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Adaptive Economizing, Technological Change and the Demand for Labor in Disequilibrium

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ADAPTIVE ECONOMIZING, TECHNOLOGICAL CHANGE AND THE DEMAND FOR LABOR IN DISEQUILIBRIUM

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An adaptive economizing framework is proposed for analyzing labor market aspects of long-term industrial development using a dynamic, disaggregate economic model based upon principles of bounded rationality and markets in disequilibrium. The approach is applied to a firm's investment-production planning problem to illustrate how labor demand is related to capital investment and technological change.

1 INTRODUCTION

Technological change as incorporated into an economy through capital investment has a bearing on the organization of production and the derived demand for labor. A widely held view is that innovation is the main spring of economic growth. We see this in the business cycle theory of Schumpeter (1934) and the capital dynamics of Hicks (1977). Both attempt to discover how an innovative impulse works itself out in a multisector economy in which there is generated a dynamic feedback process. An innovation influences the productivity and demand for labor and the distribution of income between wages and profits which has a feedback effect on investment by firms, and, hence future demand for labor. In a multisector economy where a structural shift in the demand for labor may arise, Hicks suggested that an 'innovative impulse may have drastic and possibly unacceptable effects on distribution' and that the prospects of convergence from one full employment equilibrium to another 'looks poor' [Hicks (1977, pp. 190-195; Ch. 2)].

Similarly, Malinvaud (1982, 1984) has suggested that wage and profit adjustments do not provide adequate incentives for capital investment to maintain full employment over the long-run. Instead, he argues, a complex macro dynamic process arises out of the economizing behavior of agents interacting in the labor, capital and product markets. The stability of this process cannot be taken for granted. There is a need to assess the institutional structure of labor and capital markets, and to determine how the disequilibrium adjustment processes of agents in these markets respond to innovative impulses in capital technology over the medium to long term.

For such disequilibrium analysis, new representations of the economic system, other than the neoclassical-classical aggregate models based on assumed stability of market feedback adjustment processes, are required. As Koopmans observed 'until we succeed in specifying fruitful assumptions for the behavior in an uncertain and changing economic environment, we shall continue to be groping for the proper tools of reasoning' (1957, p. 183). Clower and Leijonhufvud suggest that 'what we need is a theory capable of describing system behavior as a temporal process, in or out of equilibrium, which requires a prior account of how trade is organized in the system and of how business and household units behave when the system is not in equilibrium and is predicated on how trade is organized' (1975, p. 183).

To analyze labor market aspects of long-term industrial development what we need, then, is a new modeling framework. This paper describes such a framework, or more correctly, part of such a framework based upon principles of adaptive economizing in disequilibrium. It is applied to a firm's production-investment planning problem to illustrate how short-run and medium-term developments in labor demand are related to capital investment and technological change. The framework will be completed when various submodels of this kind are linked in a network of intersectoral and urban-regional flows. Then it will be possible to study in detail how important macroeconomic problems are generated by microeconomic forces in a way called for by Malinvaud and by Clower and Leijonhufvud.

2 THE DYNAMIC ECONOMY

An economy is comprised of a set of agents consisting of households, firms in different industrial sectors, financial intermediaries, and government, all interacting on markets for commodities, labor, and financial services. Each market is a process which coordinates plans and mediates transactions among agents, through legal institutional rules. With agents making plans for activities and transactions into the uncertain future, using imperfect information, the plans of agents may be inconsistent, and, hence transactions will be constrained and markets in disequilibrium. Under conditions of imperfect coordination, disequilibrium mechanisms such as rationing schemes, inventory-order backlog adjustment, and the use of credit and maintenance of liquidity, provide the means of mediating transactions and maintaining agent-economy viability. With feedback information from transacting in disequilibrium, agents use an adaptive planning procedure. The adaptive economizing behavior of agents, transacting on markets in disequilibrium, and the market process of coordinating plans and mediating transactions are the microfoundations to the aggregate dynamics of an economy.

At the beginning of each elemental period (week, month, quarter, year), a state of technology, resource availability, social organization, and individual preference prevails, and, of course, a history of past consumption, production and technological practice has occurred. On the basis of all this the various agents make their plans, modifying or retaining old plans, or drawing up altogether new ones, and carry out actions based in part on these plans but also on mechanisms and adjustment rules that lead to viable activity when plans cannot be carried out.

The next period the situation has changed. Resources have been depleted, capital may have been augmented, prices and other indexes of value and wealth will be modified and so on. The system is poised for a new round of planning and action.

Observed over a sequence of periods, the economy will exhibit a history of specific activities that were and were not pursued, of specific technologies and resources that were and were not utilized, of specific constraints that were or were not binding. At each point in time choices are available. Once the agents decide among them and implement their plans, the current state and its successor are connected by more or less precise relationships that determine the flow of goods and services, the accumulation of capital, the decumulation of resources and so on. In this way, the unfolding of economic events comes to be governed by dynamic structure.

When in the course of this process the consumption and/or production activities actually utilized change, or the constraints actually impining on choice and actions switch, we observe a change in dynamic structure. Some variables that appeared relevant will no longer appear so; other variables that once seemed of no importance at all will now appear to play an active role in development; some technologies may be abandoned, different ones taking their place; some resources once available in plenty and perhaps thought of as free goods, now become scarce and attain great value in exchange; still other resources once crucial in the production transformation are abandoned, perhaps even before they are exhausted, again becoming valueless.

In the short run and in the small one will see individuals and organizations occasionally change what they do and how they do it. Viewed in the aggregate, waves of growth or decline in productivity and fluctuation in output and value will occur, and in the long run, various "epochs" or "ages" will appear, dominated by characteristic activities and resources. In general the economy's technological regimes will switch; its consumption and production patterns will change: its structure and behavioral patterns will evolve.

We want to consider economizing behavior in this dynamic context.

3 **ADAPTIVE** ECONOMIZING

Economizing involves the allocation of scarce resources according to a criterion such as profit, sales, utility, or more generally, preferences. It involves doing the best one can in production or consumption or both, where "best" is clearly defined. How is economizing to be represented?

The answer depends in an essential way on a preconceived notion of the complexity of change occuring in the economic-environment and the cognitive capacity of agents. Research in cognitive psychology, see Simon (1978), suggests that the complexity of change and the limited cognitive capacity of agents, bounds the rationality of economic agents. Prior to this research in psychology, Keynes was perceptive enough to recognize that, in regards to orthodox theory, 'the hypothesis of a calculable future leads to a wrong interpretation of the principles of behavior which the need for action compels us to take' [Keynes (1937, p. 222)].

In a historical process where the emergence of novelty is the main spring of economic growth and the complexity of change is a reason for cautious, behavioral rules of thumb, prevalent in most firm planning procedures, it seems appropriate to assume that agents are boundedly rational. This is to claim they have limited foresight and computational ability, that errors in expectations is the rule and not the exception, and that a sequential process of short-term planning with behavioral rules of adjustment to market-environment feedback is characteristic of planning procedures.

Economic activities planned at the beginning of a given period are to be undertaken immediately or in future periods. The choice among alternative activities and the determination of activity levels are constrained by technology - the set of available and perceived opportunities (the state of the art) - and by resource availabilities and financial constraints. At any given time these constraining factors and the degree of their limitedness circumscribe the individual's opportunities within a feasible region of activity levels.

Associated with each constraining factor or influcence is a constraint function that determines how the various activities are restricted by that factor and a limitation coefficient that describes how limiting the particular constraint is. The latter are inherited from the past and are fixed for the time being. Their effective limitedness, however, can be reduced by the choice of certain activities. Machine capacities inherited from the past can be augmented by the purchase of new machines. The supply of money available for investment can be augmented by borrowing. However, investment in a given year is limited by reinvestment funds, and borrowing is limited by lenders' credit-rationing rules. Hence choices that reduce the effective restriction on other activities in any one year are in their turn bounded by limitations of their own. Adaptation in response to feedback from past decisions and the external environment has the effect of modifying the feasible region from one period to the next. For a given period it is fixed.

Faced with uncertainty as they contemplate change from existing patterns of behavior, decision-makers ususally limit the consideration of alternatives to a local search of those in a neighborhood of current practice. The willingness to depart from current practice, that is, the extent of the region searched may depend on experience and on the behavior of other agents. Thus, adaptation to current economic opportunity may be more or less flexible. The set of alternatives that may be considered at a given time is called the zone of flexible response. Such zones depend on experience and imitation. This dependence means that economizing is more or less cautious and the degree of flexibility changes in response to feedback.

Finally, the choice within the constraints determined by technology, resource availability and by the willingness to be flexible in responding to opportunity is directed by various goals perhaps arranged according to some (perhaps temporary) hierarchy or priority order. A first goal dominates comparison of alternatives until a satisfactory solution is obtained according to this goal; then a less important goal is used to choose among the alternatives satisfying the higher order goal, and so on, until a single choice is reached.

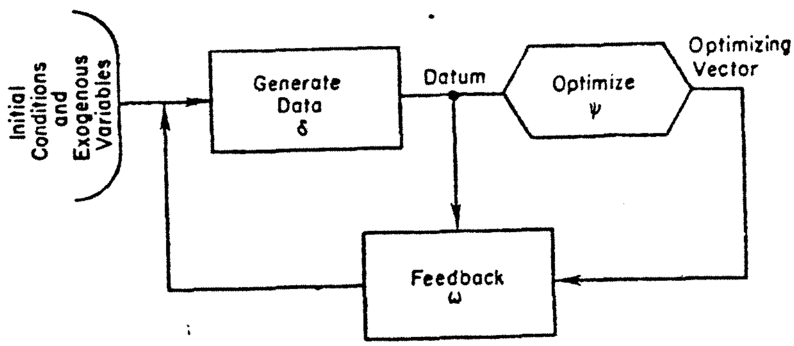
To summarize, adaptive economizing involves optimizing a sequence of simplified, constrained choice problems according to a hierarchy of objectives in which choice is restricted not only by objective reasource constraints but also by subjective constraints that have the effect of confining behavior to a region of flexible response in the neighborhood of current operating conditions. The constraints and objectives are adjusted period to period in response to experience and to feedback from the environment.

4 RECURSIVE PROGRAMMING MODELS

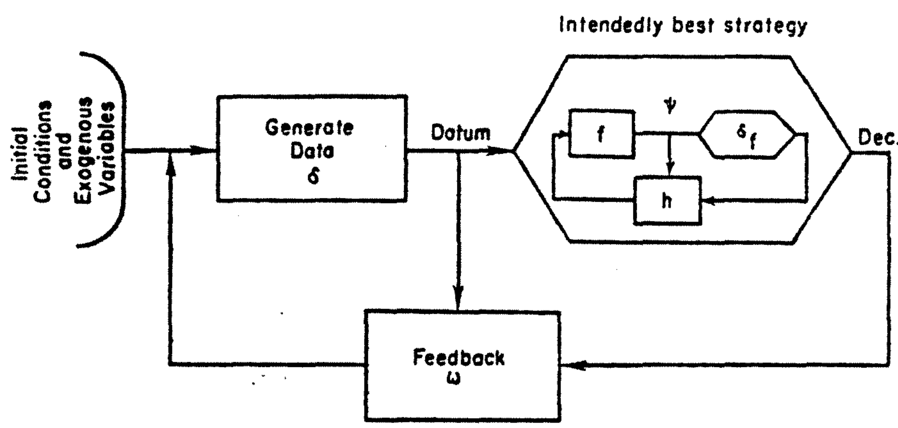
The mathematical analog of adaptive economizing is the recursive programming model. Such models provide a formal, computationally convenient means for representing boundedly rational planning. While such models can incorporate far-sighted planning over a finite (or infinte) horizon they distinguish explicitly between the agents approximate and imperfect knowledge of the environment from its true structure. By imbedding the model of adaptive economizing in a model of the "true" environment it is possible to perform simulation experiments of a modeled representation of a real time process. See Figure 1.

The solution of such a model involves the values of the various activities from period to period. Typically, solutions involve nonlinear dynamics exhibiting changing modes of behavior, nonperiodic fluctuations and sensitivity to perturbations in initial conditions and parameter values. In addition, they exhibit changing sets of utilized activities and tight constraints. When these sets switch the variables and equations governing the evolution of the system switch, in effect bringing in a different set of causal structures and feedback loops.

Figure 1 Recursive programming models. From Day and Cigno (1978)



a. The recursive programming model.



b. Recursive strategic programming model of intendedly optimal behavior (rolling plans or planning revision).

These structures are called phase structures. A given model may contain a single regime or a very large set of potential phases. The result is not only an endogenous theory of changing modes, as in any nonlinear dynamic system, but also an endogenous theory of structural evolution based on explicit economizing behavior.

The demand for any particular resource, including labor, is derived in such a model from the various production and investment activity levels which depend on all of the constraints and objective function coefficients; these in turn depend on the past activity levels and past states of the environment. In this way one derives a dynamic demand for inputs that incorporates technological change as well as the usual economic variables.

5 APPLICATIONS

Various authors have constructed and tested resursive programming models of agricultural and industrial devleopment. See Day and Cigno (1978) and Day and Singh (1977). In an early example Day (1967) one of us showed how investment in new technology influenced the utilization of labor in agriculture and patterns of rural-urban migration. In essence the process involved a labor market disequilibrium induced by labor saving technology and which precipitated intersectoral flows of people.

Analogous results could be derived from the industrial models described in Day and Cigno (1978, ch.4). In these models the structure of production is represented by sets of activities that make possible alternative production processes.

The path from "primary" inputs to "final" product usually involves a sequence of conversions which constitute a production process, a series of discrete steps during each of which a given task is performed. A task performed by a specific transformer or machine is an operation. The transformers use various inputs such as labor, fuel, lubricants, etc. The output of the operation is an intermediate good ready for the next task or final good ready for storage or sale and shipment. The use of an operation in a given time period is an activity -Koopmans' "elemental atom of technology", its intensity is the activity level. These activity levels are the fundamental decision variables of the economic unit. A collection of alternative activities for producing a given intermediate product or final good is a stage of production. Most industries involve a variety of such production stages. Assuming linearity of each activity [Koopmans (1951)] the input-output structure is represented by vectors of input-output coefficients, and the sequence of activities by a technology matrix. Although individual activities possess fixed technical coefficients, alternative activities for given tasks allow for substitution and complementarity in the use of industry resources.

Innovations in production technology are accommodated by introducing new production and investment activities. New investment activities may represent construction of capacity in the new technology or conversion of existing capital equipment. Both categories represent capital-embodied technological change. Disembodied technological change, which leads to a gradual modification of technical coefficients, requires periodic updating of the input-output matrix. Diffusion of a given technique is described endogenously so that the entire model explains its dominance or lack of dominance over competing techniques.

Production planning is viewed as passing through four stages. First, data concerning input-output structures, production goals ,input supplies, behavioral rules, production costs, and annual investment charges are formulated. Second, feasible production goals are determined. Third, production-investment activity levels are planned that minimize production and investment costs, where the latter are determined by a cash-flow, payback criterion. Fourth, given estimated expanded capacity, estimated actual production is performed at minimum variable cost leading to a final model estimate of production activity levels.

The heart of the model is the third stage in which investment levels are determined. Investment is motivated by two distinct considerations: (i) capacity expansion to meet anticipated sales and (ii) replacement of existing plant and equipment by technologically superior alternative capital goods to lower production costs. Because of this second consideration excess capacity can be generated even in the face of stable or declining demand for final production for, as long as an investment will "pay for itself" by reducing production costs to pay back the sacrified capital in a sufficient period of time (the payback period), investment will occur.

However, the rate of investment in our models is constrained, first by adjustment bounds that reflect hedging against uncertainties, second by adoption constraints that reflect learning, and third by abandonment constraints that reflect inertia in departing from established practice. These constraints determine the zone of flexible response to current economic opportunity. Because of these constraints and because of the behavioral feedback relations, investment may continue in obsolescent capacity until the willing expansion in new technology increases enough. Likewise, abandonment of obsolescent or obsolete technology may be limited by this reluctance to "plunge" in the latest techniques, as well as by an inherent inertia in the planning process. Because the model incorporates all these considerations it will generate capital capacity trajectories with overlapping, wave-like appearances. Indeed, for a given capital good the phase diagram of capacity would appear like that shown in Figure 2, where it is assumed that the sales forecast is constant over time. If the good is profitable, it follows the adaption constraint for a time, until the adjustment rule becomes tight.

Eventually, as capacity expands in superior techniques, capacity change will fall within the shaded area, perhaps increasing for a time, then declining and finally, declining at a maximal rate determined by depreciation or the production abandonment constraints.

Our models thus simulate the non-linear patterns of diffusion, the superimposed waves of "creative destruction" so characteristic of industrial development. Indeed, such patterns have been observed so often that they have been called "the Law of Industrial Growth" [Schmookler (1965)]. And idealized history generated by one of our models is shown in Figure 3 which approximates the path of U.S. open hearth steel capacity since the turn of the century.

Generally speaking when one technology is replacing another, when the old one has become obsolescent or obsolete, the demand for inputs will change, even if production levels are constant, because the different technologies have different imput requirements. Typically, the demand for some grades of labor will decline so much that even if demand is increasing for labor with other skills and qualifications the aggregate effect is an overall reduction in employment. This is why a growth in output or a growth in leasure must usually accompany technological development if full employment is maintained.

Figure 2 Phase diagram for an individual capital good with a constraint sales forecast.
The trajectory of capacity must lie within the convex, shaded region.
Source: Day and Nelson (1973)

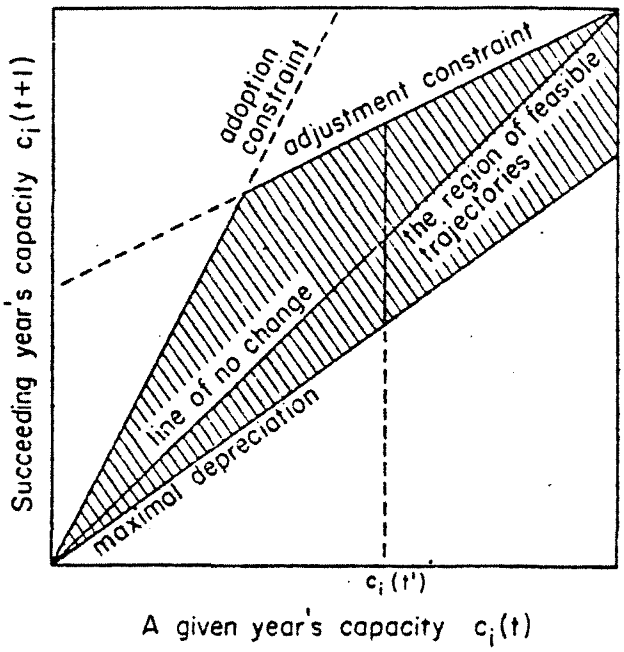
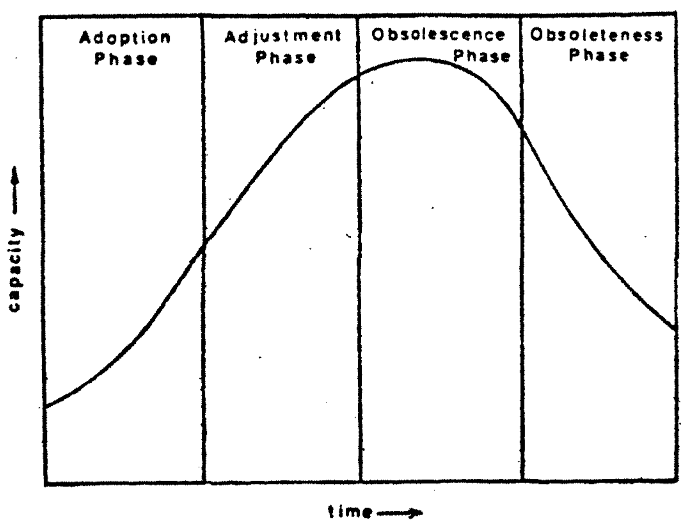


Figure 3 A typical capital good trajectory generated by one of the RP models.
Source: Day and Nelson (1973).



6 A NEW RP MODEL EMPHASIZING FINANCIAL FLOWS

There are several dimensions of firm behavior which these earlier models of industrial development did not elaborate upon. First is the financial-budgeting procedures used by firms to acquire new capital and maintain an adequate cash flow on a year to year basis. A second limitation involves construction lead times and the specification of cost coefficients in the investment planning criterion. As inflation and rising prices for primary materials and labor occurs, the inclusion of factor price escalation in the cost coefficients may influence the current choice of technology. Third, due to the potential for errors in expectations, and, hence current period plans, it is necessary to consider the use of disequilibrium butter stock mechanisms and rules of adjustment behavior.

The second author is now developing a new RP model that accomodates these three considerations. The central features are represented in Figures 4 and 5.

The general planning sequence of the firm, see Figure 5, is embedded into the market-environment feedback process of Figure 4, providing a modeled representation of a real time process. With this a recursive programming model, the dynamics of an agent-environment feedback process can be simulated.

Figure 4 Adaptive economizing model of a firm with market feedback

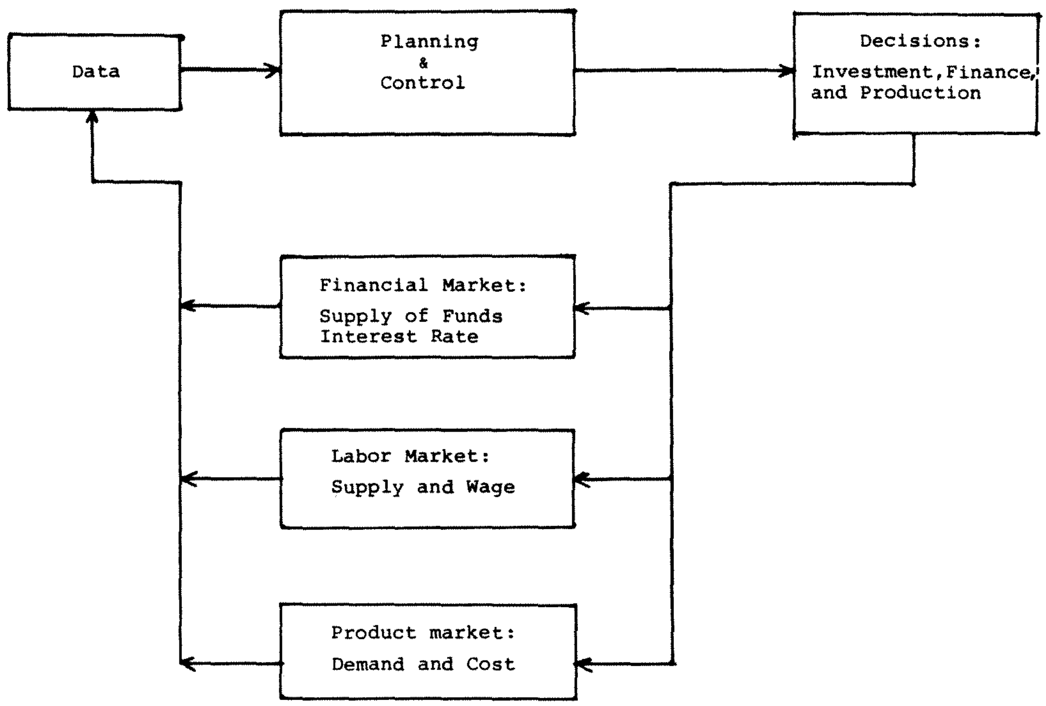
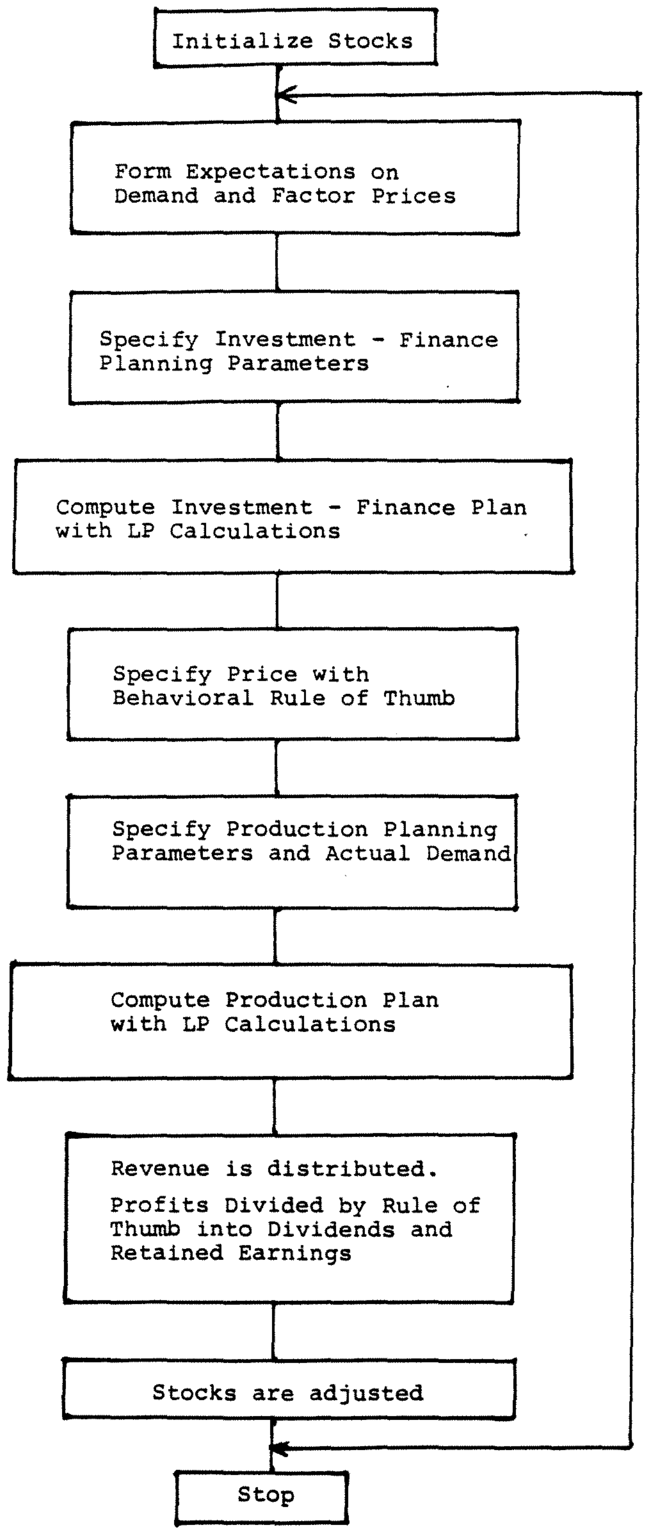


Figure 5 Firm investment-production planning model



Rather than going into the details of model structure, a simple illustration of how the choice of technology depends on anticipated factor prices and the financial situation of the firm.

Assume a firm has a given stock of financial and physical capital and confronts a growing demand. The firm has a choice of investing in two types of technology, one capital intensive and the other fuel-labor intensive. Assume the capital intensive technology has the lower levelized annual cost but requires a larger amount of external financing. Assume at first the firm's financial position is below debt capacity. As demand grows and more debt is issued the firm may reach its debt capacity requiring a more expensive source of financing. This comprises a switch in the phase of activity. Whether a shift to the fuel-labor intensive technology is the optimal investment strategy given the switch in financial policy can be determined from a phase switching rule as derived from the Kuhn-Tucker conditions. The phase switching rule in terms of the cost coefficients for the two technologies and the cost of financing before and after the switch is

$$\alpha_1 \leq \frac{CP_1 - CP_2}{CK_1 - CK_2} \leq \alpha_2$$

where

(CP_1, CK_1): fuel-labor intensive production and capital cost coefficients

(CP_2, CK_2): capital intensive production and capital cost coefficients

α_1, α_2: parameters which depend on the cost of financing before and after the phase switch, respectively, and a common economic life of the technologies.

When this inequality holds then the optimal investment strategy is to shift from capital intensive to fuel-labor intensive technology when the phase shifts to more expensive external financing. With these parameters changing from period to period due to changing expectations on prices the impact of a change in the cost of financing will vary. For instance, if the expected wage rate is higher, then cP_1 will increase relative to cP_2. If a technological change in the capital intensive technology occurs reducing cost then cK_2 will decrease relative to cK_1. A change in the cost of financing will effect α_1 and α_2. From period to period, the choice of capital technology may change in response to market feedback and innovation, leading to complex dynamics of derived labor demand. Through if - then simulation experiments a more elaborate picture of the potential for labor demand dynamics may be illustrated.

7 MARKETS IN DISEQUILIBRIUM

Equilibrium is a powerful assumption in economic analysis allowing considerable simplification in the representation of economic phenomena. Setting supply equal to demand is a mathematical convenience, but can we just assume equilibrium? Certainly considerable insight has been gained by doing so. But as suggested in the correspondence principle, 'for an equilibrium analysis one must show not only stability but also rapid convergence, otherwise the study of transient behavior, where the processes of adjustment are determined endogenously by the behavior of agents and the way markets are organized, is of paramount importance' [Fisher (1983, p. 11); also Samuelson (1948)].

With errors in expectations the plans of agents need not be consistent in the markets, and, hence there is unanticipated market feedback and spillover effects among markets, stimulating disequilibrium adjustment behavior. This potential for disequilibrium is reinforced by the bounded rationality of agents, who, having limited foresight are not able to balance adequately the short-run and long-run implications of behavior. Thus, what appears to be optimal in the short run may have a disequilibrating impact in the long run.

In this section we discuss how to extend the adaptive economizing model of firm planning and adjustment behavior to one which captures the essential ingredients of disequilibrium. A firm's capital-investment and labor demand response to labor and capital-finance market feedback provides a good example for investigating how the dynamics of adjustment to exogenous technological change need not lead to an equilibrium.

Firm investment and production plans, and derived labor demand, need not be consistent with labor supply and supply of financial funds, given real wages and the rate of interest, leading to excess supply or demands. Traditional equilibrium theories assume stability of the excess supply and demand adjustment processes which may well be valid for the implicitly assumed institutional structure of markets and agent response [Fisher (1983)].

Under existing institutional structure of markets and the bounded rationality of agents, there is no a priori grounds for assuming stability. Supply, demand, and price adjustments in the different markets need not be consistent in the sense of converging to a full employment equilibrium. The wage-profit distribution and the feedback effect on capital expansion, and, hence future labor demand need not be consistent with labor supply, leaving the economy in a dynamic disequilibrium adjustment process, where there may arise a disequilibrium unemployment above and beyond frictional or search levels.

For instance, elements of real market situations involve real wages and labor supply which are predominantly determined by such forces, autonomous to the economic process, as demographic trends and social-cultural aspirations for real relative income [Malinvaud (1982, 1984); Hicks (1977); Kaldor (1976)]. Consequently, demand and supply need not be equal at existing real wages. Similarly the required rate of return and the supply of funds in the financial market will not consistent with the profit rate from capital expansion necessary to provide adequate jobs given the supply of labor.

In developing a disequilibrium approach to economic analysis it is of interest to take a closer look at how the firm-market feedback process has evolved as a self-organizing system, endogenously modifying the institutional structure of resource allocation. Two factors instigating such structural change are technological and organizational innovation.

The changing capital technology, new energy suplies, and modes of transportation of the early 1900s permitted high volume production, mass marketing, and standardization of product price and quality which has promoted change in the internal structure of firms and the forms of contractual arrangements for transactions. Most noticeable have been horizontal and vertical integration of production [Williamson (1981); Hicks (1977)]. With boundedly rational management, organizational innovation was necessary to govern the growing modern corporation. One outcome is the multidivision firm with a hierarchical planning and budgeting procedure.

As these developments were occurring in the organization of production, labor market institutions were changing as well. Trade unions were rising in power, promoting the share of labor in the division of income. Change in financial markets also occurred as the limited liability of firm owners altered the procedure of financing capital. A conflict between wages and profits did not arise until the 1970's when the growth in productivity declined.

Given the structure of the modern firm and markets, several new elements must be introduced into the adaptive economizing representation of firm behavior and market feedback, relative to the temporary equilibrium framework for a disequilibrium perspective.

First, a distinction between plans and realized activities must be made, for there will be errors in expectations, and a given plan may not be practicable. The firm will therefore devise disequilibrium mechanisms to buffer the impact of these discrepancies. For instance, there is a precautionary maintenance of such buffer stocks as inventory-order backlog on the commodity market and working capital-financial liquidity on the financial market.

Second, there is a feedback response to a maladjustment of stocks and flows. Due to unrealized plans the firm will initiate an adjustment process. Flexprice and fixprice adjustment are two extreme, pure cases, suggested by Hicks and considered in the literature. According to various factors, such as industrial structure, demand elasticity, inventory cost, and production technology, a firm will use some combination of price, production, and inventory-order backlog adjustment rules on the commodity markets, the use of which will also depend on the state of the macroeconomy. The use of these different adjustment rules will have different implications for labor demand which is derived from production activities.

Third, a more detailed representation of the internal structure and planning process of a firm is necessary. A natural division in firm structure is based on the length of planning horizon. First there is the planning of production and factor demand given capital stocks. Second is the planning of capital investment which will involve a planning horizon long enough to account for construction lead times and economic life or repayment period of capital. A third department serves as a controling agency using a financial-budgeting procedure.

A final element in need of consideration is the contractual arrangements for transactions. In recognition that agreements are incomplete and there is pressure to maintain ongoing relations, the nature of contracts will have built-in flexibility over what transactions are promised at what price and over what period of time. These factors may be incorporated into the constraint set on the firm [Williamson (1981)].

Currently the details of a firm model with these disequilibrium features is being developed. Once completed it will be possible to distinguish different types of firm-sectors and experiment with the dynamics of multisector interactions with transactions in disequilibrium. Upon introducing labor saving technological change in one sector it will be possible to simulate the impact on derived labor demand.

8 A FINAL COMMENT

We have summarized some models of adaptive economizing and have described how they can shed light on embodied technological change and the derived demand for labor. We have also proposed a more general framework for a multisectoral model of adaptive economizing in intermarket disequilibrium. Such studies are by nature more complicated than models of optimal intertemporal equilibrium and contain more structural ingredients than conventional econometric models of labor demand based on production function and equilibrium assumptions about productivity, profits and wages. Consequently, they are more costly in research and computational input and pose special problems for analysis and interpretations.

Becuase of these modeling costs it is doubtful if the adaptive economics approach could replace conventional methodology. It is probable that we must continue to rely on the powerfully simplifying assumptions of economic equilibrium and econometric technique. None the less, it seems to us that far more research effort should be direct to the adaptive economics approach which, though more complicated, allows for incorporation of strategic details of production technology and of real economic behavior. Without attention to those strategic details it seems doubtful to us that a real understanding of how labor markets and, indeed, the economy as a whole work over time. And without this improved understanding it seems unlikely that better policies for enhancing human welfare can be developed for the rampant "creative destruction" of evolving market economies.

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