THE REFERENCE MODE

AS A GUIDE TO TRANSPARENT CAUSAL STRUCTURE

by

Dale Runge

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139, USA

This paper establishes the importance and usefulness of a well-defined reference mode as a guide to developing transparent causal structures for system dynamics models. The importance of a transparent causal structure is twofold: it enhances understanding the model dynamics, and it facilitates communicating to others the model and the insights derived from model simulations.

The paper offers as a fundamental guideline for selecting transparent causal structures the following: strive for as highly-aggregated and as simple a structure that will generate the dynamics of interest. Ability to follow the guideline depends on a well-defined reference mode, which in turn requires a clear model purpose.

To illustrate how a well-defined reference mode can guide the selection of a transparent causal structure, the paper traces the development of a model of the labor market. First, the model purpose is described. Next, the evolution of the basic causal structure is discussed, utilizing the reference mode embodied in the model purpose to select a transparent structure. Finally, the causal influences on model rates of flow are highlighted.

To establish the suitability of the selected structure, the paper then summarizes the results of model tests. As the paper shows, the relatively transparent causal structure chosen for the model appears capable of providing insight into the real-world labor market, and of enhancing labor-market policy analysis.

TABLE OF CONTENTS

I. INTRODUCTION

A critical step in developing any system dynamics model is to choose the basic causal structure of the model. The term "causal structure" refers principally to the set of levels and rates that comprise the model. Deciding which levels, and their associated rates, to include in a model is rarely a straightforward matter. Commonly, questions about a desirable degree of aggregation, and about an explicit versus implicit treatment of certain processes, cloud the matter and make selecting a basic causal structure an agonizing phase of model development. Models of population provide a ready example: often the modeler encounters difficulty in deciding how fine a representation of the aging process (which determines the basic set of levels and rates in the model) should be used.

This paper asserts that difficulties encountered in selecting a basic causal structure can be traced to an inadequate formulation of the reference mode for which the model is designed. The uncertainty resulting from an inadequate statement of the reference mode most commonly leads to more detail in model structure than is desirable.

The importance of a clear reference mode for a model cannot be overstated. Only if the modeler has a clear reference mode in mind can he or she hope to evolve a "transparent" causal structure for the model. The transparency of a model's causal structure has importance for two principal reasons. First, only if the model is significantly less complex than the real world can the modeler hope to understand its dynamics

and attain any enduring insights into the real-world system being modeled. The absence of a relatively transparent causal structure, ensuing from an ill-defined reference mode, means the modeler may have gained little by building the model. Second, even if a modeler can cope with an unnecessarily detailed model, his or her ability to communicate to others the model itself, and insights derived from model simulations, is greatly diminished. The intellectual effort required of others to wade through a labyrinth of detailed structure greatly reduces the impact of a modeling effort.

Transparency of causal structure, then, is an important aim in developing a model. What guidelines exist for achieving transparent causal structures? The fundamental guideline appears to be: strive for as highly aggregated and as simple a structure that will generate the dynamics of interest. The dynamics of interest, of course, revolve around the reference mode, which is in turn a function of the model's purpose.

The reference mode of a model under development can be stated by drawing a graph of the expected behavior of major variables of interest. Doing so also helps define more clearly which variables must appear in the model. The reference mode may also be stated descriptively, by a discussion of the phenomena the model is meant to portray. Often, the reference mode encompasses different possible specific time paths for model variables, and a descriptive treatment of the reference mode may actually convey more of the purpose of the model than a graph of expected behavior.

An unfortunate aspect of many treatments of methodology is that the generalities and guidelines offered lack concrete meaning to the reader. For example, the guideline that one should "strive for as highly aggregated and as simple a structure" as possible may be of little use to the reader when attempting to implement it. A concrete illustration of how the guideline has actually been followed in practice is worth more than repeated exhortations. Accordingly, the remainder of this paper traces the process by which a clear notion of model purpose and the consequent reference mode led to a relatively transparent model causal structure. As the discussion will reveal, a less well-defined reference mode could have led to a considerably more complex—and consequently less useful—causal structure. To demonstrate that the transparent causal structure is still adequate for generating the dynamics of interest, the paper will also summarize the results of model testing.

II. ILLUSTRATIVE CASE: DEVELOPMENT OF A MODEL OF THE LABOR MARKET

To provide a concrete illustration of how the reference mode serves as a guide to transparent causal structure, this section relates the development of a system dynamics model of the labor market. The procedure will be first to discuss the purpose of the labor-market model, in which the reference mode of the structure under development is described, then to trace the selection of levels and rates, and finally to highlight the causal influences on the rates.[1]

A. Purpose of the Model

The labor-market model comprises one sector, called the labor sector, of a larger model of national socio-economic behavior.[2] The terms "labor-market model" and "labor sector of the National Model" refer interchangeably to the structure described in this paper. The purpose of the labor-market model is twofold: first to increase understanding of labor-market dynamics, and second, in conjunction with the larger National Model, to analyze labor-market policies.

---

[1] The model discussed here is developed fully in the author's Ph.D. dissertation (Runge 1976a). The dissertation research was carried out under several grants, including those from the Rockefeller Brothers Fund and the National Science Foundation.

[2] The larger model, the System Dynamics National Model, is being developed by the System Dynamics Group, Alfred P. Sloan School of Management, MIT. For a description of the scope and purpose of the National Model, see Forrester, Mass, and Ryan (1976).

The System Dynamics National Model incorporates the major features of national socio-economic behavior as endogenous variables. The interaction of these variables will generate the economic growth, instability, and inflation that characterize the United States economy. The National Model will address short-range and medium-range issues, such as the causes of business-cycle (3-7 year period), Kuznets-cycle (15-20 year period), and Kondratieff-cycle (45-60 year period) fluctuations, and long-term issues such as the one-time transition from growth to equilibrium. The National Model consists of six distinct model sectors: the production, labor, demographic, household, financial, and government sectors. The labor sector--the "labor-market model" discussed in this paper--receives inputs from other sectors on the demand for workers, worker income and assets, transfer payments, and the size of the workforce.

The labor sector supplies workers to the production sector of the National Model. The production sector, in turn, contains a standard set of equations, which are replicated for different sectors of the economy, such as capital goods or services. For each replication of the standard production sector, the labor sector determines worker hiring and quits, which along with layoffs comprise the flow of workers between employment and unemployment. In addition, the labor sector captures worker mobility between sectors. Wages are also generated in the labor sector for workers in each replication of the standard production sector.

A major short-term issue treated in the National Model will be the apparent tradeoff between inflation and unemployment. When coupled with the other sectors of the National Model, the labor sector will exhibit short-term variations in unemployment and wage changes. The availability and willingness to work of

unemployed workers in the labor sector will significantly influence both the short-term inflation/unemployment tradeoff and the effectiveness of policies aimed at altering the tradeoff. The wage-change equation in the labor sector does not <u>assume</u> a tradeoff between unemployment and wage changes; rather, it seeks to incorporate the actual pressures that bear on wage-setting processes in the real world, such as the difficulty employers have in filling job vacancies.

Among the long-term issues treated by the National Model is the industrialization process, and constraints arising from shortages of capital, technology, and labor. When embedded in the National Model, the labor sector will display long-term changes in employment patterns among sectors of the economy. The labor sector will also demonstrate the effect of the availability of workers on such long-term changes. Any restriction in the flow of workers among sectors would constrain the growth of sectors attempting to expand. Moreover, higher wages needed to attract workers to growing sectors can contribute to inflation.

B. Evolution of Basic Causal Structure

Representing worker stocks and their interconnecting rates of flow in a multi-sector economy is a potentially formidable undertaking. Because labor is a factor of production in each replication of the standard production sector of the National Model, the pool of employed workers in each sector must necessarily be represented. From that predetermined starting point, one is faced with a wide array of possible representations of unemployed worker pools, and the flow of workers between unemployed and employed pools.

First, one must settle the question of how to define the "unemployed" stock or stocks of workers. To be classified by the United States Bureau of Labor Statistics as "unemployed", but still in the labor force, a worker must be actively seeking work. In terms of the actual number of jobless workers available for hiring, such a definition understates the size of the pool of workers from which employers can draw labor. Accordingly, jobless workers in the labor-market model are assumed to include the "passive" unemployed, or those not actively seeking work. To avoid confusion with the Bureau of Labor Statistics concept, jobless workers in the labor-market model are termed "nonemployed", rather than "unemployed", to reflect the inclusion of the "passive" as well as "active" unemployed.

Figure 1 shows one obvious alternative for handling nonemployed workers in the model structure. In the figure, nonemployed workers are aggregated into a single pool, and hiring for the sector employed pools of all sectors draws on workers from the single general nonemployed pool. Such a structure offers a simple, transparent representation of the labor market. However, brief reflection reveals its inadequacy. Regardless of the total number of nonemployed workers at any time, the number of workers available to a given production sector is limited. Whether by tradition, training, or lack of information, each sector faces a constraint of limited worker availability. The real-world segmentation of the labor market, which leads to the existence of "noncompeting groups" (Kerr 1954),

strongly suggests the inability of the structure in Figure 1 to capture labor-market dynamics adequately. Figure 1 appears to enhance simplicity at the expense of dynamic capability; accordingly, a more complicated representation appears necessary.

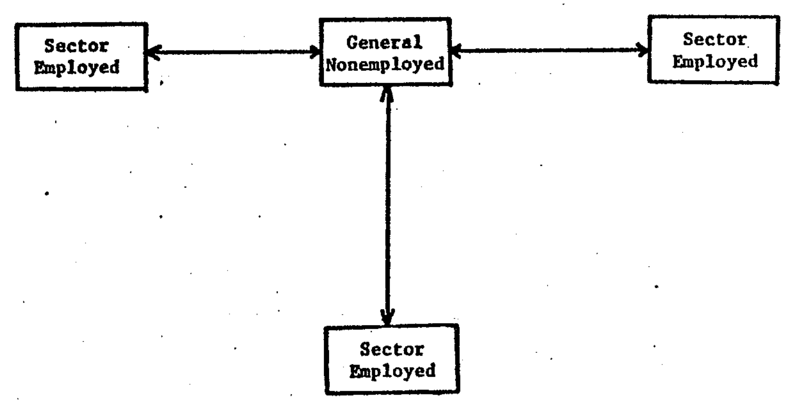


Figure 1. Labor-Market Structure with One Nonemployed Pool.

Figure 2 depicts an attempt to incorporate labor-market segmentation by introducing one pool of nonemployed workers, called the "sector nonemployed" pool, for each production sector. The structure in Figure 2 clearly satisfies the need to incorporate the real-world limitation of worker availability faced by each production sector. Moreover, by associating a nonemployed pool of workers with each production sector, the structure potentially allows examination of policy issues arising from inter-sectoral differences in the economic well-being of nonemployed workers. For example, such a structure can aid examination of the effect of an increase in nonemployment compensation on nonemployed workers' willingness to accept work in a sector, or to move to a different sector.

A significant question the structure depicted in Figure 2 leaves unanswered is how to represent the intersectoral flow of workers. Data on the United States labor market strongly suggest the need to incorporate intersectoral worker flows. The long-term movement of workers out of agriculture and into manufacturing and services provides one example. Even on a short-term basis, intersectoral worker flows are significant. According to Gallaway (1967, p. 29), at least 25% of the employees in one industry in 1957 were employed in another industry in 1960. Data from Bancroft and Garfinkle (1963, pp. 1-10) show

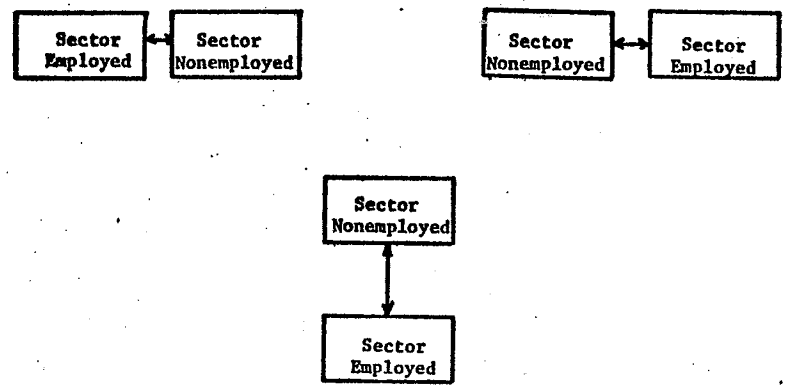


Figure 2. Labor-Market Structure with a Nonemployed Pool for each Employed Pool.

that over one-half of the job changes in 1961 involved a movement from one of fourteen industry classifications to another. While the need to incorporate intersectoral worker flows is clear, the means of doing so is perhaps the crucial unanswered question faced in developing a structure for modeling the labor market.

Figure 3 presents one alternative for representing intersectoral worker flows. In the figure, all logically possible flows—from each pool to every other pool—are depicted. The flows in Figure 3 capture flows that actually occur in the real world. A nonemployed worker in one sector may move to a second sector, either by being hired directly out of the first sector's nonemployed pool or by moving to the second sector's nonemployed pool and there looking for work. Similarly, an employed worker in one sector may leave his job and go to the nonemployed pool in a second sector to seek work. Moreover, he may go directly to a new job in another sector. In fact, direct job-to-job flow is more than a logical possibility: Bancroft and Garfinkle (1963, p. 1) show that in 1961 approximately 40% of all job changes occurred without an intervening period of unemployment.

From the above considerations, the network of worker flows in Figure 3 would appear necessary for a realistic representation of the labor market. However, while an accurate literal portrait of worker movements, the network of flows in Figure 3 presents a tremendous burden to the analyst, first in specifying the determinants and parameters for

all the flow rates, and second in interpreting the dynamics inherent in such a complicated structure. Testing and understanding the model structure implied in Figure 3 would require such a devotion of attention to detail that the model behavior would likely be as conceptually impenetrable as the real world. Figure 3 clearly illustrates the tradeoff entailed in detailed representation of the real world in a model: one quickly becomes immersed in a task that is unlikely to generate insight and understanding because of the amount of detail. Consequently, some alternative to Figure 3 appears desirable. What is needed is a structure for intersectoral worker movements that gains in simplicity over Figure 3, yet does not lose its basic dynamic characteristics.

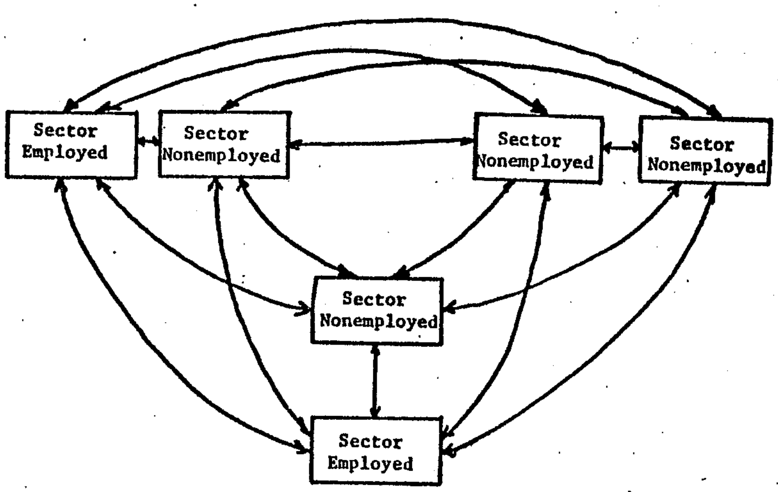


Figure 3. Potential Intersectoral Worker Flows.

Figure 4 shows the basic structure of worker pools and their interconnecting flow rates used for the labor-market model. The structure in Figure 4 combines features of Figure 1, in which all workers were drawn from one general nonemployed pool (meaning that intersectoral flows occurred implicitly), and Figure 2, in which workers for a sector were drawn from a local, and limited, supply. In Figure 4, workers for a given sector are hired from the nonemployed pool associated with that sector. The general nonemployed pool in Figure 4 now provides a channel for worker movement between sectors. All intersectoral flows are represented in Figure 4 as the result of movement out of the sector nonemployed pool of one sector, into the general nonemployed pool, and from there to the sector nonemployed pool of another sector.

The structure in Figure 4 retains the important feature in Figure 2 of constraining at any one time the availability of workers for hiring in a particular sector. But what of the pattern of intersectoral movements in Figure 4? Clearly, the structure in Figure 4 is less rich than that in Figure 3, where all the real-world flows were shown. How can such a simplification be justified?

The key to accepting the conceptual adequacy of the basic structure shown in Figure 4 lies in a grasp of the aggregation such a structure embodies. The structure in Figure 4 asserts that even a direct real-world flow from a job in one sector to a job in a second sector is constrained to flow successively through the nonemployed pool in the first sector, the general nonemployed pool, and finally the nonemployed pool in the second sector. The worker flows through each nonemployed pool have associated time constants, which represent the average duration of stay in each pool. The average duration of stay in a given pool derives from a wide distribution of individual durations of stay; some workers stay in each pool much longer than the average, some stay much less than the average time. Direct job-to-job movement can be interpreted as a flow through the intervening nonemployed pools in Figure 4 with a zero duration of stay. Therefore, while on first glance the structure of Figure 4 appears to omit important real-world worker flows, closer consideration of the aggregation embodied in such a structure suggests that it is nonetheless capable of exhibiting the same dynamics as the real-world labor market.

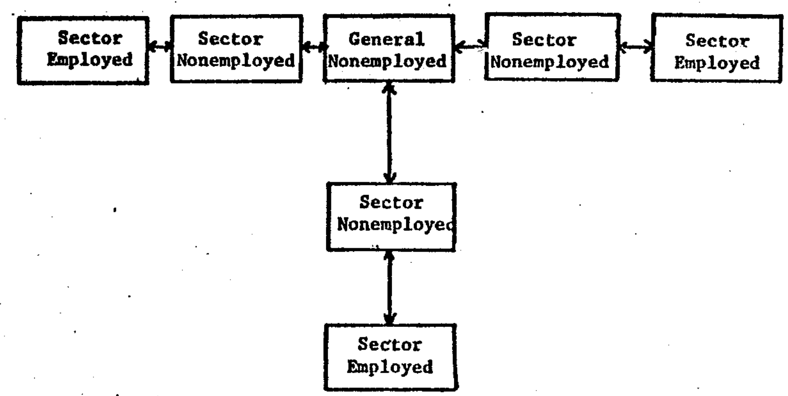


Figure 4. Labor-Market Structure that Combines Use of General and Sector Nonemployed Pools.

Figure 5 shows a more refined version of the basic causal structure selected by the above reasoning. Figure 5 illustrates a typical arm of the star-shaped network of labor-market flows first seen in Figure 4. The general nonemployed pool connects with as many sector nonemployed pools as there are production sectors in a given version of the National Model. The flow of workers from the general nonemployed to the sector nonemployed pools is called arrivals in sector; the opposite flow is dermed departures from sector. The hiring rate and the separation rate connect the sector nonemployed and the sector employed pools within each production sector.

All production sectors are treated in a standard way in the labor-market model: the same mobility equations operate for each production sector, with parameter values set to represent the particular characteristics of each sector. In other words, the labor-market model cpatures all worker mobility in the four flow rate equations indicated in Figure 5. One additional rate in Figure 5 represents the change in wages in each sector. These five equations form the core of the labor-market model.

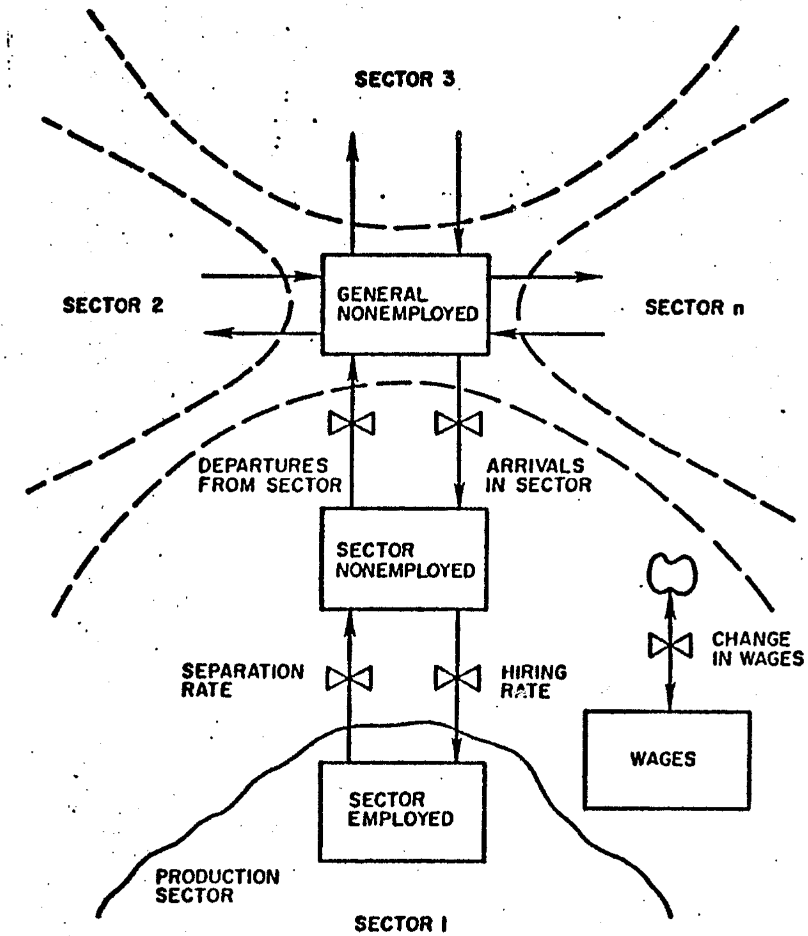


Figure 5. Basic structure of the labor-market model

C. Causal Influences on Model Rates of Flow

Having selected the basic causal structure shown in Figure 4 and refined in Figure 5, the remaining tasks of formulating rate equations and interpreting model behavior are vastly simplified. Instead of the multitude of flows implied in Figure 3, all worker movements in the labor-market model are captured in only four generic flow equations. The remainder of this section highlights the influences on those four mobility equations and on the equation for the change in wages, to facilitate interpretation of the test results in the section that follows.

1. Hiring rate

Figure 6 shows the influences on the hiring rate. As depicted on the right side of Figure 6, an increase in the backlog for workers (analogous to job vacancies) raises the hiring rate. However, a higher backlog for workers also reduces the relative availability for hiring, defined as the ratio of the sector nonemployed to the backlog for workers. The probability that a given job opening is filled in a given time period decreases as the relative availability for hiring declines. Therefore, a higher backlog for workers decreases the probability of filling a given job opening in a given time period, thereby making any rise in the hiring rate less than proportional to the increase in backlog.

The disposable income of sector employed also influences the hiring rate. As disposable income of sector employed increases, the hiring rate also rises due to the greater attractiveness of holding a job in the sector. However, the net effect of disposable income of sector employed on the hiring rate depends on the length of week for labor. For a given income, a longer length of week for labor tends to depress the hiring rate. If the length of week for labor in a sector is too long, workers are discouraged from accepting work in the sector.

In Figure 6, the hiring rate is negatively affected by the well-being of the sector nonemployed. The well-being of the sector nonemployed increases as transfer payments to the sector nonemployed increase, duration of transfer payments lengthen, and assets per worker grow; well-being decreases as the duration of stay in the sector nonemployed pool (equal to sector nonemployed divided by hiring rate plus departures from sector) lengthens. An increase in the well-being of sector nonemployed reduces the economic incentive to work and tends to depress the hiring rate, and vice versa.[3]

[3] The positive effect that a long duration of unemployment has on a worker's willingness to accept a job is a cornerstone of the job vacancy-turnover theory of the labor market. The effect of transfer payments on job-search activity are reported, for example, in Myers and Schultz (1951).

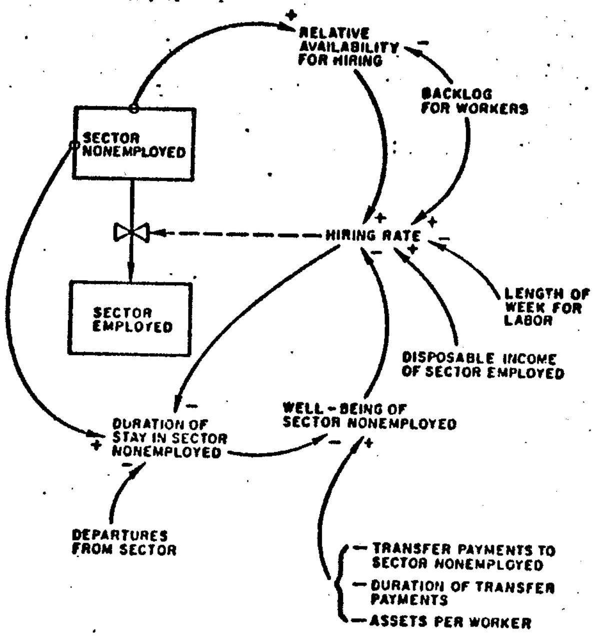


Figure 6. Influences on hiring rate

2. Separation rate

Figure 7 shows the influence on the separation rate. The separation rate is the sum of the quit rate and the layoff rate. The quit rate is basically proportional to the number of sector employed workers, but is also influenced by the well-being of sector nonemployed, the disposable income of sector employed, and the length of week for labor. Whenever job openings increase, and the hiring rate consequently rises, the duration of stay in sector nonemployed decreases. As a result, the well-being of sector nonemployed increases due to the reduced need to consume assets while not employed. Higher well-being of sector nonemployed tends to increase the quit rate.[4] On the other hand, high disposable income of sector employed tends to diminish the quit rate by making present jobs more attractive.[5] The length of week for labor also affects the quit rate. If the length of week for labor exceeds its traditional length (at a given income) or becomes excessively fatiguing, the quit rate rises.

The layoff rate in Figure 7—determined in the production sector of the National Model—is governed by a comparison between the desired and the actual number of sector employed. An excess of desired over actual sector employed leads to fewer layoffs; conversely, if actual sector employed is greater than desired, a higher layoff rate results.

[4] The response of quits to increased demand and hiring is discussed in Behman (1964), pp. 261-262.

[5] Burton and Parker (1969) discuss empirical evidence for the negative influence of [illegible] (and therefore income) on quits.

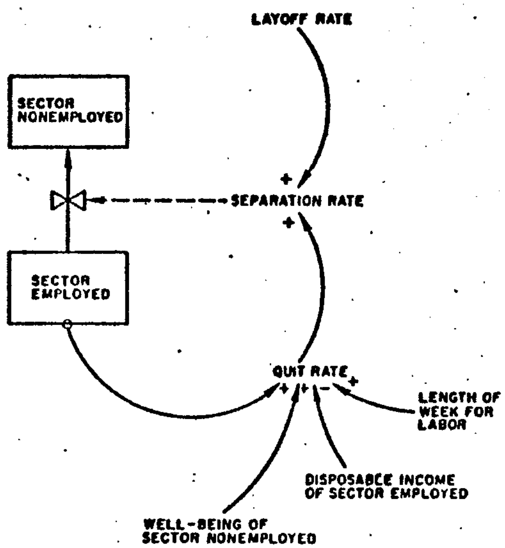


Figure 7. Influences on separation rate

3. Arrivals in sector

Figure 8 shows the influence on arrivals in sector. Arrivals in sector are proportional to the size of the workforce in the sector (the sum of sector employed and sector nonemployed). As discussed in Myers and Schultz (1951, pp. 70-71), a large portion of job information is transmitted by word-of-mouth; therefore, the larger the sector, the more nonemployed workers outside the sector are likely to work there. Arrivals in sector are affected as well by the size of the general nonemployed pool; a smaller (larger) general non-employed pool means a lower (higher) flow

out of the pool. The duration of stay in the general nonemployed pool (equal to a general nonemployed divided by total arrivals in sector) also influences arrivals in sector. A lengthening duration of stay in general nonemployed increases the financial hardship of those remaining in the general nonemployed pool and raises the incentive to seek work. Therefore, in Figure 8, an increase in the duration of stay in general nonemployed raises the relative duration in general nonemployed, which then increases arrivals in sector. Transfer payments to the general nonemployed also influence arrivals in sector through their effect on the "acceptable" duration of stay in the general nonemployed pool. An increase in transfer payments to general nonemployed shortens the relative duration in general nonemployed, corresponding to greater economic well-being, which lessens the incentive to seek work and thereby depresses arrivals in sector.

Aside from the size of the workforce in a sector, the major sector-specific influences on arrivals in sector are the perceived income ratio and the relative perceived hiring delay. The perceived income ratio reflects the perception by workers in the general nonemployed pool of the income of workers in the sector relative to the average income of all workers in the economy. An increase in the income of workers in a sector tends to raise arrivals in sector because of the attractiveness of the greater earning potential there. The relative perceived hiring delay indicates the perception by workers in the general nonemployed pool of the hiring delay in the sector relative to the average hiring delay in the economy. The hiring delay measures the average time required to find work in a sector. A short hiring delay, signaling favorable demand conditions in a sector, increases arrivals in sector because the likelihood of finding work there is high.

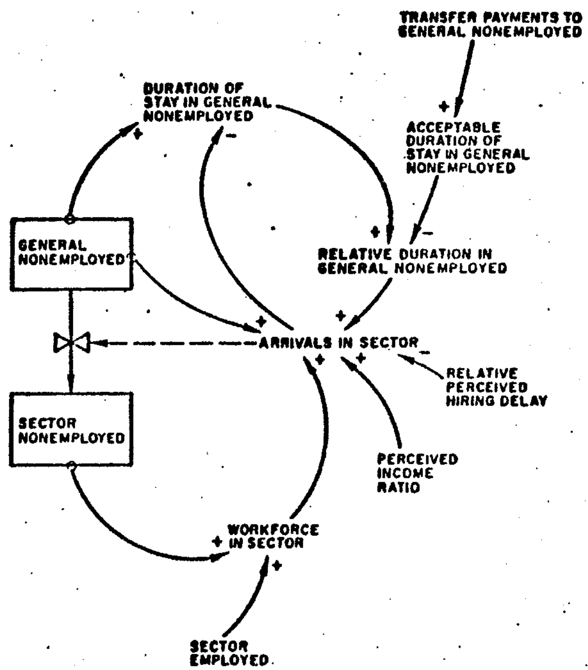


Figure 8. Influence on arrivals in sector

4. Departures from sector

Figure 9 shows the influence on departures from sector. Normally, some fraction of the sector nonemployed can be expected to depart to the general nonemployed pool for a variety of reasons, such as dissatisfaction or upward

mobility; therefore, departures from sector are proportional to the size of the sector nonemployed pool. Departures from sector are also influenced by the well-being of sector nonemployed: the higher the well-being of sector nonemployed, the less impetus for leaving the sector to seek work elsewhere. Departures from sector are also tempered by perceived average income, a measure of the perception by the sector nonemployed of the average income elsewhere in the economy. High average income elsewhere increases the attractiveness of leaving a sector.[6]

In Figure 9, the mobility of workers through the general nonemployed pool also influences departures from sector. A short relative duration in general nonemployed suggests high mobility, an encouragement for departures, and vice versa. The effect of the relative duration in general nonemployed on departure thus indirectly reflects the ease of finding work elsewhere.

[6] A comparison of the sector-specific influences on arrivals in sector (Figure 8) and departures from sector (Figure 9) indicates that arrivals are responsive to such particular conditions in the sector as income and hiring delay. In contrast, departures are influenced only by the well-being of sector nonemployed. The concept of asymmetrical influences on arrivals and departures is consistent with the main thread of recent migration studies as discussed in Morrison and Relles (1975, pp. 1-4).

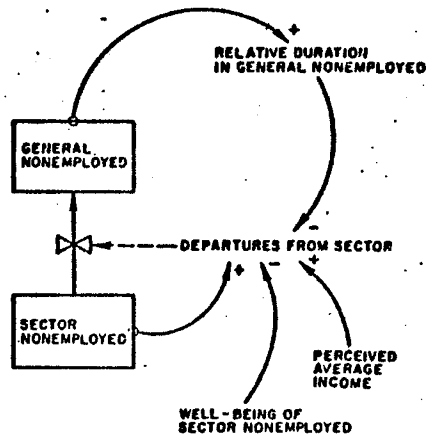


Figure 9. Influences on departures from sector.

5. Change in wages

Figure 10 shows the influences on the change in wages in each sector. The change in wages is proportional to existing wages. In other words, the absolute change in wages due to a given percent change depends on the level of wages. The other influences on the changes in wages, when multiplied by the level of wages, determine the absolute change in wages.

Relative wages--wages in the sector relative to average wages in the economy--influence the change in wages. If average wages outside the sector increase, relative wages within the sector decline, creating upward pressure on the change in wages. The impact of relative wages on the change in wages

captures the effect of "secondary wage drift" discussed in Phelps Brown (1962). Secondary wage drift describes the influence that wage changes in one part of the economy have on wage changes elsewhere.

Perceived inflation in the nation also influences the change in wages. The perceived inflation in nation represents worker and employer perception of the rate of increase in prices.

Another influence on the change in wages is the delivery delay for workers. The delivery delay for workers, a measure of the average time needed to fill a job opening, provides the principal influence on the change in wages from the worker supply-demand balance in the model. A short delivery delay for workers reflects a slack labor market where job openings are easy to fill; a long delivery delay for workers, on the other hand, reflects tight labor-market conditions where job openings take a long time to fill. The use of delivery delay for workers as an influence on the change in wages in the labor-market model contrasts with the dominant practice in empirical economics. In a tradition established by Phillips (1958), model equations for the change in wages typically incorporate the unemployment rate as an indicator of the worker supply-demand balance. The unemployment rate is frequently used because data is lacking on other, more realistic indicators of the worker supply-demand balance. In the labor-market model, on the other hand, the delivery delay for workers indicates the relative difficulty employers have in filling job openings; the delivery delay for workers comes much closer to capturing real-world pressures on wage changes than the unemployment rate.

Figure 10 also shows an influence on the change in wages from the employment ratio in sector, which is the ratio of the actual to the desired number of sector employed. When the desired exceeds the actual number of sector employed, upward pressure is placed on the change in wages, and vice versa.

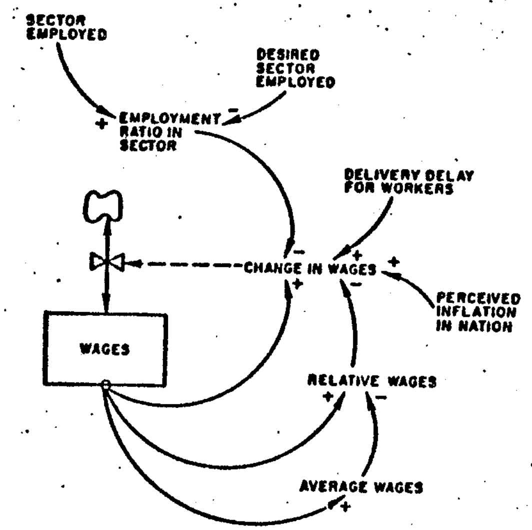


Figure 10. Influences on the change in wages

III. EVALUATING THE CHOSEN STRUCTURE

Elegant verbal justifications for a particular causal structure aside, the true test of a model's ability to generate the dynamics of interest and to foster understanding of the real world lies in its response to inputs. Accordingly, this section reviews and briefly highlights the results of initial tests of the labor-market model. The test results suggest that the transparent causal structure developed in Section II indeed fulfills its dual role of generating both appropriate behavior and insight.

The labor-market model, in both one- and two-sector versions, has been tested extensively for validation purposes. The model has been subjected to two classes of test inputs: simple (that is, step and fluctuating) inputs, and time-series inputs. Initial tests utilized a step increase in, and a fluctuating level of, desired employment. The initial test results showed a plausible model response to test inputs, and a relative insensitivity to sizeable parameter changes. The test results have permitted comparisons between the behavior of the model and the real-world labor market. Moreover, the model structure has provided explanatory insights into numerous features characterizing both the model and real-world labor markets.

The model has also been subjected to inputs derived from real-world data. A two-sector version of the model, representing the entire US labor market, proved capable of replicating real-world worker mobility and wages over the period 1954-1973, when driven by time series inputs.

Selected results of subjecting a one-sector version of the model to simulated business-cycle conditions will be reviewed below. The model was subjected to a ±10% fluctuation in desired employment, with a period of 4 years, to approximate US business-cycle fluctuations in the demand for workers. The test provided a wealth of material for comparing model behavior to the real world. However, due to space limitations, only certain phase relations and correlations in the model will be treated here.

In Figure 11a, the hiring rate, the backlog for workers, and the levels of sector employed and sector nonemployed all fluctuate over amplitude ranges that agree with US business-cycle fluctuations.[7] The backlog for workers in Figure 11a leads the sector employed, peaking about 3/4 year before sector employed. A comparable phase relation exists between nonagricultural job openings and nonagricultural employment in the United States.[8]

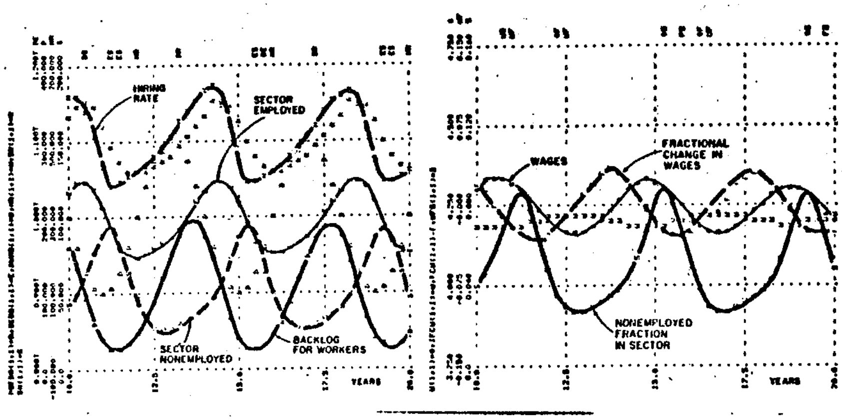
Figure 11b shows the behavior of wages in the labor-market model. Wages fluctuate, in response to changing demand for and supply of workers, about an average value greater than their initial value. The tendency for wages to increase on the average arises from the greater flexibility of wages upward than downward. In the one-sector model used for Figures 11a and 11b, average wages in the economy are assumed to be constant; they therefore exert downward pressure whenever wages in the sector rise. Wages in Figure 11b

[7]The simulation shown in figures 11a and 11b spans 20 years. The figures show only year 10 to year 20, however, to reveal more detail and facilitate examination of phase relations and correlations.

[8]See Moore and Shiskin (1967, p. 55).

fluctuate about a value where the downward pressure from the effect of relative wages offsets the greater upward flexibility of wages in the sector. If wages were increasing elsewhere in the model, the downward pressure on wages in the sector would diminish and wages would exhibit a secular rise in their average value. Such a tendency in the labor-market model—as in the real world—can be an important component of inflation. Wages in Figure 11b lag behind sector employed in Figure 11a by about 5 months. The lag of wages behind sector employed agrees with the real-world lag of wages behind employment in manufacturing, as noted in Gordon (1961, p. 289).

Figures 11a and 11b show correlations between model variables that correspond to real-world correlations. For example, Figure 11a shows that the backlog for workers and the sector nonemployed are negatively correlated; an increase in the backlog for workers is accompanied by a decline in sector nonemployed, and vice versa. Figure 12 shows annual values of the backlog for workers and sector nonemployed from the simulation in Figure 11a plotted as percents of the workforce in the sector. On the vertical axis, the backlog fraction in sector is defined as the backlog for workers divided by the workforce in sector. The horizontal axis shows the nonemployed fraction in sector expressed in percent terms.



(a) (b)

Figure 11. Response of labor-market model to fluctuating desired employment.

Figure 12b shows real-world data comparable to that in Figure 12a.[9] In Figure 12b, the number of vacancies pending at the US Employment Service as a percent of the labor force, called the vacancy rate, is plotted against unemployment as a percent of the labor force. A comparison of figures 12a and

[9]Figure 12b reproduces Figure 6 in Holt et al. (1971, p. 40).

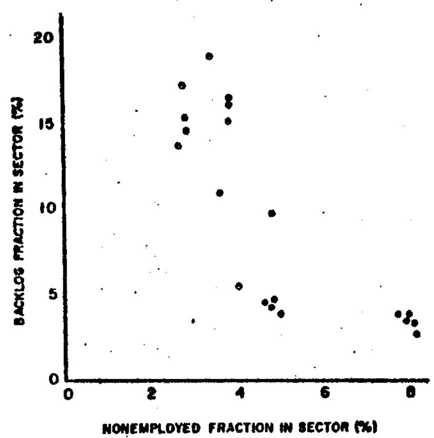


Figure 12a. Backlog fraction in sector versus nonemployed fraction in sector from simulation in Figure 11a.

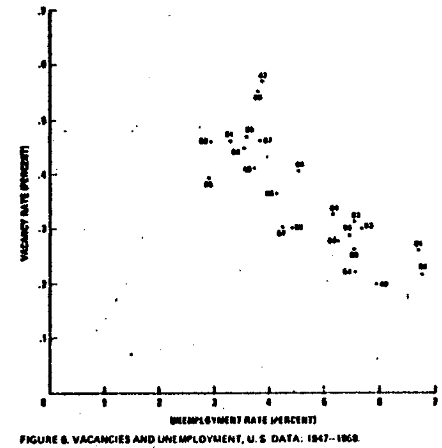


Figure 12b. Vacancy rate versus unemployment rate in United States.

12b shows the qualitative agreement between the correlations in the two figures.[10] The structure of the labor-market model explains why such a correlation should exist in both the model and the real world. An increase in the backlog for workers, by increasing the hiring rate, tends to decrease the number of sector nonemployed, and vice versa, thereby inducing a negative correlation between backlog for workers and sector nonemployed.[11]

Figure 11b reveals a second correlation of interest. The nonemployed fraction in sector and the fractional change in wages tend to be negatively correlated; an increase in the nonemployed fraction in sector is accompanied by a decline in the fractional change in wages, and vice versa. Figure 13a graphs data from the simulation shown in Figure 11b on the fractional change in wages versus the nonemployed fraction in sector, both expressed in percent terms. The curve through the data in Figure 13 expresses a regression of the fractional change in wages (FCW) on the reciprocal of the nonemployed fraction in sector (NFS), in an equation of the form FCW = A + B/NFS.

[10] The vertical scales are different between figures 12a and 12b because vacancy data used for Figure 12b understates the actual number of vacancies in the economy. Even if the data in Figure 12b did report all job vacancies, the scales would still differ because backlog for workers is a more inclusive measure of demand than officially defined job vacancies. (For example, "backlog for workers" includes demand for workers being recalled from layoff, but "job vacancies" does not.) The difference in vertical scale between two figures only alters the slope of the negative correlation; the underlying qualitative agreement between the two correlations is not affected.

[11] The model also displays a shift in the correlation between backlog for workers and sector nonemployed when transfer payments to the sector nonemployed increases. Gujarati (1972) found the same results in the real world.

Figure 13b reproduces the original Phillips curve that relates the rate of change of money wages to the unemployment rate in the United Kingdom.[12] Comparison of figures 13a and 13b reveals close agreement between the correlations in the two figures. Both show that the rate of wage change tends to accelerate as the unemployment rate declines. Conversely, as the unemployment rate increases, the rate of wage change falls with decreasing steepness. Moreover, the values of the fractional change in wages in Figure 13a agree well with those in Figure 13b for corresponding values of the nonemployed fraction in sector. The labor-market model structure explains the negative correlation between the fractional change in wages and the nonemployed fraction in sector: when the nonemployed fraction in sector declines, the increased competition for workers raises the difficulty of matching workers with jobs in a given time period, as manifested in a longer delivery delay for workers. The resulting upward pressure on wages from a longer delivery delay for workers induces a wage increase that correlates with the decline in the nonemployed fraction in sector.

The correspondence between model and real-world labor markets reveals the model's ability to capture labor-market dynamics realistically. Among other features, the model also shows a positive correlation between hiring and wage changes that agrees with the correlation shown in Behman (1964, p. 259). Moreover, the model structure explains the negative correlation commonly found between wage changes and the rate of change of unemployment[13] on the basis of stock-flow interactions in the labor market.[14]

[12] Figure 13b reproduces Figure 1 in Phillips (1958, p. 285).

[13] See Bowen and Berry (1963) for example.

[14] Space limitations preclude full discussion of such features here. See Runge (1976a, Chapter IV).

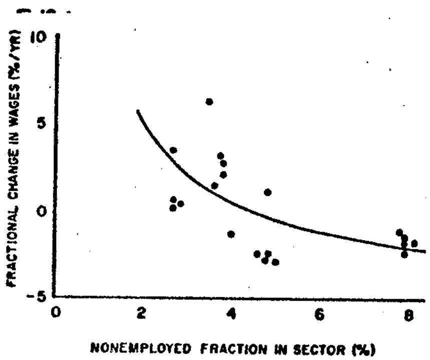


Figure 13a. Phillips curve derived from simulation in Figure 11b.

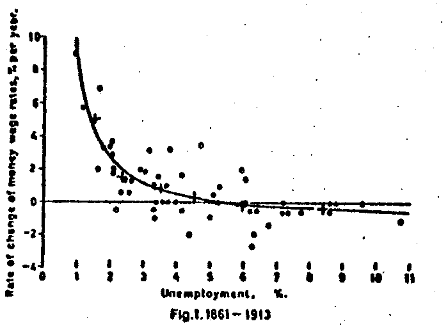


Figure 13b. Original Phillips curve relating the rate of change of money wages and employment.

IV. CONCLUSIONS

This paper has shown the usefulness and importance of a well-defined reference mode as a guide to transparent causal structure. The value of a transparent causal structure was seen to lie in two areas: first, it enhances the modeler's ability to understand the model's dynamics and acquire enduring insights about the real world; second, it facilitates communication to others of the model, and of insights derived from model simulations.

The fundamental guideline offered for achieving transparency in a model's causal structure was: to strive for as highly-aggregated and as simple a structure that will generate the dynamics of interest. Furthermore, the paper argued that without a clearly-stated purpose of the model, and a consequently well-formulated reference mode, the chances of achieving a transparent model causal structure were slight.

To illustrate how a well-defined reference mode can guide the modeler in developing a transparent causal structure, the paper traced the development of a model of the labor market. The basic causal structure selected was significantly less complex than a literal representation of labor-market stocks and flows would have been. The aggregation and simplicity embodied in the model structure was defended verbally by describing how it could capture the essential dynamics of the real-world labor market. The key to accepting the plausibility of the model structure lay in understanding that the time constants of flow through the nonemployed pools were average values. Consequently, real-world flows that were not explicitly represented in the model were implictly captured in the averaging process.

The ultimate evaluation of a causal structure, transparent or not, lies in its behavior when tested. Accordingly, the paper summarized some results of tests of the labor-market model to show that the transparency of its structure did not detract from its dynamic capabilities. The model tests to date have provided a solid initial basis for confidence in the model. The model's response to simple step and fluctuating inputs, as well as its performance when subjected to time-series inputs, yield many areas of congruence between the model and the real world. The model structure also sheds light on the dynamics of the real-world labor market. While further testing is required, the labor-market model, whose transparency derives from a well-defined reference mode, appears to promise a means of better understanding labor-market dynamics and of better formulating labor-market policies.

REFERENCES

Bancroft and Garfinkle (1963) — Bancroft, G., and S. Garfinkle. "Job Mobility in 1961," Monthly Labor Review, August 1963.

Behman (1964) — Behman, S. "Labor Mobility, Increasing Labor Demand, and Money Wage-Rate Increases in United States Manufacturing," Review of Economic Studies, vol. 21, no. 4 (October 1964), pp. 253-266.

Bowen and Berry (1963) — Bowen, W., and R. Berry. "Unemployment Conditions and Movements of the Money Wage Level," Review of Economics and Statistics, vol. XLV (May 1963), pp. 163-172.

Burton and Parker (1969) — Burton, J.F., Jr., and J.E. Parker. "Interindustry Variations in Voluntary Labor Mobility," Industrial and Labor Relations Review, vol. 22, no. 2 (January 1969), pp. 199-216.

Forrester, Mass, and Ryan (1976) — Forrester, J.W., N.J. Mass, and C.J. Ryan. "The System Dynamics National Model: Understanding Socio-Economic Behavior and Policy Alternatives," Technological Forecasting and Social Change, vol. 9 (July 1976).

Gallaway (1967) — Gallaway, L. W. Interindustry Labor Mobility in the US, 1957-1960, Social Security Administration Research Report #18 (Washington: Department of Health, Education, and Welfare, 1967).

Gordon (1961) — Gordon, R.A. Business Fluctuations (New York: Harper and Row, 1961).

Gujarati (1972) — Gujarati, D. "The Behavior of Unemployment and Unfilled Vacancies: Great Britain 1958-71," The Economic Journal, vol. 82 (March 1972), pp. 194-204.

Holt (1970) — Holt, C. "Job Search, Phillips Wage Relation, and Union Influence: Theory and Evidence," in Micro-Economic Foundations of Employment and Inflation Theory, by E. Phelps et al. (New York: W.W. Norton and Co., 1970).

Holt and David (1966) — Holt, C., and M. David. "The Concept of Job Vacancies in a Dynamic Theory of the Labor Market," in The Measurement and Interpretation of Job Vacancies, National Bureau of Economic Research (New York: Columbia University Press, 1966).

Holt et al. (1971) — Holt, C., C. MacRae, S. Schweitzer, and R. Smith. The Unemployment-Inflation Dilemma: A Manpower Solution (Washington: The Urban Institute, 1971).

Kerr (1954) — Kerr, C. "The Balkanization of Labor Markets," in Labor Mobility and Economic Opportunity, by E. W. Bakke et al. (Cambridge: MIT Press, 1954).

Laird (1974) — Laird, M. "Dynamic Migration Models," in Readings in Urban Dynamics: Volume 1, edited by N.J. Mass (Cambridge: Wright-Allen Press, 1974).

Moore and Shiskin (1967) — Moore, G., and J. Shiskin. "Indicators of Business Expansions and Contractions," Occasional Paper #103 (New York: National Bureau of Economic Research, 1967).

Morrison and Relles (1975) — Morrison, P.A., and D.A. Relles. "Recent Research Insights into Local Migration Flows," Paper P-5379 (Santa Monica, Calif.: The Rand Corporation, February 1975).

Myers and Schultz (1951) — Myers, C., and G. Schultz. The Dynamics of a Labor Market (Englewood Cliffs, N.J.: Prentice-Hall, 1951).

Phelps Brown (1962) — Phelps Brown, E.H. "Wage Drift," Economica, vol. XXIX, no. 116 (November 1962), pp. 339-356.

Phillips (1958) — Phillips, A.W. "The Relation between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861-1957," Economica, no. 25 (November 1958), pp. 283-299.

Runge (1976a) — Runge, D. "Labor-Market Dynamics: An Analysis of Mobility and Wages," unpublished Ph.D. dissertation, Alfred P. Sloan School of Management (Cambridge: MIT, June 1976).

Runge (1976b) — Runge, D. "A Dynamic Model of Worker Mobility and Wage Determination: Structure and Behavior," Proceedings of the 1976 Summer Computer Simulation Conference (La Jolla, Calif.: Simulation Councils, Inc., PO Box 2228, 1976).

Severn (1968) — Severn, A. "Upward Labor Mobility: Opportunity or Incentive?" Quarterly Journal of Economics, vol. 82 (February 1968), pp. 143-151.