes are built with interior and exterior walls of concrete block, reinforced concrete roofs, and concrete floors. Concrete floors are often surfaced with ornamental ceramic tile. The exterior walls are usually finished in stucco or stone and the interior walls are plastered. Homes of this type are usually found on a paved, suburban street with concrete curbs and sidewalks.

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[4] Universidad de Nuevo Leon Centro de Investigaciones Economicas, Boletin Bimestral, (April 1965).

[5] Ibid.

[6] Ibid.

In sharp contrast are the lowest quality dwellings. The homes of the very poorest are built with thatch or adobe walls, thatch roofs, and dirt floors. The most common house has wood walls, a corrugated metal roof, and a concrete floor. Those located near the center of the city are usually built in row-house fashion with common sidewalls. Each unit typically consists of two or three rooms of approximately 100 square feet each. The front room usually serves both as a living room and a bedroom, and the rear room doubles as bedroom and kitchen. In units of three rooms, the center room serves as a bedroom but seldom with outside ventilation. Many of the houses located farther from the center of town are built (squatting) on government land. In some areas, homes will be surrounded by a small garden which is usually cultivated.

2.2. The Fundidora Steel Mill

The subjects of this study -- the test group of workers who relocated in improved housing as well as their control group counterparts who did not -- are employed by the Fundidora de Fierro y Acero de Monterrey, one of Mexico's largest iron and steel producers. The Fundidora, a privately-owned company, has been in continual operation since its founding in 1900. In 1964, the company employed 4,154 production workers and 972 white collar workers. Between 1949 and 1964, steel production has tripled, whereas the number of production workers has increased by only 25 percent (Table 4). Substantial investment in machinery and equipment during the 15-year period accounts for much of the increase in output per man.

2.3. The Fundidora Housing Project

In 1951, Fundidora completed the first in a series of housing projects for its employees. Under the current program, roughly 30 new homes per year are raffled to qualified workers. Qualification is based on a minimum of six

TABLE 4. OUTPUT, EMPLOYMENT AND INVESTMENT
FUNDIDORA STEEL PLANT, 1949-1964

Year	Steel Production (Metric Tons)	Number of Workers		Investment in Equipment and Machinery (1958 Pesos)	Output per Production Worker
		Production	Administrative		
1949	148,316	3,380	365	777,261	43.8
1950	139,753	3,274	369	698,048	42.7
1951	159,590	3,200	364	1,116,355	49.9
1952	179,441	3,366	370	1,365,525	53.3
1953	137,840	3,082	375	437,500	44.7
1954	146,676	3,057	378	447,710	48.0
1955	162,097	3,104	388	4,167,131	52.2
1956	181,867	3,196	403	3,308,023	56.9
1957	211,791	3,154	425	927,768	67.2
1958	202,325	3,093	453	509,189	65.4
1959	208,893	3,133	461	10,395,146	66.7
1960	202,730	3,220	494	25,270,990	63.0
1961	287,403	3,509	559	18,019,022	81.9
1962	354,088	3,531	624	3,484,370	100.3
1963	412,754	3,994	684	1,259,389	103.3
1964	465,857	4,154	972	3,583,257	112.1

years tenure with the company with a reasonably low rate of absenteeism. By 1964, the company had provided housing for 622 workers and their families. With favorable financing terms provided by Fundidora, workers pay for the construction cost of the structure over a 12-year period. The Company donates the land and improvements, including paved streets, curbs, gutters, sewers, and utility connections.

Table 5 gives a breakdown of these costs, by housing type/size, for the units completed in 1951. In that year, the costs assumed by Fundidora amounted to savings to the worker ranging from 29 to 44 percent of the total cost of the dwelling. In addition, monthly payments were lower than normal because of the favorable financing terms which provided for a below-market interest rate and a relatively long amortization period.

TABLE 5. DWELLING UNIT COSTS, FUNDIDORA HOUSING PROJECT, 1951
(U. S. Dollars)

	House Type/Size		
	1	2	3
Materials and Labor	$716.24	$1,104.64	$1,348.09
Overhead	191.26	294.97	359.99
Total Cost to Worker	$907.50	$1,399.61	$1,708.08
Land Value	700.00	700.00	700.00
Total Cost of House	$1,607.50	$2,099.61	$2,408.08
Land Value as a Percentage of Total Cost	44%	34%	29%
Monthly Payment	$6.26	$9.66	$11.79
Number of Houses Represented by Study Sample	33	3	1

Units in the project completed in 1951, as they appeared in 1967, are shown in Figure 1a. Walls are concrete block with stucco on the exterior and plaster on the interior. The floors are ceramic tile over concrete slab, and the roofs are of reinforced concrete. Electricity, natural gas for heating, and sewer connections are all installed. The homes range in size from 600 to 1,000 square feet and have two to three bedrooms with one bath.

These units represent substantial improvements in housing quality for most of the test group workers. This fact is illustrated in Table 6 which gives the percent distribution of workers by housing quality class before and after rehousing. Housing quality is divided into four categories. Class "a", the highest class, is Fundidora housing, as described above, or housing of equivalent quality. Class "d", housing, frequently referred to as "jacales" in Monterrey, is of the lowest quality. The best jacales have wood walls, concrete floors, and corrugated iron roofs (Figure 1b). Classes "b" and "c" represent intermediate quality construction classified on the basis of type of building material.

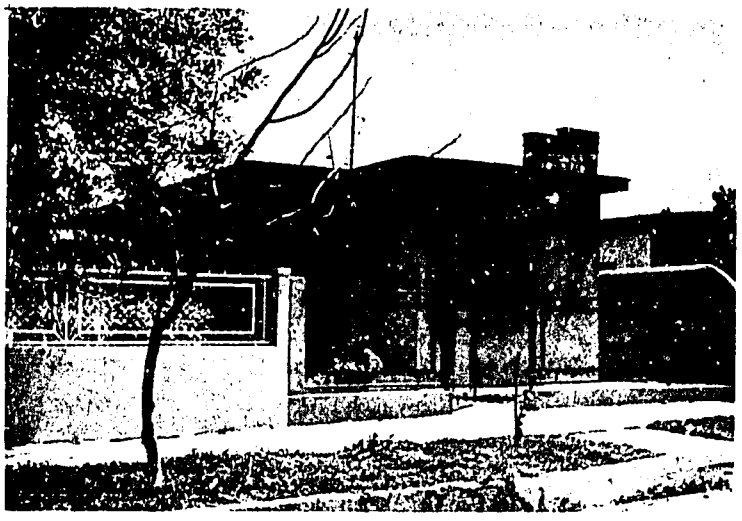
TABLE 6. PERCENTAGE DISTRIBUTION OF WORKERS BY HOUSING QUALITY CLASS*

Housing Quality	Control Group Workers by 1949 Housing Quality	Test Group Workers by 1949 Housing Quality	Test Group Workers by 1951 Housing Quality
a. Highest	23.10	12.50	100.0
b. Higher than Average	30.75	43.75	
c. Lower than Average	0.00	12.50	
d. Lowest	46.15	31.25	
TOTAL	100.0	100.0	100.0
Number of workers included in distribution	13	16	37

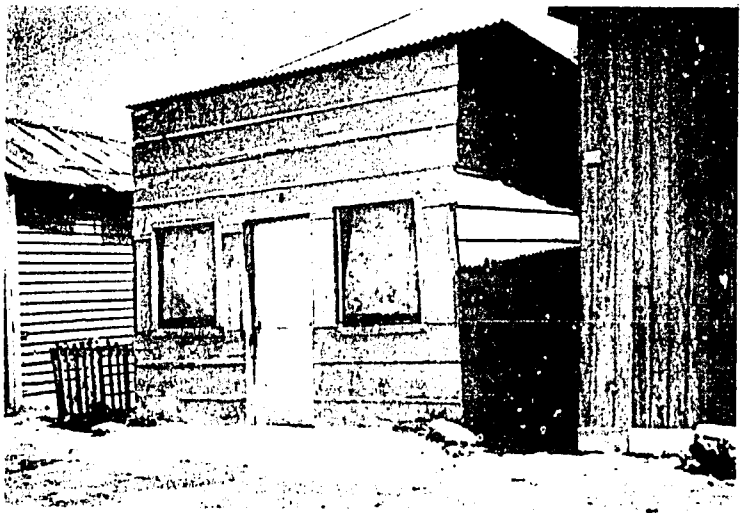
*The percentage distribution is limited to those workers for whom the information was available.

FIGURE 1

TYPES OF DWELLINGS: FUNDIDORA HOUSING AND JACALES, 1967



FUNDIDORA HOUSING



JACALES

Prior to rehousing, over 30 percent of the test group were living in jacales and only 12.5 percent lived in the highest quality class. Upon rehousing, all the workers in the test group moved to class "a" housing. In contrast, nearly half of the control group occupied jacales in 1949.

Although the quality of construction and features was superior in the houses to which the test group moved, the new units were only marginally superior in terms of occupancy intensity. In 1949, the average number of persons per room among test group workers and their families was 2.00 compared to 1.92 in 1964. Curiously, the comparable 1949 figure for the control group was only 1.47.

3. SITE SELECTION AND SAMPLE DESIGN

3.1. The Housing-Productivity System

The general system within which improved housing and worker productivity interact is described graphically in Figure 2. The diagram, which illustrates both hypothesized and exact (or definitional) relationships, is a useful device for comparing ideal test site conditions to those that exist for the case described in this report.

In words, the system traces through an induced environmental change, at the top, to the ultimate output, at the bottom. 1) The system is activated by a change in income or a new investment. 2) If the former, the income recipient may use his increment for improving his housing condition through purchasing or renting a better quality, more expensive dwelling. Similarly, the new capital may be invested in new, better quality housing. Or, it may be invested in an alternate social overhead program -- for example, health or educational facilities -- which will lead to changes in income but, for our measurement purposes, are defined is irrelevant. (In the system, relevant factors, or those which are directly connected to the transmission mechanism extending from housing quality

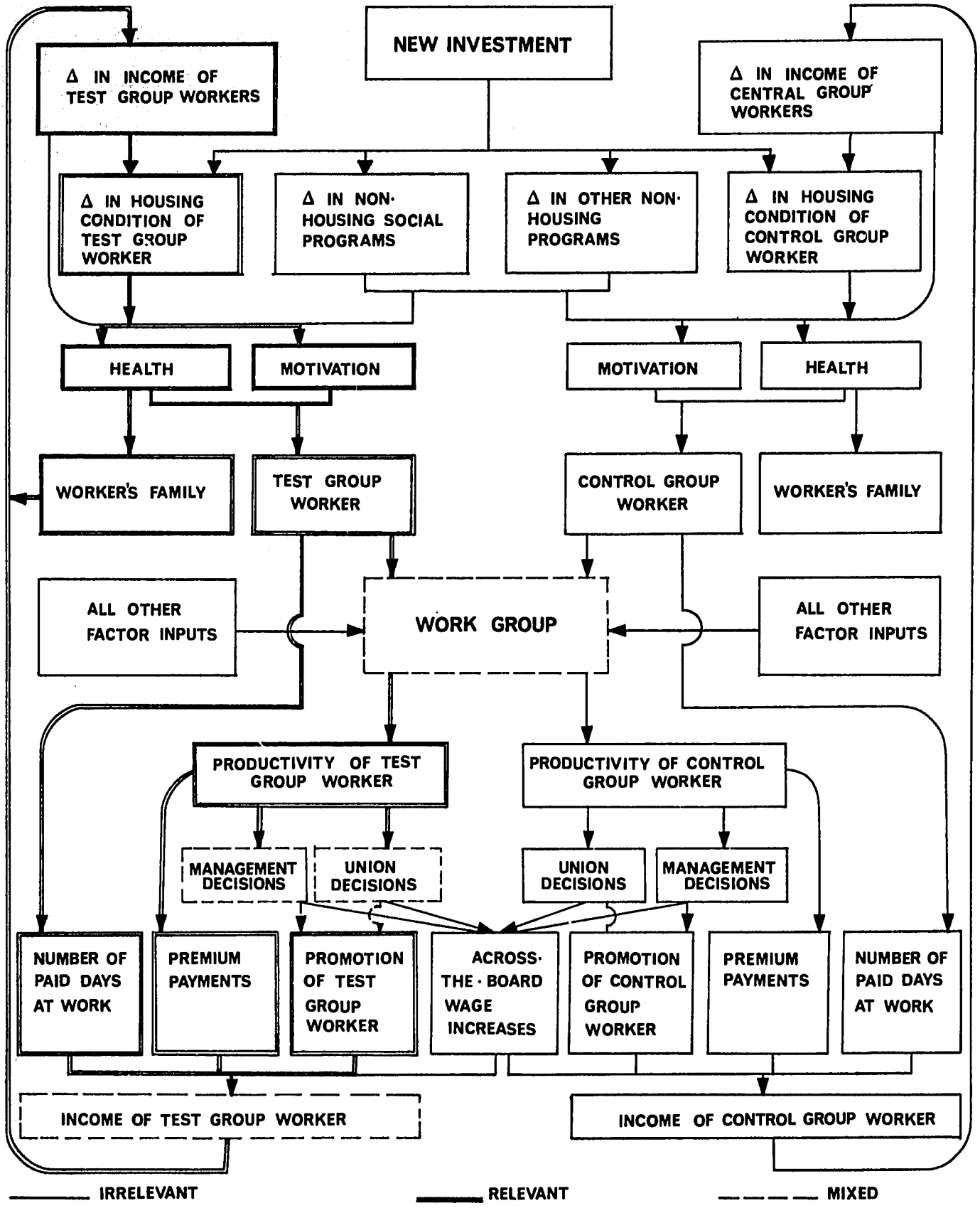


FIGURE 2
DIAGRAM OF HOUSING · PRODUCTIVITY SYSTEM

changes to income changes, are diagrammed in bold line; irrelevant factors are those involved in the transmission but not relevant to the measurement of housing effects and thus necessarily corrected for). Conceivably, too, the change is brought about without burdening capital resources. Changes in production scheduling or management techniques are examples. 3) The effects of all environmental changes, whether in housing or in other sectors, are transmitted via improvements in health and motivation. The benefit transmission may result directly from the initial change in income as well. Examples are improved diets, increased medical attention and other expenditures which raise the level of living and the quality of labor. 4) The beneficiaries of the health improvement may be the worker and his family. To the extent that health benefits are realized by the worker's family, real income is increased by the amount saved in medical expenses. 5) Isolating the effect of the improvements in the worker's health and motivation, derived from a change in his environment, requires correcting for changes in all other factor inputs -- substitution of a labor-saving device is one example -- and identifying his contribution to the overall efficiency of his work group if he is so employed. This separation is critical for the measurement of benefits from environmental change if causation is to be correctly attributed. 6) The benefits generated by environmental change translate into monetary units via several channels. If the worker is healthier, he is absent from work less frequently, consequently, increases his time wages. If his productivity increases, his improved performance may be rewarded if piece rates or other wage incentives are paid. 7) To the extent that promotion policy is accurately reflected in management and/or union decisions, improved performance may be recognized by advancement; on the other hand, if tenure is the overwhelming consideration, for example, productivity and promotion rate are

likely to be unrelated. 8) Thus, additional days worked, premium payments for increased output, and promotions all involve income increments. In addition are across-the-board wage increases that add to income, the measurement under consideration. 9) Finally, income increases are attributable to a change in housing quality plus a set of other factors irrelevant to our measurement. The system becomes recursive when income acts as a new impulse setting in motion, once again, the process described.

The system, graphically and in words, fairly accurately describes the mechanism in operation at the Monterrey site. In brief, a change in housing condition improves the quality of labor as an input into the recursive production process (a sub-system that includes non-rehoused workers as well as non-labor factors independently affecting output), thus generating increases in income as the final output of the system.

3.2. Site Selection Criteria

Specific conditions established for the selection of this test site, and for others, were structured in an attempt to eliminate, or at least minimize, the effects of irrelevant factors which would confound accurate measurement and attribution. These criteria, and their relation to the Fundidora Steel Mill test site, are as follows:

a. The production process must be in operation before, during, and after a sudden qualitative improvement in housing.

If the impact of improved housing is to be correctly assessed, productivity levels existing prior to rehousing must be known. As noted above, the Fundidora Steel Mill has been in continuous operation since 1900. On most counts, the new housing units provided for the test group were superior to the former accommodations, also as indicated above. The 37 workers comprising the test group were rehoused in the company-sponsored housing project in January

1951. Our analysis, covering the period extending from this date to December 1964, thus provides a unique opportunity to investigate long-run benefits of rehousing.

b. The "income effect" must be absent or amenable to control.

Figure 2 shows that income loops back to improved housing; that is, increased demand for housing results from increased income. In terms of major impact, one would expect productivity, via income, to have a greater impact on changes in housing quality than a change in housing quality would have on productivity. If this is true, a simple positive association between the two reveals little about the effect of improved housing on productivity.

The income effect is controlled when the chain of causation is initiated by a housing improvement in the first of a series of periods. Income plays a role, of course, in subsequent periods. As improved housing increases productivity and, with it, income, the rehoused worker is likely to increase his housing consumption in future periods. For our purposes, the important condition is the existence of an initial, exogenous "shock" to the system -- in this case provided by a housing improvement -- which through the multiplier mechanism described above results in an absolute increase in productivity.

The housing improvement experienced by the rehoused Fundidora workers was made possible by housing partially subsidized by the employer. Hence, the rehoused workers received better housing not because of increased income but from their employer's beneficence. The income effect is, therefore, not operative.

c. The environment external to housing must remain unchanged over the measurement period or its effects must be held constant.

Our system diagram illustrates the numerous non-housing forces -- the "irrelevant" factors -- which bear on worker productivity. It is obviously

unrealistic to assume that the non-housing environment remained static over the entire 16-year period covered in our time series. Therefore, in order to isolate the effects of housing, the non-housing environment must be "held constant." The influence of non-housing factors on performance can be identified by observing the performance over a coterminous period of a sample composed of workers not rehoused (a control group), but with similar characteristics as those rehoused, and equally exposed to the non-housing environment. Adjusting the before-after changes in performance of persons rehoused (a test group) by the performance of the control group during the same time period leaves the changes resulting from housing as a residual. This analysis is illustrated in Figure 3. The comparison is only valid when the test and control groups are identical in all respects except housing condition. They must be employed in similar occupations and under similar conditions, so that all non-housing environmental changes would bear equally on the two groups. Such a control group was thought to be available in the Monterrey Test Case.

d. Changes in labor productivity must be measurable in quantitative units of output.

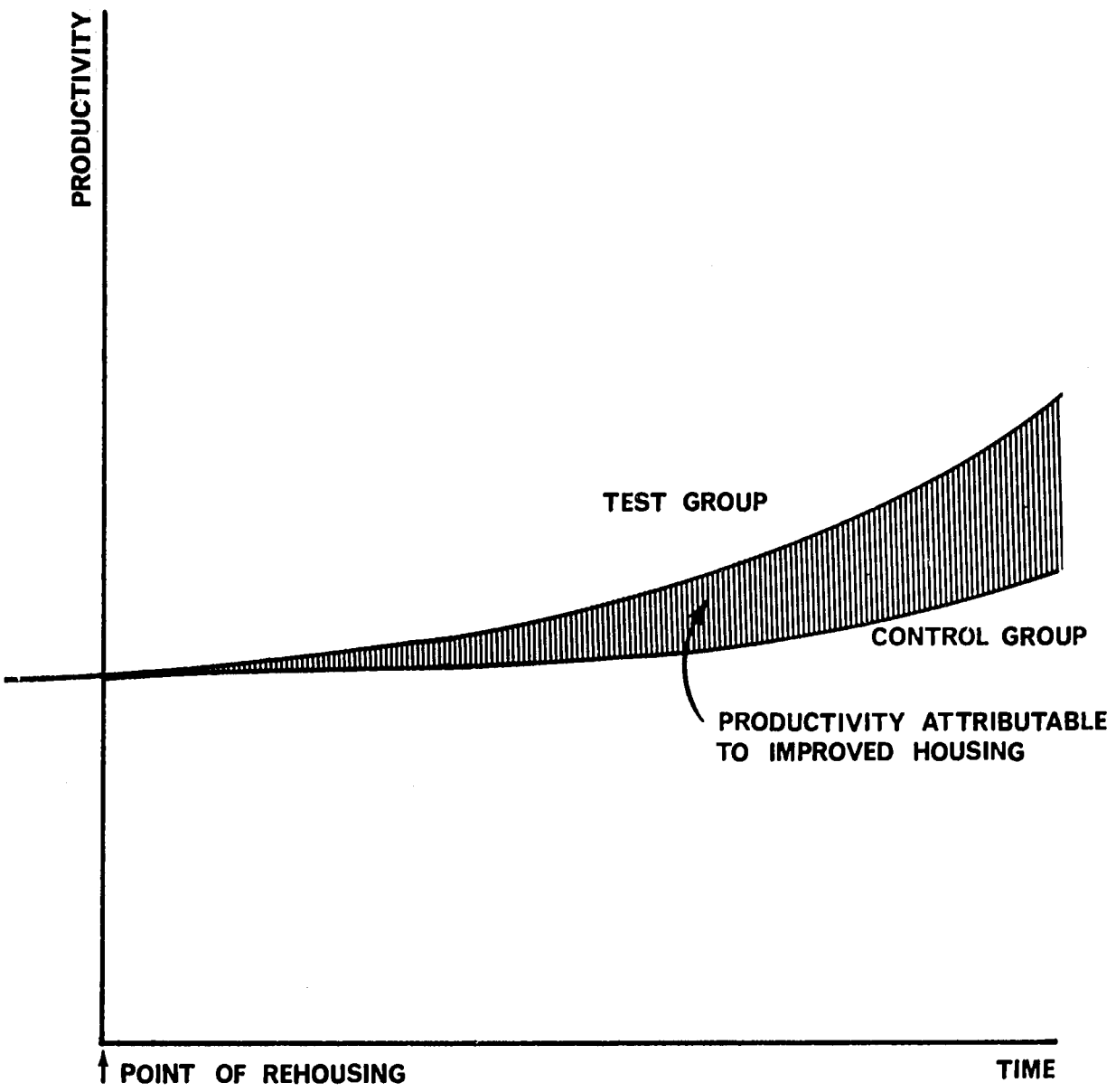
The production workers are paid a flat wage plus a small premium based on gross output. The available data included aggregate worker income for each of the years 1949 through 1964. The inclusion of a premium payment in aggregate income was considered sufficient for acceptance of this statistic as a valid indicator of productivity.

e. Reliable data in sufficient detail must be available.

Fundidora was generous in making available the relevant data in their files. The Instituto de Investigaciones Industriales, a research group of the Monterrey Institute of Technology, collected the pertinent information for the test and control group samples.

FIGURE 3

HYPOTHETICAL TEST – CONTROL GROUP COMPARISON



f. The worker must be able to control his level and rate of production.

In order to estimate the effect of environmental change on labor productivity, output level must be subject largely to the worker's own control. If output is machine-dictated, or if the employee is hired for a specified time period without regard for availability of work, then it cannot be assumed that the worker controls his output. We initially understood that each worker individually controlled his level of output, but later discovered that each performed as a member of a work group in which the individual's productivity was subject to the pace of the other members of the group. If housing status within each group were homogeneous -- that is, if all of the members of a given work group were either rehoused or not -- the effect of the housing quality difference could be identified easily. Unfortunately, however, the groups were found to be mixed. This discovery after the initial data had been collected prompted the formulation of an alternate research strategy.

Given mixed work groups, productivity comparisons between test and control groups are pointless,for the increased income of the more productive rehoused worker would be dispersed throughout the work group, hence to both test and control group members. However, increased productivity should result in more rapid promotion. If improved housing favorably reacts on health and motivation, thence on productivity, then housing quality should be reflected in the rate of promotion. In the long run, promotion sizably affects income. Consequently, comparison of test and control group incomes would still indicate housing's contribution to productivity. The necessary assumption is that promotions are made in recognition of productivity; that is, the more productive are promoted more rapidly. If this is not true, then we might expect to find little or no difference between the income levels of the two groups even though

productivity differences indeed exist. The degree to which this assumption holds will be discussed below.

Another assumption required for the valid comparison of income levels as proxies for productivity is that test and control group members are equally affected by plant-wide wage rate increases. Fundidora's across-the-board percentage wage increases are applied to all jobs every two or three years coincident with the renegotiation of union contracts. Hence, this assumption is accurate.

3.3. Site Selection Procedure

The choice of the Fundidora Steel Mill followed the procedures established for selection of all test sites to be included in the second phase of research for the International Housing Productivity Study. First, the list of criteria just enumerated was submitted through AID, Washington, to missions or U. S. embassies in most developing countries. Potential test sites were tentatively chosen from the responses of these queries.

Further correspondence with interested parties in Mexico resulted in our contact with the Instituto de Investigaciones Industriales, a non-profit research group that has had considerable experience in studying productivity in Mexican industry. After reviewing our detailed list of necessary criteria for site selection, the Institute suggested the Fundidora de Fierro y Acero de Monterrey, a steel plant in Monterrey, Mexico, as a feasible test site.

3.4. Sample Design

The only workers considered for inclusion in this study were those in production-type jobs, that is, those whose work effort results in a measurable physical product. The test group was composed of all workers rehoused in 1951 with complete work records of continuous employment in production-type jobs for

the period 1949 to 1964. Thirty-seven workers fell into this category. The control group was composed of fifty workers selected randomly from the population of non-rehoused workers who were continuously employed in production positions over the 1949 to 1964 period. The sample design is described schematically in Figure 4.

Annual income and absenteeism data for each worker were provided for the 16-year period covered in this analysis. Because the date of rehousing was so close to the beginning of the calendar year, the before-rehousing period was defined as calendar years 1949 and 1950, and the after-rehousing period covered the 14 years, 1951-1964. Data were obtained also on housing quality and educational attainment. An example of the questionnaires together with a description of the information collected appears in Appendix A.

Changes in labor productivity attributable to better housing are assessed in the following section. Part 5 considers benefits in the form of improved health and of higher propensity for education.

FIGURE 4

SAMPLE DESIGN

	Before Rehousing	After Rehousing
Test Group	37 workers to be rehoused	The same 37 workers, now in improved housing
Control Group	50 workers not rehoused	The same 50 workers not rehoused

January 1, 1949 — January 15, 1951 (date of rehousing) — December 31, 1964

4. THE EFFECT OF IMPROVED HOUSING ON LABOR PRODUCTIVITY

The principal hypothesis under consideration is that improved housing leads to increased productivity. Given the linkages assumed in the housing-productivity system (Figure 2), causation runs from housing to productivity change which, in the long run, is reflected in income change. Figure 3 illustrates the hypothesis testing method; that is, a comparison of productivity between test group (rehoused) and control group (unrehoused) workers. This comparison can be accomplished by three slightly different methods. Two methods rely on time-series comparisons of incomes earned as accurate reflections of productivity change and promotion rate. A third method correlates income and productivity change to the degree of housing improvement.

1. The first method involves regressing average annual income against time independently for the test and control group, then comparing the periodic rates of change between groups. A linear estimation of absolute average changes per time unit would yield biased estimates since across-the-board percent wage increases, a scheme employed at Fundidora for periodically realigning wages to the cost of living, exaggerate absolute increases for the higher wage earner; that is, because the base to which the percentage is applied is higher, the absolute increase is also higher. Thus, if at a point of time the test group's wages were higher on average, at any subsequent point in time, wages would be unrealistically high due merely to the higher base rather than to productivity increases per se. A non-linear function, of the following form, measures relative rather than absolute increases in wages over time, thus correcting for the bias:

$$Y_t = \alpha e^{\beta t}$$

where Y_t = income in year t,

α = a constant,

e = the constant, 2.718 ...,

β = the rate of growth, and

t = an index of time beginning with zero in the base year.

For estimation of parameters α and β the following log transformation was performed:

$$\ln Y_t = \ln \alpha + \beta t,$$

Regressing annual incomes of the test and control group workers for the post-rehousing period 1951-1964 provides estimates of β, the average annual rate of income growth. If β calculated for the test group exceeds the estimate for the control group, by a statistically significant amount, then the rehoused were promoted more rapidly than the non-rehoused. Regression using the above log-linear form yields the following results (standard errors in parentheses):

Test Group: $\ln Y = 6.254 + \underset{(.0044)}{.0995t}$ $\quad r^2 = .976$

Control Group: $\ln Y = 6.065 + \underset{(.0042)}{.1082t}$ $\quad r^2 = .982$

The estimates indicate that income of the control group increased an average of 10.82 percent per annum compared to the test group's average income increase of 9.95 percent. The difference between the two growth rates, however, is not statistically significant at the .05 level.[7]

2. Because the above computational scheme only considers the average annual change over the entire time period, an alternate method based on a comparison of annual changes between groups was also used. Actual test group income for each year is compared to "expected income," or control group income each year. "Expected" test group income is derived by multiplying the 1949 test

[7]The t-value for the difference in growth rates is 1.43.

group mean income by an index based on the mean income for the control group for 1949 and each subsequent year. Thus the test group's actual earnings are adjusted for the earnings they would have received (expected) had they not been rehoused. The results are given in Table 7.

Test group average income is substantially higher than for the control group in the initial year, 1949, and remains higher throughout the 16-year period. However, by the end of the period, 1964, the two income levels are nearly equal.

Still there is substantial variation in actual and expected levels during intermediate years. For the first four years following rehousing actual income fell short of expected. Then, for the next six years, actual exceeded expected, except in 1958. From 1961 to 1964, expected income once again exceeded actual. The yearly actual-expected differences are statistically significant at the .05 level, however, in only four of the years: 1955, 1957, 1962, and 1964. Actual test group income is significantly higher than that expected from control group income changes in 1955 and 1957. But in 1962 and 1964, expected is significantly higher than actual.

Regrouping the data by the three periods 1951-54, 1955-60, and 1961-64, yields somewhat different results. Expected significantly exceeds actual in the initial and terminal periods but the reverse holds for the intermediate period (Table 8). Despite probing, no information was uncovered to explain these results.

3. A third method addresses a relationship implicit in our original hypothesis; that is, a change in productivity and income is positively associated with the magnitude of the housing improvement. Two measures of the latter were used for assessing the relationship:

TABLE 7. ACTUAL MINUS EXPECTED TEST GROUP INCOME, 1949-1964
(U. S. Dollars)

Year	Actual Test Group Mean Income	Control Group Mean Income	Index of Control Group Mean Income (1949, 1950=1.0000)	Expected Test Group Mean Income	Actual Minus Expected	Standard Error of Actual Minus Expected
1949	$522.97	$426.46	.9630	$503.62	19.35	23.35
1950	537.03	469.22	1.0595	554.09	-17.06	22.37
1951	667.35	572.78	1.2934	676.41	-9.06	22.93
1952	741.46	667.20	1.5066	787.91	-46.45	27.29
1953	707.16	611.58	1.3810	722.22	-15.06	24.84
1954	751.24	661.70	1.4942	781.42	-30.18	28.05
1955	1083.65	778.38	1.7577	919.22	164.43*	32.91
1956	1091.78	908.76	2.0521	1073.19	18.59	37.82
1957	1359.05	1029.00	2.3236	1215.17	143.88*	38.90
1958	1263.92	1123.08	2.5360	1326.25	-62.33	45.65
1959	1589.03	1308.10	2.9538	1544.75	44.28	73.11
1960	1740.89	1426.76	3.2218	1684.90	55.99	72.56
1961	1984.46	1703.16	3.8459	2011.29	-26.83	95.70
1962	1866.70	1779.74	4.0188	2101.71	-235.01*	96.30
1963	2241.41	1933.88	4.3669	2283.76	-42.35	105.62
1964	2287.70	2132.22	4.8148	2518.00	-230.30*	115.63

*Significantly different from zero at .05 level.

TABLE 8. ACTUAL MINUS EXPECTED TEST GROUP INCOMES, 1951-54, 1955-61, AND 1962-64 (U.S. Dollars)

Period	Average Actual Minus Expected	Standard Error of Actual Minus Expected
1951-54	-25.18	12.80
1955-61	60.80	20.47
1962-64	-169.22	61.18

a. The before-after change in occupancy intensity. Occupancy intensity is measured by the number of persons per room; "before" is dated at 1949 and "after" is 1951. The year 1951 was chosen over any later year since the only portion of the total housing improvement relevant to our discussion is that which took place when the workers relocated in company housing on that date. The correlation between increased test group income and changes in persons per room is indeed low (.17) as the scatter diagram (Figure 5) illustrates. The fact that occupancy intensity actually increased for many of the rehoused families, however, suggests that this measure of housing quality change, taken alone, is poor.

b. The relative quality of the test group's prior housing. This measure is appropriate when the sample is limited to those whose new housing was identical in quality. One can say, therefore, that the better the quality of prior housing, the less the improvement in housing.

The relationship between income change and 1949 housing quality is shown in Table 9 which gives the average change in 1949 to 1964 income for workers in four housing quality categories as determined by type of materials used in the structure from which they moved. If our theory is correct, then the higher 1949

FIGURE 5

RELATIONSHIP BETWEEN CHANGE IN INCOME (1949-1964) AND CHANGE IN OCCUPANCY INTENSITY (1949-1951) TEST GROUP

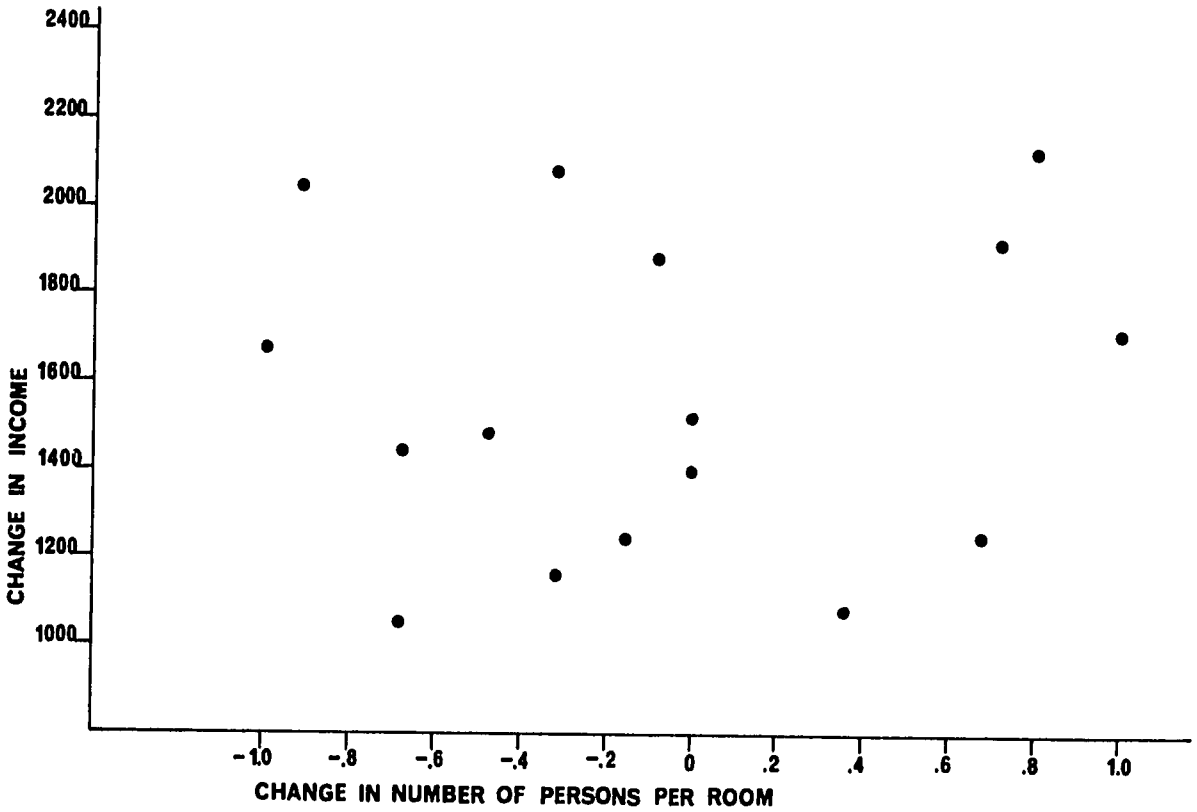


TABLE 9. AVERAGE INCOME INCREASE, 1949 - 1964 FOR WORKERS WITH VARIOUS 1949 HOUSING QUALITIES

1949 Housing Quality	Average Income Increase, 1949 to 1964 (U.S. Dollars)
a. Highest	2,032
b. Higher than Average	1,538
c. Lower than Average	1,446
d. Lowest	1,625

housing qualities should be associated with smaller increases in worker income. However, as the data indicate, no definite pattern emerges from the analysis.

5. RELATED EFFECTS OF IMPROVED HOUSING

Additional data were marshalled to test two related hypotheses:

1. That improvements in housing quality lead to improvements in health, and
2. That improvements in housing quality lead to increased exposure to education.

5.1. Absenteeism Due to Illness

An earlier study in this series identified a highly significant, negative relationship between better housing and the rate of in-patient and out-patient admissions.[8] The measures of health used in the Monterrey case differ somewhat.

[8] B. K. Tjioe, Report on Productivity in Relation to Housing Conditions and Community Facilities in Hambaek, Korea (Los Angeles: International Housing Productivity Study, University of California, 1966), processed.

For this case, information on the number of days absent from work due to illness was collected from company records for each worker in the two samples. If housing favorably reacts on health, then the after-rehousing trend in absence for reasons of illness should be lower for the test group workers compared to their control group counterparts.

The average number of work days absent due to illness was calculated for the test and control group members for each year in the 1949 to 1964 period. The results appear in Table 10. One is immediately struck by the fact that the test group illness rate is significantly higher than the control group rate in nearly every year. Despite considerable investigation, no reason for this vast difference could be discovered.

In 1951, the year of rehousing, the test group illness rate dropped substantially but returned to its before-rehousing level in subsequent years. The magnitude of year-to-year fluctuation in the series suggests that the 1951 decrease could easily have resulted from non-housing factors. Data were not available for identifying such factors and estimating their importance in determining the substantial changes. The trend in absence is not significant for either group. However, the large unexplained variation in each of the series together with the sizable difference in health levels between test and control group argue for ignoring the analysis and discarding the results.

5.2. Propensity for Education

At the suggestion of the Instituto de Investigaciones, we next examined the relationship between housing quality and the "propensity for education;" that is, the likelihood of increased exposure to schooling. Information on years of education completed by sons in test and control group families was obtained by questionnaire. Only sons of workers were chosen for the samples because,

TABLE 10. AVERAGE NUMBER OF DAYS PER YEAR ABSENT FROM WORK DUE TO ILLNESS, TEST AND CONTROL GROUPS 1949-1964

Year	Test Group	Control Group	Test Minus Control	Standard Error of Test Minus Control
1949	11.43	0.56	10.87*	0.26
1950	5.35	1.16	4.19*	0.73
1951	1.95	0.58	1.37*	0.29
1952	6.22	1.72	4.50*	1.11
1953	9.24	2.24	7.00*	1.45
1954	9.32	1.50	7.82*	0.83
1955	8.46	1.00	7.46*	0.37
1956	7.05	0.28	6.77*	0.12
1957	12.51	0.16	12.35*	0.06
1958	15.62	1.86	13.76*	1.12
1959	9.00	7.38	1.62	6.92
1960	8.32	3.44	4.88*	2.42
1961	7.59	8.46	-0.87	6.73
1962	10.16	0.16	10.00*	0.10
1963	8.81	0.32	8.49*	0.13
1964	6.73	0.24	6.49*	0.14

*The statistic is significantly different from zero at the .05 level.

if significant relationships emerged, the benefits could be monetized as increments to income after entrance to the labor force. Because Mexican women rarely are employed, monetization of their benefits would be excessively difficult. Scatter diagrams relating age to number of years of school completed by sons of rehoused workers as of 1964, and for non-rehoused workers, appear in Figures 6 and 7.

Comparison of the two figures suggests that rehoused sons complete more schooling than do the non-rehoused. However, this conclusion is reliable only if age differentials between the two groups are standardized. Since primary schooling is normally completed by age 16, and in order to minimize the age effect, our analysis is limited to persons between ages 17 and 30. Test group members who had completed schooling prior to the rehousing date -- that is, were 30 years or older in 1964 -- were excluded from the tabulation since their educational exposure was likely to be independent of the housing improvement; to provide for comparability, the same exclusion was applied to the control group sample as well. Table 11 contains comparative data for sample members who received less than ten and ten or more years of education. The evidence reinforces our earlier conclusion for nearly one-half of the test group completed ten or more years whereas only 35 percent of the control group pursued their schooling to that level.

However, a significance test reveals that the differences are inconsequential. A chi-square test (see Appendix B for calculation) reveals that the housing-education parallel could easily result from mere chance. Consequently, the hypothesis cannot be accepted.

6. SPECULATIONS AND CONCLUSIONS

The empirical tests described in previous sections fail to support the three hypotheses. Several speculations on the nature of the results are in order.

FIGURE 6

THE RELATIONSHIP BETWEEN AGE AND YEARS OF SCHOOLING SONS OF REHOUSED WORKERS-1964 (EXCLUDING THOSE SONS WHO HAD COMPLETED SCHOOL WHEN REHOUSING TOOK PLACE)

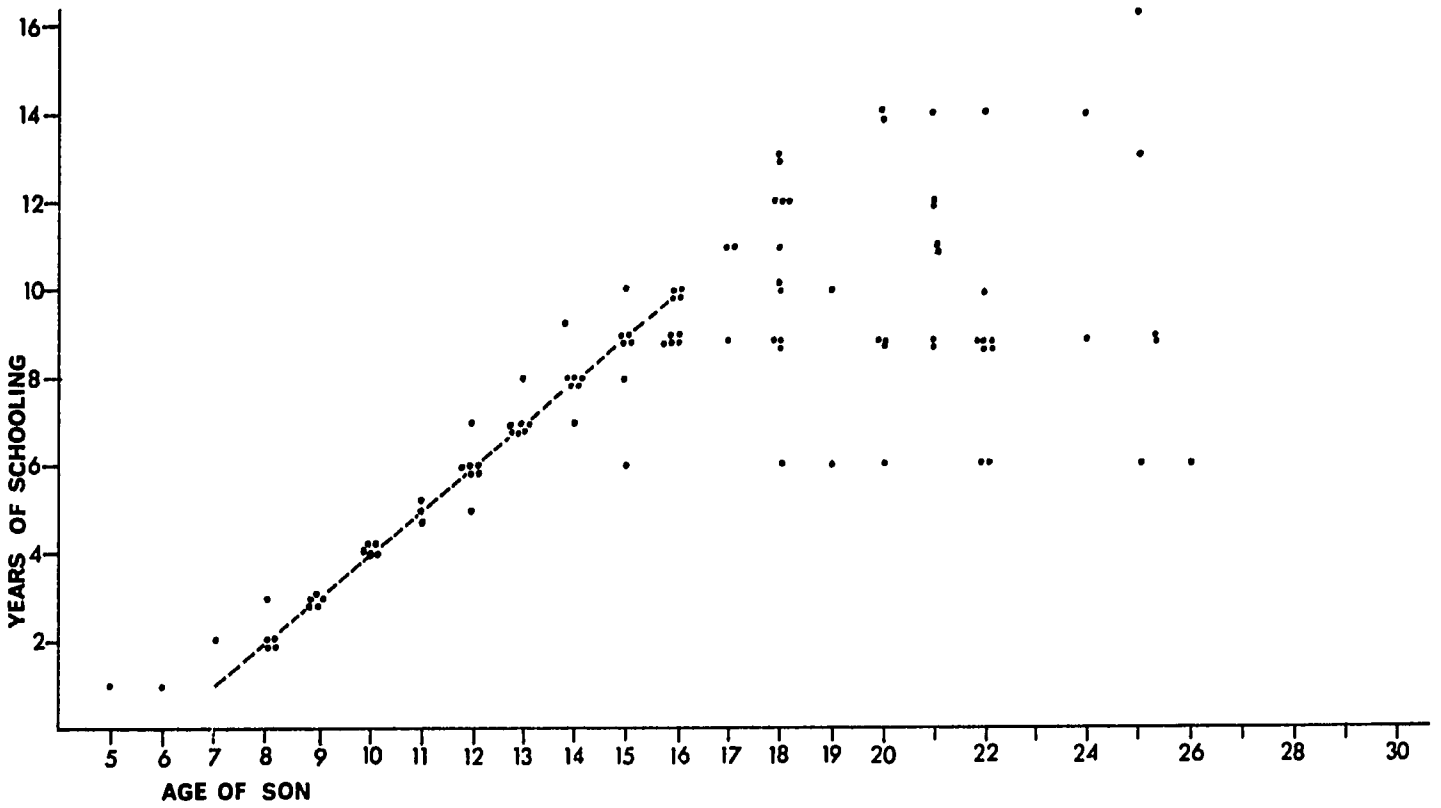


FIGURE 7

THE RELATIONSHIP BETWEEN AGE AND YEARS OF SCHOOLING SONS OF NON-REHOUSED WORKERS-1964 (EXCLUDING THOSE SONS WHO HAD COMPLETED SCHOOL WHEN REHOUSING TOOK PLACE)

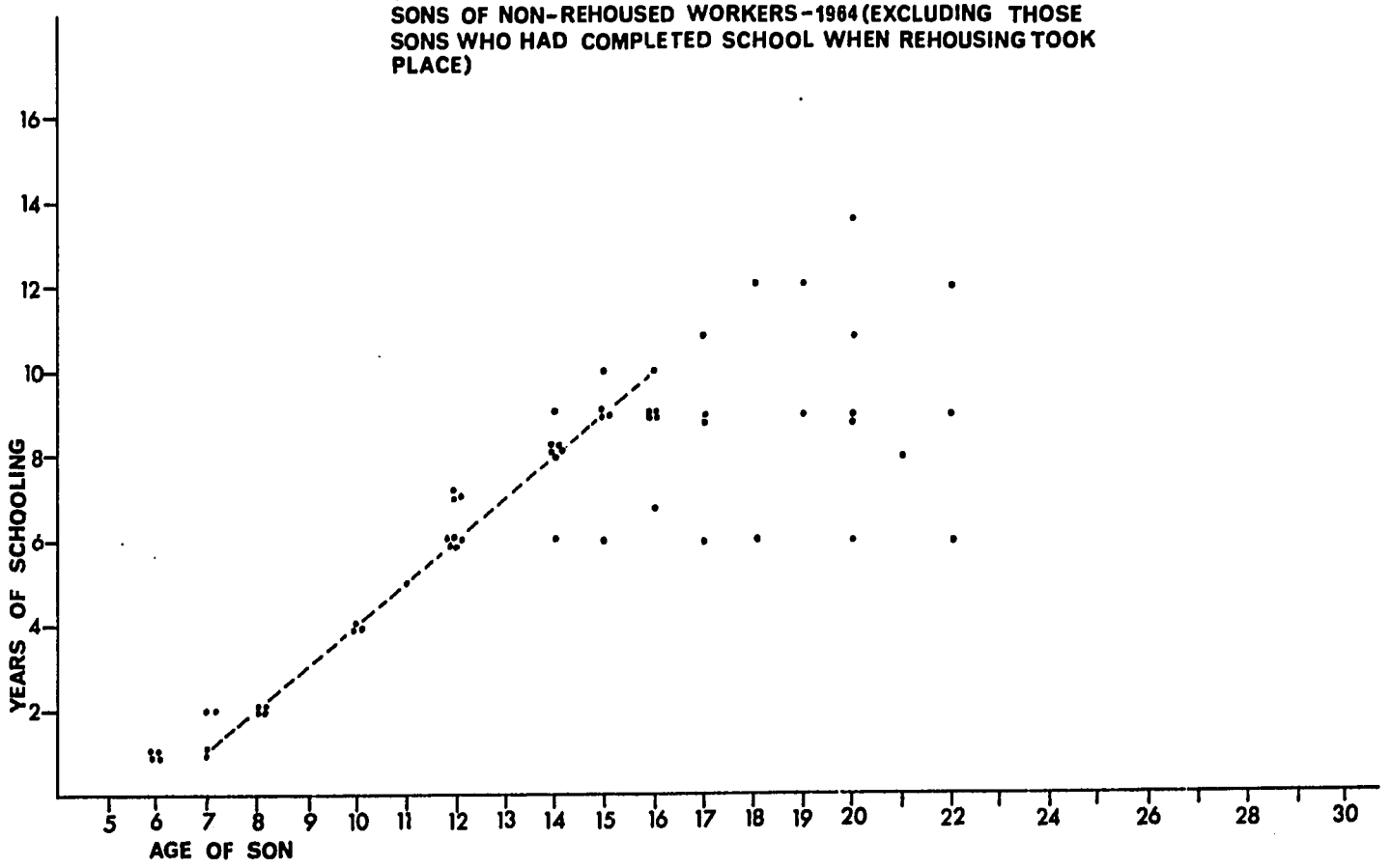


TABLE 11. EDUCATION, TEST AND CONTROL GROUP WORKERS' SONS
AGE 17 TO 30, 1964

	TEST	CONTROL
Number who had completed 10 or more years of school.	23	6
Number who had completed fewer than 10 years of school.	24	11
Sample size	47	17

6.1. Sample Bias

For valid experimentation, the control sample should be drawn randomly from a population homogeneous save for the single variable -- housing in this case -- being examined. Because test and control group absenteeism rates were significantly different prior to rehousing, it is unlikely that the samples complied fully with this requirement. Therefore, considerable doubt is cast on the value of the non-rehoused group as an experimental control. Although considerable care was exercised in structuring the two samples, this problem obviously did not become apparent until the data had been collected and analyzed.

The requirement that only workers in production capacities were eligible for selection for the samples could have injected bias as well. This requirement was considered necessary when the sample was initially chosen because at that time it was assumed that income payments directly and accurately reflected productivity via the mechanism of the premium payment. The constraint

effectively excluded all workers who were employed in production jobs in 1949 but had been promoted into non-production (usually supervisory) positions by 1964. This exclusion could have introduced a bias into the samples which explained the narrowing income difference between test and control groups during the study period. A proof of this possibility is found in Appendix C. Data were not available to correct for this possible bias.

6.2. Productivity Proxy

The income variable, in this case, proved to be a poor measure of productivity. However, when test and control group incomes are compared over time, the resulting series should adequately reflect productivity differences, given certain assumptions. These assumptions were reviewed in Sec. 3 with a discussion of the manner in which all except one were satisfied. This exception was that productivity and rate of promotion were closely related.

Clarification of the promotion procedure at Fundidora, however, casts doubt on whether the effect of productivity can be separately identified as one of several factors influencing advancement. Fundidora fills vacant positions in cooperation with labor unions. The union is first notified that a position is vacant and responds with a candidate who may or may not be management's choice. If the company is displeased with the candidate, and has evidence that the union's candidate is not suitable for advancement to the position, then the union must find an alternate. Most importantly, the union's decision is based on the candidate with the greatest seniority among peers unless the candidate has a "poor" work history.

Although the correlation between productivity and promotion within such a framework may be positive, one would expect it to be far from perfect. With seniority operating as well as performance, the linkage becomes tenuous indeed.

The exact nature of the relationship, of course, is almost impossible to determine. This information deficiency thus frustrates any interpretation of the housing-income relationship and could account for the lack of a statistically significant relationship between improved housing and income.

6.3. Conclusions

Does the testing reported, and the findings narrated, mean that no relationship exists between housing and productivity in this particular case, or does the result stem either from the low correlation between productivity and promotions or from sample bias? Any one or a combination of these three possibilities could explain the non-significant relationships, but the real reason cannot be determined. Thus, even if the housing improvements had generated productivity increases at the Fundidora Steel Plant, they may not be revealed from an analysis of the housing-income relationship. The results of the analysis, taken alone, are therefore inconclusive with respect to the relation hypothesized between improved housing and productivity. Similarly, the sample bias prevents us from making any positive statements about the hypothesized relationship between improved housing and health.

Hence, the evidence in total and in its parts, leads to the conclusion that no relationship can be found relating improved housing to higher productivity, to better health, or to improved education. It should be emphasized, however, that although the evidence fails to support any of these hypothesized linkages, neither does the evidence lead to the conclusion that housing improvements are unrelated to productivity, health or education.

APPENDIX A
EXAMPLES OF FORMS USED FOR DATA COLLECTION

DATA FORM 1

CIA. FUNDIDORA DE FIERRO Y ACERO DE MONTERREY, S. A.
Test Group (Workers rehoused in superior housing)
Worker No. 3
Job Title Mechanician Turner

Year	1949	1950	1951	1952	1953	1954	1955	1956
Number of Days Absent[1]								
R								
S	4	3		2	3	2		1
E			13					3
P		1		1				
K								
Income Earned Annually ($)	908	809	1159	1202	1165	1301	1501	1423

Year	1957	1958	1959	1960	1961	1962	1963	1964
Number of Days Absent[1]								
R								
S	1	1	5	2	3	1	2	
E			14					
P			1					
K								
Income Earned Annually ($)	1672	1771	1846	2040	2289	2388	2680	2830

House Type[2] 3 Rehoused January 15, 1951

Housing and Family Conditions in 1965

House:
- Number of rooms: 5
- Number of floors: 1
- Wall material: Concrete block
- Floor material: Tile
- Painted: Yes (x); No ( )

Family:
- Number of workers living in house: 5
- Number of workers in household: 2
- Number employed in Cia Fundidora de Fierro y Acero de Monterrey: 1
- Monthly family income earned: $380.

[1]Absences are classified as follows:
R: Justified absence; without pay.
S: Unjustified absence; without pay.
E: Absence due to illness or accident; with pay.
P: Permitted absence; without pay.
K: Disciplinary action resulting in worker's temporary suspension from work; without pay.

[2]Houses are classified as follows:
Type 1: Dining-living room, bedroom, sanitary facilities, and porch.
Type 2: Living room, dining room, kitchen, two bedrooms, sanitary facilities, and porch.
Type 3: Dining-living room, kitchen, three bedrooms, sanitary facilities, and hall.
Special: Living room, kitchen-dining room, two bedrooms, sanitary facilities, and hall.

DATA FORM 2

CIA. FUNDIDORA DE FIERRO Y ACERO DE MONTERREY, S. A.
Test Group (Workers rehoused in superior housing)

Worker No. 3
Job Title Mechnician Turner

A. Before Rehousing:

1. Number of Persons Living in House:

Relation to Worker	Age (years)	Sex	Years of School Completed
Worker	37	M	6
Wife	30	F	6
Daughter	7	F	1

2. Characteristics of House:

Number of rooms	4
Rent (monthly payment)	Proprietor
House type	2
Wall material	Ashlar stone
Floor material	Concrete
Ceiling material	Concrete

3. Remarks: _____

B. At Present (1964):

1. Number of Persons Living in House:

Relation to Worker	Age (years)	Sex	Years of School Completed	Date Moved From House
Worker	53	M	6	
Wife	46	F	6	
Daughter	23	F	9	
Son	20	M	14	
Son	12	M	5	

2. Remarks: _____

APPENDIX B

SIGNIFICANCE TEST FOR DIFFERENCES IN PROPENSITY FOR EDUCATION

A chi-square test[1] was applied to the following four-cell distribution in order to determine if the greater proportion of test group sons having completed 10 or more years of school could be attributed to sampling variance.

	Test	Control	Total
Number who had completed 10 or more years of school	23	6	29
Number who had completed fewer than 10 years of school	24	11	35
Total	47	17	64

The chi-square statistic is calculated as:

$$X^2 = \sum_{i=1}^{n} \frac{(a_i - e_i)^2}{e_i}$$

where,

n = number of cells,

a = actual number of observations in cell i,

e = expected number of observations in cell i; determined by multiplying the relevant row and column totals and then dividing by the overall total.

The chi-square calculation, in this case, is:

$$X^2 = \frac{(23.0 - 21.3)^2}{21.3} + \frac{(6.0 - 7.7)^2}{7.7} + \frac{(24.0 - 25.7)^2}{25.7} + \frac{(11.0 - 9.3)^2}{9.3}$$

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[1]For a description of the test see, for example, Ronald A. Fisher, Statistical Methods for Research Workers (London: Oliver & Boyd, 1958).

and, after squaring and summing,

$$X^2 = .934.$$

This value is far lower than the 3.841 necessary for significance at the .05 level. Therefore, the distributional difference in education between test and control group sons could very easily result from chance.

APPENDIX C

PROOF OF SAMPLE BIAS

The dynamic system of job positions within which the sample workers operate can be described by the following Markov matrix:

$$P_k = \begin{array}{c} \text{POSITIONS IN TIME PERIOD } t \\ \begin{pmatrix} 1 & 2 & \cdots & k \\ p_{11} & p_{12} & \cdots & p_{1k} \\ p_{21} & p_{22} & \cdots & p_{2k} \\ \cdots & & & \\ p_{k1} & p_{k2} & \cdots & p_{kk} \end{pmatrix} \end{array} \begin{array}{l} \\ 1 \\ 2 \quad \text{POSITIONS IN PERIOD } t+1 \\ \cdots \\ k \end{array}$$

where,

$$o \leq P_{ij} \leq 1 \qquad (i = 1 \ldots k, \quad j = 1 \ldots k)$$

$$\sum_{i=1}^{k} P_{ij} = 1 \qquad (j = 1 \ldots k) .$$

Each P_{ij} gives the probability that a worker in position i at time period t will be in position j at period t+1. Each P_{ij} must lie between zero and one, and each column must sum to one.

If the column vector, d_o, gives the distribution of workers in positions 1 through k in some initial state, then the distribution of workers at the end of period one is given by

$$d_1 = P_k d_o \quad .$$

Also,

$$d_2 = P_k d_1 = P_k^2 d_o$$

and in general,

$$d_n = P_k^n d_o$$

An important theorem from Markov process theory tells us that under most conditions the limit of d_n as n goes to infinity defines a steady state distribution which is independent of the initial distribution, d_o.[2] For example, if we start out with two quite different distributions of workers by job level and no one is ever permitted to be promoted beyond position k, then as time passes the distribution of the two groups will become more alike and eventually become identical. This implies that two groups of workers with different initial mean incomes will eventually have the same mean incomes if subjected to the above described Markov process. Furthermore, the difference in mean income is likely to diminish quite rapidly. An example will be useful to illustrate the point.

Assume first that there are only two levels of "production" positions, second that the initial test group distribution is 20 percent in slot one and 80 percent in slot two, and third that the initial control group distribution is 50 percent in slot one and 50 percent in slot two. Assume, too, that the position-one wage is $1,000, the position-two wage is $2,000, and the matrix of promotion probabilities is

$$P_2 = \begin{pmatrix} .9 & 0 \\ .1 & 1 \end{pmatrix}$$

That is, there is a 10 percent probability of being promoted from step one to step two during any given period and a 100 percent probability of remaining in step two once a worker reaches that level.

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[2]See, for example, J. G. Kemeny, et al., Finite Mathematical Structures (Englewood Cliffs: Prentice-Hall, Inc., 1958), pp. 384-411.

Under these conditions, at the end of 14 years the test group distribution, $d_{t,14}$, will be

$$d_{t,14} = \begin{pmatrix} .9 & 0 \\ .1 & 1 \end{pmatrix}^{14} \begin{pmatrix} .2 \\ .8 \end{pmatrix} = \begin{pmatrix} .229 & 0 \\ .771 & 1 \end{pmatrix} \begin{pmatrix} .2 \\ .8 \end{pmatrix} = \begin{pmatrix} .045 \\ .955 \end{pmatrix}$$

and the control group distribution will be

$$d_{c,14} = \begin{pmatrix} .9 & 0 \\ .1 & 1 \end{pmatrix}^{14} \begin{pmatrix} .5 \\ .5 \end{pmatrix} = \begin{pmatrix} .229 & 0 \\ .771 & 1 \end{pmatrix} \begin{pmatrix} .5 \\ .5 \end{pmatrix} = \begin{pmatrix} .114 \\ .886 \end{pmatrix}$$

The initial test group's mean income, $\overline{Y}_{t,o}$, is

$$\overline{Y}_{t,o} = (1{,}000)\ (.2) + (2{,}000)\ (.8) = \$1{,}800,$$

and the initial control group's mean income, $\overline{Y}_{c,o}$, is

$$\overline{Y}_{c,o} = (1{,}000)\ (.5) + (2{,}000)\ (.5) = \$1{,}500$$

So, initially, the difference in mean income is \$300. At the end of fourteen years, the test group mean income, $\overline{Y}_{t,14}$, is

$$\overline{Y}_{t,14} = (1{,}000)\ (.045) + (2{,}000)\ (.955) = \$1{,}955$$

and the control group mean income, $\overline{Y}_{c,14}$, is

$$\overline{Y}_{c,14} = (1{,}000)\ (.114) + (2{,}000)\ (.886) = \$1{,}886$$

The difference in mean income at the end of 14 years is only \$69, compared to the initial difference of \$300.

This bias was introduced into the sample design by excluding those workers who passed from production into non-production positions thus placing an arbitrary upper bounds on the income of sample workers.