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THE DYNAMICS OF SUPPLY AND ECONOMIC GROWTH – How industrial knowledge accumulation drives a path dependent economic process

by

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THE DYNAMICS OF SUPPLY AND ECONOMIC GROWTH
- how industrial knowledge accumulation drives a path-dependent economic process

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Knowledge . . . occupies a slum dwelling in the town of economics. Mostly it is ignored. The best technology is assumed to be known. The relationship of commodities to consumer preferences is a datum. And one of the information producing industries, advertising, is treated with a hostility that economists normally reserve for tariffs or monopolists."

George J. Stigler (1961)

1 FROM ASSUMPTION TO DYNAMICS

While the supply process has never really managed to conquer a prominent position in economic theory, growth theory and many national policy programs have relied heavily on its continued superb performance in the Western industrial nations. Assumption rather than analysis has characterized the theory of economic growth.

In fact, so strong has been the assumption of a "solar fueled" exogenous supply process that modern supply side economists have committed themselves to the belief that when constraints to economic growth are removed, economic growth unexplained will simply be released.

How can such strong beliefs in exogenous economic growth originate and persist to the extent that its explanation has been neglected in core economic theory?

This paper argues that standard equilibrium theory offers no explanation of economic growth. The question is whether a theory of economic growth is at all possible and meaningful. If policy advice is the objective of growth theory, the answer turns out to be affirmative. The analysis should then focus on how the creation, diffusion and use of industrial competence occur in production. This will make information processing a dominant production activity in what I call the *experimentally organized economy* (explained below), and the efficient creation, allocation and use of knowledge the prime explanation of economic growth.

Carlsson, B. (ed.) 1989, Industrial Dynamics: New Issues in Industrial Economics. Boston: Kluwer Academic Publishers.

As we shall see, there are three "essential building blocks in growth theory": (1) *scale*, (2) *unpredictable entry and exit* of technology (dynamics) and (3) *globalization of production*.

Economies of scale manifest themselves in many ways and can be viewed empirically as a form of technical change, or synergy effects of reorganization. On this point I follow Young's (1928) argument that increasing returns "in the small" essentially depend on the progressive division and specialization of industries. In my interpretation this whole process depends on the introduction of new technology or -- more generally -- industrial knowledge. Increased "knowledge" input enhances the productivity of other factor inputs. The most important knowledge input is the general organizing competence that exercises a leverage on all factor inputs and manifests itself as total factor productivity growth, scale economies or technical change according to the specification of the production function. Hence, economies of scale simply become one way of formulating the output effects of technical change. The unpredictable innovator/entrepreneur creates new scale economies through the application of scarce local knowledge and his (her) willingness to take risks. If the scale effects compete favorably with the efficiency by which the market coordinates resources, the firm grows.

The creation of heterogeneous and scarce local industrial knowledge through research and experimentation at the micro level bounds the economy from above, but its creation becomes the key investment process in a modern industrial economy. Hence, the theory of the firm has to be a theory of how knowledge or competence is applied to create coordination and synergy effects ("scale") that are superior to market coordination. Therefore, the notion of the firm as a filter that upgrades and allocates talented people, ideas and projects becomes useful.

The supplementary notion is that the theory of economic growth has to be a micro-based macro theory with the technology of information processing explicitly modeled. Using this approach we will find that the technology of information processing of the economy is embodied in its organization structure.

Economies of scale, the *first* building block, involve upgrading of economic activities through increased specialization, increasing the demands on coordination. In this formulation, scale effects originate in the use of technological information (upgrading of economic activities) and of economic information through markets or hierarchies.

The *second* building block, free entry and exit of technology, emphasizes the openness of the economy and the importance of free competition, including the difficulties of coordination associated with quality change, uncertainty (unmeasurability) and variability in the number of players (dynamic competition). Unrestricted flow of technology removes the possibility of converting uncertainty into calculable, micro-level risks, as in the rational expectations assumption or in expected utility theory, or in other fabrications needed to convert dynamic theory into static general equilibrium mathematics (Eliasson 1989b).

The *third* building block, internationalization, introduces the global business opportunity set. Together with limited knowledge on the part of the entrepreneur, this is enough to establish (a) unpredictability of microeconomic change under the open market regime introduced by category (2) and (b) to introduce a scale factor in international knowledge monitoring; "the international market as a school". The knowledge factor, not market size or raw material resources, now becomes the limiting factor behind economic growth. (Information processing in the unpredictable, experimental economy becomes the dominant production activity.) Hence, the organization of upgrading (technology), coordination and knowledge transfer ("schooling") activities becomes a major technology in itself, and the prime concern of this paper.

The paper is organized in the following way. Having presented the three building blocks of growth theory, we introduce in section 2 the modern firm as an information processor that filters people, ideas and projects to produce quality of output rather than volumes of output and that operates on knowledge capital. The conclusion is that we measure neither this important input nor the important quality output well. This leaves the basic structure of the supply process unspecified. We cannot even define the most important investment, knowledge accumulation. We try to remedy this situation by studying how the "production of knowledge" is organized (in section 3). In order to understand the dynamics of the market allocation process, including knowledge allocation and the returns to talent, we have to carry on our argument within a complete economic system with demand and price feedback, such that the economic returns to knowledge are properly accounted for. Hence, the final section 4 includes a sketch of the appropriate dynamic micro-macro theory to accommodate that.

1.1 Scale or Learning Effect

Empirical studies have long supported the existence of economies of scale at all levels of aggregation. At the macro level, scale economies can be parameterized in the production function. Increasing returns to scale is, however, a static concept of scale that does not explain what we are looking for. At the micro level, scale becomes synonymous with what is sometimes called synergy effects. However, economies of scale pose problems in received general equilibrium theory. They are normally inconsistent with internal solutions, or the existence of traditional static equilibrium properties. Scale factors cause corner solutions in the form of concentration of all production to a few, or to one producer. Part of the problem has to do with the fact that the general equilibrium model is only a statement of conditions for equilibrium. It offers no explanation of the convergence of the economic process to a possible equilibrium. Hence, it is also incapable of dealing with the dynamics of the accumulation of knowledge, or the market concentration process. Recent developments, such as contestable market theory, the "new" theory of international trade or similar approaches in which equilibrium conditions are derived based on competition among a small number of producers may offer a way out of static equilibrium economics, even though I am not convinced.[1]

The static nature of equilibrium-based theory unfortunately removes the core branch of economics from application to growth problems. Furthermore, the notion of scale as it appears in macro production function analysis is much too crude to be useful as an explanation. Economies of scale are linked to innovative behavior that leads to specialization of work within firms and between firms. What Schumpeter called new business combinations emerge as a result of innovative coordination of activities that result in scale or synergy effects. The merger of Hughes Aircraft and GM, Electrolux and White Consolidated Industries, and the reorganization of production flows within a Philips plant are all intended to create such effects. They are all based on a combination of knowledge and experimentation that sometimes succeeds, but often fails.

Hence innovative activity, dynamic market coordination, and organizational change together provide the driving forces behind economic growth. However, without the steady infusion of industrial knowledge, the growth process grinds to a halt. In order to understand this, one needs a dynamic, micro-based macro theory, in which the accumulation of (learning) and use of knowledge are explicit. In such a theory it is almost impossible to distinguish between scale economies and technical change. General equilibrium analysis currently offers no way of representing these factors. Adam Smith (1776), however, did not neglect them in his original discussion of economic specialization and coordination where scale economies in the small -- through increased specialization -- was the moving force behind the "wealth of industrial nations". The idea that the "progressive division and specialization of industries is an essential part of the process by which increasing returns are realized" was adopted by Young (1928).[2] It makes increasing returns to scale at the macro economic level partly a matter of economic organization, a notion that I will make use of.

Schumpeter in his *Theory of Economic Development* (1912) thought that entrepreneurial innovative activity exploiting economies of scale at the micro level was essentially a random, unpredictable process. Thirty years later, Schumpeter in *Capitalism, Socialism and Democracy* (1942) observed the emergence of giant corporations embodying, as he thought, the organizational skills to routinize the innovative activity, hence providing the foundation for a continued presence of positive economies of scale based on unique knowledge. The old Schumpeter of 1942 would generate a centrally planned economy on the model of the classical general equilibrium model. Was Schumpeter of 1942 wrong, or is the classical model wrong? The answer determines our way of looking at things economically and makes empirical studies of innovation a priority concern in economic research.

1.2 The Birth and Death of Firms

Jagrén (1986) followed a random sample of 115 firms that existed in 1918 through the 1970s. Only 21 firms remained in 1981 -- the rest had either gone out of business or been acquired by other firms. The aggregate output of the remaining firms nevertheless had grown somewhat faster than the total Swedish manufacturing output. However, 19 of the remaining 21 firms had grown very slowly, if at all, throughout the period. They remained small in 1981. The total growth was explained by two mammoth corporations, Electrolux and Bofors. Obviously, a *selection process* had been at work during the 60-year period 1920-81. This selection process critically focuses on the returns to capital and the ability of the capital market not only to filter out the winners and forcing the low performers to exit, but also to make all potential winners participants in the game (the incentive problem).

Two critical notions emerge. What do entry and exit mean for competition compared to the general equilibrium model where neither entry nor exit, nor innovative behavior occurs? What kind of capital regulates the entry and exit processes? And how are rate of return requirements on that capital exercised? We will explain the outcome of this selection in terms of scale, industrial knowledge and competition. The key question is to what extent Jagrén's results can be generalized. Are they what one should expect from any random sample of firms selected some 50 to 100 years ago? Can the outcome be influenced by policies? If so, the nature of this selection process must be a prime element of any theory of economic growth.

1.3 Internationalization or Concentration

The size of the market, according to Adam Smith and Karl Marx, limits the exploitation of economies of scale and, hence, is the critical factor behind growth in capitalist economies. Jagrén's results appear to support this notion. The two firms that rise out of the remains of the original sample have both grown into giant producers by exploiting the enlarged market available through internationalization, allowing them to earn higher returns through increased specialization (see Eliasson 1987a).

If scale and increased specialization matter, internationalization has made it possible for small advanced economies like Sweden, Switzerland and the Netherlands (see Table 1) to overcome the market constraint and to create, nevertheless, very large and global business organizations. The consequence has been an extreme concentration of the production of the entire economy to a few giant firms (see Table 2 and Figure 1 and Eliasson 1986b).

Globalization has made possible enormous production flow efficiencies due to scale. At the same time an element of vulnerability, or instability, of the national economy has entered due to the concentration of production to a few players. If one firm -- like Volvo in Sweden -- experiences significant problems, the consequences rock the entire industrial sector of the nation. However, while relative size bolsters productivity and national wealth and makes the nation vulnerable to international competition, size and global reach also provide insurance against falling behind in competition. Once a firm has become a global performer in product and process technology and gained a significant share of the

Table 1 Average size of the five largest firms in 1984

	Number of employees of corporate group (thousands)						
	Netherlands	Sweden	US[a]	UK[b]	West Germany	Japan	Switzerland
1972	121	51	451	219	195	-	70
1983/84	100	67	444	167	223	134	85

[a] These figures do not include the giant acquisitions of Zanussi and White Consolidated by Electrolux in 1986 and the merger of ASEA with Brown Boveri in 1987.

[b] Excluding Shell and Unilever.

Source: Eliasson, 1986b.

global market, it has also gained access to the global pool of industrial knowledge in its field, provided it is properly organized to tap that knowledge (Eliasson 1987a, 1988b). It is constantly rivaled by the best competitors, and its size ensures the resources to monitor the pool of knowledge. The firm is constantly learning. The outcome depends on how well this learning process is organized.

Table 2 The share in domestic manufacturing employment of the largest manufacturing firms: global firm employment in percent of domestic manufacturing employment 1983

	Sweden	US[a]	UK[b]	Switzer-land	Japan	West Germany	Canada	France
5 largest	26.1	7.9	10.6	53.7	3.4	10.8	11.8	11.5
10 largest	36.2	11.2	16.8	73.2	5.2	16.5	16.7	17.1
20 largest	46.4	15.3	25.5		7.2	21.6		
40 largest	57.0	21.4						

[a] 1984. The number for the US may appear large. The reasons are that the largest US manufacturing firms -as in Sweden and Switzerland- are very internationalized and that US manufacturing employment in percent of total employment is relatively low.

[b] Excluding Shell and Unilever.

Source: Eliasson, 1986b.

1.4 The Scarce Knowledge Capital -- the Missing Link

The flow efficiency of a modern firm is not that of a steel plant that can deliver increasing volumes of steel to global markets at diminishing unit costs, by expanding output by more fully utilizing the existing plant or by enlarging it. The modern firm does much more than manufacture goods. It develops, manufactures, markets and distributes products. The emphasis is on internal service production, adding quality to output volume. Competitiveness in global markets is defined by the ability to innovate products and to coordinate the entire production process efficiently. This is predominantly an information-using knowledge machine at work. The economies of scale originate in the ability to put a unique body of knowledge to work over a large total production space.[3] Hence, learning effects are really the results of improved technology that in turn reflect the application of knowledge, and attention should be focused on the nature of knowledge accumulation through research, experimentation and knowledge transfer.

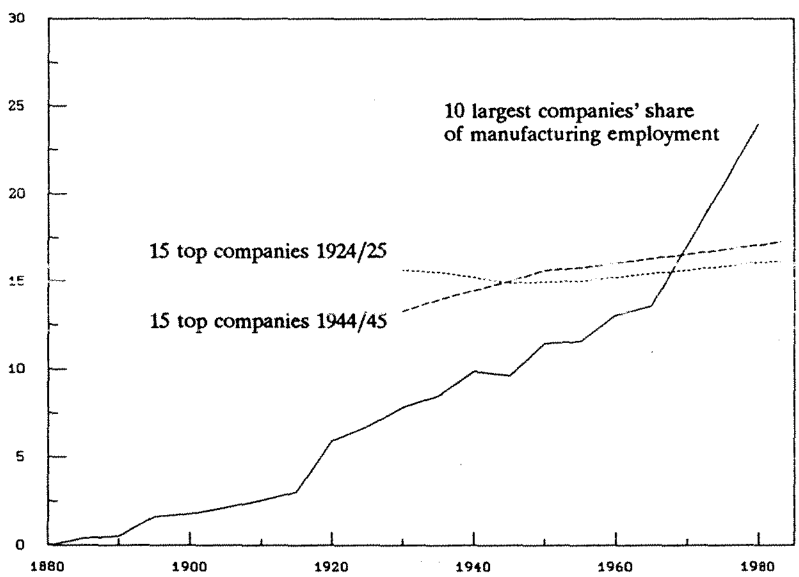
1.5 Dynamic market feedback

What is it that keeps market concentration from continually increasing as suggested by static general equilibrium theory, as firms acquire superior organization for knowledge accumulation, each economy winding up with only one or a few producers? To understand the dynamics of supply or long-term capacity growth of an economy, this question has to be satisfactorily answered.

To do that, we need a general theory of dynamic (monopolistic) competition that allows full feedback through both demand and prices, in which also the time dimension of price feedback is made explicit.

Temporary rents from innovative behavior that create economies of scale constitute the moving force behind capacity growth of an economy. *Dynamic competition* through innovations is the factor that closes the economic system and controls the concentration of value or wealth in the economy. To understand this, all factors have to be brought together in a consistent intellectual framework -- a *micro-to- macro theory of economic growth* . This analysis concludes the paper in section 4.

Figure 1 The 10 largest companies' share of total Swedish manufacturing employment, 1880-1983



Source: IUI.

2 THE TECHNOLOGY ELEMENTS OF A KNOWLEDGE-BASED GROWTH THEORY

This section introduces the modern firm as a knowledge- based information processor that upgrades the quality of output (technological competition) and coordinates various specialized activities through the application of competence acquired through successful competitive performance in markets.

2.1 The Knowledge Base of Economic Growth

A theory of long-term economic growth is concerned with the technological factors that raise the capacity to supply goods and services. Demand feedback and coordination through the price system become part of the supply problem. Rates of return and the competitiveness of firms are not independent of demand and prices. This suggests that *in long-term dynamics, demand and supply should not be treated as theoretically separated.* We first discuss the nature of innovations and production organization that determines how economies of scale or technology in the modern firm operate. After that we return to the coordination aspect under the heading of micro-macro economics. Production in the modern firm, being very service intensive, is best characterized as advanced, knowledge-based information processing. The accumulation and application of unique and scarce *knowledge* capital become the focal point of a theory of economic growth. Hence, the following factors become the key elements of a growth theory.

Table 3 The four elements of economic activity

(1) *Opportunities* (the creation of new technology)

(2 *Coordination* through markets (competition) and hierarchies (management)

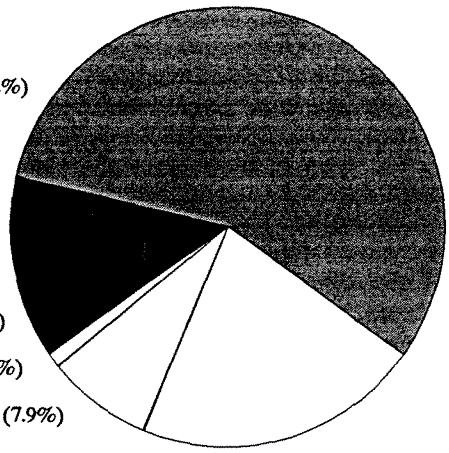
(3) *Filtering* of people, ideas and projects

(4) *Learning* (education and knowledge transfer)

Source: Eliasson, 1987d, p. 12.

I use this somewhat unusual classification because the modern type firms that push the advanced industrial economies forward allocate the bulk of their resources on various forms of *information processing* oriented towards the *upgrading of product quality* through the use of technical information (product development), or through advanced marketing techniques. Managing the requisite knowledge capital profitably requires an elaborate accumulation of knowledge which has to be an integrated part of ongoing production and investment activities (next section). We do not have data on the extent of all these activities. We only know that they together use up almost all resources of production. Table 3 and Figure 2 give indications of the relative magnitudes of some of these resources. A significant part of productivity advance, furthermore, depends on access to the international pool of industrial knowledge and the ability to exploit that knowledge in local production. Here the multinational firm obviously has a competitive advantage (see further Eliasson 1987d, 1988b).

Figure 2 Distribution of labor cost on various functions in large Swedish manufacturing corporations, 1982



Source: Eliasson, Carlsson, Deiaco, Lindberg & Pousette, 1986, p. 204.

2.2 The Quality Factor (the Creation of New Technology or Technology Upgrading)

The Marxist notion -- originally Adam Smith's idea -- of unlimited production opportunities but limited markets has so far been proven wrong, if only in the sense of being premature. The globalization of the world economy has lifted the ceiling. A number of large international corporations certainly strive to conquer world markets by acquiring competing firms. The imperialistic drives of industrial nations to expand the markets of their producers linger on in many economic policies. Trade liberalization has, of course, played an important role. However, most of the globalization appears to have been endogenous without the intervention of political institutions.

We still hear Marxist notions that the effects of trade liberalization have now been exploited and that stagnation tendencies will soon set in. These notions have been common in the discussion of the economic effects of the European Common Market.

The notion of an upper, physical limit to economic growth due to the limited absorption capacity of markets for all practical purposes vanishes if we allow the modern industrial corporation to enter the scene.

The modern industrial corporation allocates the bulk of its resources to upgrading the quality of its products rather than expanding their volume. There is no limit to the capacity to consume quality, like better and better cars, wines or -- for that matter -- books. The limits are instead set by the firms' unique knowledge to compete with product quality in world markets.

As a consequence, the modern firm invests heavily in knowledge capital oriented towards product competition in world markets. Table 4 indicates the relative size of two such "intangible" investment items; technological product development and marketing. The table includes only routinized spending on these accounts classified in the cost accounts of the firms. It ignores many small, hardly measurable improvements that occur constantly, their costs being mixed with general production costs. The table also excludes the two perhaps most important knowledge investments in the modern firm, namely organizational know-how and internal education and knowledge transfer. The administrative know-how to operate huge and complex industrial groups successfully over long periods of time is something that distinguishes the advanced industrial nations from industrial nations in general. Such knowledge takes decades or centuries to build and should be characterized as part of the industrial tradition (Eliasson 1988c). Internal, job-related education and knowledge transfer is part of the tradition. Practically nothing quantitative is known about the extent of such educational activities.[4] Scattered evidence suggests that in the large international corporations, "routinized" internal education and knowledge transfers of the measurable[5] class room type -- as distinguished from on-the-job training -- are of almost the same order or magnitude as R&D spending (Eliasson 1987d). And this (in itself) is only part of total "knowledge accumulation" in the modern firm. Most of the knowledge base of a business entity is tacit and embodied in people and the way they are organized as teams or as a whole firm. It is partly a matter of worker skills acquired in the form of experience during apprentice years and partly a matter of executive competence acquired during a career.

This learning is often lifelong, and indistinguishable from job performance. A varied job career is probably the most productive educational experience of an individual. Costs of such education are very difficult to measure. And they are only part of the total learning process, which includes the selection (hiring) of individuals, the organization of work teams and the trial and error experimentation that goes on at all levels within a modern firm engaged in technological competition. In fact, the bulk of R&D spending is devoted to imitation and experimentation -- in short learning and the accumulation of knowledge. Likewise, marketing is partly production in the sense of searching the markets for the right customers, but also a learning process, entering new markets, learning about new demands on product specification, and so on. Any firm trying out something of the above, without previous experience, will soon learn the large costs involved in acquiring that knowledge. One could easily define the cost accounts of a firm in such a way that most production activities are called "learning". We will not attempt any such classification here, only observe that "learning" is a costly and probably dominant activity in a modern industrial firm. IBM's venture into the office digital Switching (PBX) market is a good illustration. After an aborted in-house development of the technology, IBM tried a joint venture (with Mitec) that did not succeed. It then acquired Rolm, which again seems to have been less than a success. A new venture with Siemens appears to be a way out of a money-losing activity for IBM (*Business Week*, Dec. 26, 1988).

Neither long-term capacity growth nor short-term competitiveness of the modern industrial corporation can at all be understood without both a quantitative and a qualitative understanding of the knowledge-investment process at the micro level, within the firm organization.

Table 4 **Investments[a] in the 5 and the 37 largest Swedish manufacturing groups, 1978.**
Percent. Firms ranked by foreign employment

	The 5 largest groups		The 37 largest groups	
	Entire group	Foreign subsidiaries only	Entire group	Foreign subsidiaries only
R&D	25	10	21	6
Machinery and buildings	45	41	52	42
Marketing	30	49	27	52
TOTAL	100	100	100	100

[a] Investments in Marketing and R&D have been estimated from cost data.

Source: Eliasson, (1987b).

2.3 Complexity, Coordination and Competence

Economic progress can be seen as an evolution towards increasing exploitation of economies of scale and scope through further division of labor and, hence, as the coordination of increasingly complex production activities (Leijonhufvud 1986b). In our interpretation, the learning effects manifest themselves in the form of new product introductions and product quality upgrading. Specialization, the utilization of scale at various stages of production, and product quality upgrading require knowledge. For many reasons, that knowledge is only locally available and impossible or prohibitively costly to communicate. As a rule, this knowledge arises out of a risky search process in which the majority of trials fails. It is, hence, unpredictable and creates what I have called the experimental economy (Eliasson 1986c, 1987d). IBM's venture into the PBX market is again a good example.

The coordination of complex micro behavior in an experimentally organized economy also includes a *filtering* function. It involves the choice of organizational mode for coordination; i.e. hierarchies *vs.* the market, choice of economic system, choice of managerial system and internal organizational forms, etc. (item 3 in

Table 3). Such choices gradually emerge as a "tacit" organizational learning process, but make institutions endogenous in the sense of Åkerman (1950).[6]

This institutional framework controls short-term process coordination of the economy as well as the filtering of economic activities (entry, recombinations, exits). The filter not only affects the exit rate of bad performers. It also regulates the entry rate of potential winners. Since quality-based competition is not predictable, winners cannot be selected on *a priori* grounds but have to be tested in the market. An efficient filter minimizes the loss due to winners not making it to the market test and maximizes the exodus of bad trials. Hence, the failure rate will be high in an efficiently operating market economy. This takes us far beyond the slack or waste minimizing paradigm of static economic theory, which is probably a misleading tool for allocation analysis.

Both the design and the operation of "the filter" are knowledge-demanding activities. Product and process upgrading, as well as coordination and filtering of economic activities require sizeable inputs of resources, mostly in the form of human capital.

2.4 The Returns to Knowledge Capital

The sheer magnitude of total expenditures on knowledge makes it important to consider the returns to knowledge capital. Also, the high rate of return on knowledge capital makes it necessary to understand the accumulation and diffusion of industrial knowledge in order to comprehend the direction of change in manufacturing industry. The only visible signs of the skewed distribution of intangible industrial knowledge among firms are a persistently high market valuation of visible capital in some firms compared to other firms, e.g. pharmaceutical companies. The close association of organizational and management know-how to a small group of executive people (cf. the notion of embodied technical change) makes the valuation of other assets critically dependent on exits from and entry into that group. The influence of human-embodied organizational and management knowledge that exercises a leverage (a "scale" effect) over the entire corporation stretches all the way up to the "owners", providers and intermediators of fresh venture capital. Even though high q-values also reflect too many other factors, predominantly risk, to make them useful indicators in this context, this presentation of the rate of return problem of the modern, knowledge-based corporation throws us head on into the intellectual quagmire of capital theory.

The value of knowledge capital reflects the talent applied to the business operation. Proper returns to talent can only be reaped if talent holders are also holding contracted claims to that market value in proportion to the value of the knowledge that they contribute. Thus, the "distributional problem" associated with talent input is formidable. It is important to observe, however, that this is nothing new. The knowledge factor has always been decisive in generating market value. What is new is -- I repeat -- the in creasing importance of industrial knowledge, the rapidly increasing expenditures on accumulating and transferring it, and its economic vulnerability to competing knowledge accumulation elsewhere. This observation introduces a new dimension to knowledge capital. It cannot be treated simply as an asset. It is tacit, vested in the organization or a group of people in the organization. There is a technology associated with keeping the knowledge capital viable which also draws extensive resources (see further Eliasson 1988c).

The disturbing thing, however, is the observation that firm managements have only vague notions about the size (value) of their in-house knowledge capital and hence also about the returns to the same capital. This is in contrast to the elaborate capital accounts and decision routines maintained on hardware equipment and the apparent excess attention paid to what is measured compared to what is not measured.

Most knowledge investments (product development, marketing and internal education and knowledge transfer) are on current account. The implication is that the risk element in such investments is exaggerated and the returns to such investments underestimated.

2.5 Knowledge as a Scale Factor

Many studies have recognized the presence of economies of scale associated with one particular form of knowledge investment, namely R&D spending. R&D investment often needs large production volumes for costs to be recovered. The discussion of scale effects associated with technological development has mostly been phrased in terms of expanding markets through internationalization, i.e. through exports or through direct foreign investment in production.

The modern firm, however, is mostly concerned with customized product development for specialist markets. Since product development is becoming increasingly costly, an international marketing organization is needed to reach, inform and convince the right customers. Hence, marketing may be considered a form of product development. Strong synergy (scale) effects result from combining extensive R&D spending with large investments in international marketing. In fact, a proper balance between these two intangible capital items seems to be a necessary complement to a satisfactory return on process capital investments, the only type of capital activated in the accounts of firms (Eliasson 1985c). In addition, a global marketing organization that allows the firm to implement and to cash in immediately on new innovations, rather than sell licenses, or be imitated or cloned, appears to be the best protection from competition, if the firm is technologically competitive to begin with (Eliasson 1986d).

However, huge administered hierarchies, displaying orderly, "equilibrium" internal behavior appear not to be the best habitats for innovative behavior.

Capturing the complexity of this activity mathematically remains in the distant future. I will only discuss the problem here. The formal analysis closest at hand originates in production function analysis, and I will begin there. However, the neoclassical production function, even if formulated at the micro (firm) level, is not really what I have in mind as the ultimate formulation.

A *production function* describes the relation between input and output. However, production analysis conventionally approaches this relationship at a high level of aggregation. The theoretically unclear nature of capital has been the major reason for criticizing the notion of a production function, but also the fact that the most important explanations of production and productivity performance -- for instance organizational know-how-disappear with aggregation. This is, however, true already when aggregating capital up to the level of the firm or even the plant. What is needed, it is argued, is a sequential process description of production that captures also organizational change (the coordination factor). Carlsson (1980), using the Swedish micro-to-macro model, did that for establishments coordinated by markets and registered large organizational effects on macro productivity. To capture the impact on knowledge capital, a sequential process formulation, I argue, is necessary. This requires a micro-based macro model as an analytical tool.

In its simplest form the macro production function includes measures of capital and labor inputs weighted together by a power function and quite often a trend or shift factor, representing what has come (after Solow 1957) to be called disembodied technical change. In most early econometric applications, this time trend captured most of the growth in output and hence left growth largely unexplained. The parameterization of the production function allows us to specify whether economies of scale are present or not. If introduced at the micro level in a general equilibrium setting, anything above constant returns to scale causes trouble.

Solow (1959) elaborated his earlier analysis into the equally well-known vintage representation, where each vintage was a constant-returns-to-scale production function, which shifted upward for each vintage of best-practice introductions of new capital. Each vintage embodies a new superior technology. However, while some technical progress may be embodied in capital and labor to be captured by adjusting labor hours and capital stocks for quality change (Denison 1967), other improvements, again, occur through "outside" disembodied influence. The well-known Horndal effect (Lundberg 1961) and the "learning-by-doing" conjecture (Arrow 1962a) belong to this category. Intriligator (1965) brought the two approaches together. Jorgenson -Griliches (1967) almost managed to remove the shift-factor through quality corrections of aggregate factor inputs.

This is still not sufficient to capture the influence of knowledge on production growth. First, we have the actual process application of certain types of knowledge. The *upgrading* of quality of products through R&D spending has already been introduced as a separate factor of productivity by Nadiri (1978). We do the same for marketing capital. However, the *general organizing and innovative know-how (organization)* is still not accounted for. And this knowledge should operate directly as a leverage, or scale factor on total factor productivity. Let me try to introduce this factor in a standard production function framework. We are still thinking of the production function as a choice of technology.

Suppose, following Romer (1986, p. 1015), that the production function

$$Q = F(k_i, K, x_i)$$

is concave as a function of measured factor inputs k_i and x_i for any fixed value of K. K is the *level of general knowledge* which improves the productivity of all other factors. K is a capital good with an increasing marginal product. As long as there are diminishing returns in the activities that create K, the static general equilibrium model will have a finite solution.

Let us assume that the measured factor inputs are:

k_1 = Machinery and equipment capital
k_2 = Product-oriented R&D capital
k_3 = Marketing capital items,

x_i = Labor input, standard hours, allocated to the various capital items, $i = 1, 2, 3$

K is now the general, unmeasured knowledge base of the firm that is accumulated as part of the ongoing production process. In so far as some "tacit knowledge" has been compensated in the form of wages to other factors X_i, the K incorporates the general organizing knowledge needed to organize all other factors into a team, a firm. K has thereby been defined as the recipient of residual profits when all other factors have been paid. This is a capital input traditionally associated with the risk taking of owners, but it can very well be associated with all knowledge (competence) input of the owners (Eliasson 1988a). In so far as top-level managers hold stock in the company, they get paid two ways for their competence input: in the form of salaries and in the form of dividends and capital gains on company stock, if their competence contributions generate excess profits.[8]

The main point here is that the competence capital K generates increasing returns to all other factors of production of the company, but that it is a scarce resource whose production occurs at diminishing returns. The K factor input does not depreciate from use, as do other factor inputs.

It now only remains to show that K in fact has the "scale" or "leverage" properties we have postulated. To do that -- following Romer (1986) -- assume F( ) to be homogeneous of degree one as a function of (k_i, x_i) when K is constant. This is an insignificant further restriction. Given that, for any $\phi > 1$.

$$Q = F(\phi k_i, \phi K, \phi x_i) > F(\phi k_i, K, \phi x_i) = \phi F(\,).$$

F now exhibits increasing returns to scale in K. In the growth process of the firm, K is the know-how created, say from organizational learning that can be exploited by increasing the size of the firm.

The proof I have given has been in terms of the traditional, static production function. We can then use the term economies of scale, although economies of scope may be a better term. However, even this term is not the right one, since we are talking about an organizational learning process that creates tacit competence embodied in the organization and its people.

If both traditional economies of scale and unspecified embodied knowledge accumulation are present, the two cannot be econometrically separated. And if the tacit knowledge capital -- whatever it is -- is perfectly correlated with "scale", a prior scale formulation will reinterpret improvements in organizational competence as originating because of scale and vice versa. The acquisitions of Zanussi (Italy) and White Consolidated Industries (U.S.) by Swedish Electrolux provide a good illustration. Obviously the acquisitions enlarged the scale of Electrolux in physical terms. There should be mechanical scale benefits to exploit. However, the success of Electrolux over the years has to do with more than that in the sense that top management in other firms doing exactly the same thing would not necessarily have created the same successful results, because they lacked the particular experience the Electrolux management team had obtained over the years. Even though one can give several examples of pure, physical economies of scale with economic implications (e.g. the natural laws controlling electricity transmission, see Smith 1966), the notion of scale becomes the wrong concept if the exploitation of economies of scale requires technology, i.e. knowledge. The question, then, is how to represent the dominant competence input in the production process mathematically. The above production function representation, borrowed from Romer (1986), is a step in the right direction, but it does not take us out of the static neoclassical world, since it does not explain the accumulation of the competence. This has to be done simultaneously with the explanation of production if competence, or knowledge capital, is "tacit" and "learned" through participation in production. Then dynamics is created and a "path-dependent" economic process to which we now turn.

2.6 The Ultimate Dilemma -- the Path-Dependent Economy

Let us first "think micro" and ask whether it is reasonable to separate out all listed categories in the production function and whether factor quality can be separated from labor hours and capital inputs. Can all inputs be varied independently of each other? We can identify various capital items and labor hours both in marketing and in R&D spending. But they would not generate any output without the knowledge inputs. Knowledge becomes a dominant factor and has to be vested in humans, either directly through L, or indirectly (embodied) in capital equipment. So perhaps we can throw out labor hours and concentrate on knowledge capital? This is not possible for two reasons. There certainly exist goods production, product development and marketing of a routine character such that the increased application of standard labor time will expand production. Furthermore, this process occurs in a sequential manner. Hence, a "separable" production function for each stage of the production process would solve this problem. But then knowledge capital, labor hours, financial capital (inventories, "cash," etc.) and perhaps equipment (computers) to coordinate activities internally (administratively) would be needed. This coordination is costly and not necessarily stable as to its production specifications. Stability may occur at higher levels of aggregation, but then we lose sight of parts of *the use of costly knowledge to coordinate activities*.[9]

This problem of neoclassical production theory becomes insoluble if we allow one final, totally neglected item in production function analysis (see Pelikan 1986), namely the use of knowledge (1) to coordinate activities, including the *choice and allocation of knowledge* at each separate phase of production and (2) the use of labor and knowledge to upgrade the knowledge base of the business entity, including the type (1) knowledge above. None of these two inputs -- to my knowledge -- has ever been measured and used in production function analysis.

These non-measured factors add to value added, but they are not represented as factor inputs. (Think in terms of the innovative inputs of the entrepreneur or the organizing input of the owner mentioned above.) How does this input show up? If all factor markets are assumed to be perfect, it shows up as a discrepancy between value added and weighted factor inputs. As a consequence, it manifests itself as disembodied technical progress in the production function (Eliasson 1987b, p. 285). However, who receives this "value"? Workers or other specified factors? No one, because then factor markets would not be in equilibrium. Capital owners or entrepreneurs? Yes, perhaps, but then some market, for instance the capital market, cannot be in equilibrium. If it is not, we do not have the slightest idea about the competitive state of all other markets. So we do have a problem.

There is only one way of capturing this general, organizing or innovating knowledge factor, namely as a *choice of technology*. Since "choices" of technology go on continuously and at all levels within a business organization, both the business organization and the entire economy have to be represented as economic systems with memory, or as *path-dependent* economies. What has been learned as K at time *t-1* is memorized and affects performance in period *t*. The aggregate production function, even at the plant level, is not a stable entity independent of ongoing production because technological choices and other allocations, depending on relative prices and the accumulation of new information (learning), occur all the time. But this formulation takes us back to the notion of a "filter". The critical "allocation" knowledge that constitutes technological change has to do with the design of that filter and that filter will essentially be seen to be a filter to allocate human talent. The "leverage" on the performance of the business organization is large. In the rest of the paper I will think of the knowledge factor as a leverage factor to be able to stay with the standard terminology, even though this is a deliberate "misspecification".

3 THE ACCUMULATION OF INDUSTRIAL KNOWLEDGE -- THE MARKET AS A LEARNING PROCESS

The earlier analysis was restricted to the output from the factory process which is sold in global markets as a result of product know-how, process know-how and marketing know-how. Data on this knowledge capital are, to some extent, available within firms (see Table 4 and Figure 2). This section introduces the educational investment process per se and the accumulation of general coordinating (management) knowledge that governs the choices of technology and organizational forms -- the choice of production function.

3.1 The Educational Problem of a Firm

Every business organization faces an educational problem of the following kind. In a dynamic market environment its "capital base" will be heavily tilted towards the factor endowments that paid off well in the past. While profits originate increasingly in product development and marketing, the competence or human capital base of the firm is heavily biased towards process technology. The educational problem that determines the long-run survival of the firm lies in the "educational technology" applied to correct this situation.

Before we go on it seems appropriate to sort out a terminological question. "Education" does not create knowledge; it diffuses and transfers knowledge. In that sense it is a typical production process that also includes "imitation" etc. Knowledge is created through innovative activities of various kinds, including experimentation and research. Trying out a new product in the market is knowledge creation.

3.2 Trade in Know-How

An argument commonly made by economists of the Chicago school is that concepts like the entrepreneur, or the owners, are not necessary to explain innovative and organizing activities. In sophisticated economies, the special innovative or organizing know-how associated with these people can always be hired in appropriate amounts in markets (see e.g. Fama 1980). Not so in our world where unequally distributed and incommunicable (tacit) information is the key factor behind economic success or failure. Technical and marketing expertise can be hired. But for a market to exist there has to be a broad supply of choices. Hiring the right expertise in such critical areas requires know-how. Suppose such know-how can also be acquired through hiring. However, making the appropriate choice again requires more know-how, and so on (see Winter 1964, and Pelikan 1986). The ultimate choice referring to the whole requires the most sophisticated know-how. This is the choice where the potential payoff (or loss) is the greatest. The leverage between input and output is the greatest. As a rule, the successful owner, or organizer, controls this choice.[10]

3.3 The Internal Talent Filter

While process equipment, R&D spending on product development, and market investments still have some kind of physical relation to the tangible output good, the general knowledge base of the specific industrial activity cannot easily be defined. However, the accumulation of that knowledge base is critically linked to people who are filtered upward in the organization through what is usually referred to as careers. There is both entry into, and exit from, the upward flow of people. Even though their human assets, cannot be defined well, the group can be identified rather well, their career paths can be followed, and some personal specifications can be traced; even costs and (educational) investment allocated to them can be measured. Hence, while one cannot define educational output, one can at least describe how it is produced. A varied career offers both a possibility for higher level management to monitor one's skills and a varied experience. The design of the filter can be observed, even though practically no research has been carried out on this important industrial activity (see Eliasson, Carlsson, Deiaco, Lindberg & Pousette 1986 and Eliasson 1987d).

The institutional adjustment needed is by no means easy. The provision of the increasingly differentiated and heterogeneous knowledge capital put to use in industry requires a variety of organizational solutions. This is illustrated in the following examples;

(a) *Mechanical engineering* industries are based on a huge traditional, slow-moving knowledge base. A significant part of that knowledge base has been "routinized" to the extent that it is being taught at advanced technical institutes. General know-how in this field is not tacit. The pool of knowledge is reasonably diffused through the advanced industrial world. New technological developments occur in universities. Firms specialize in moving these technological developments through production to the market.

(b) In *pharmaceutical industries* the knowledge base is moving fast. Academia lags behind. Because of the clinical orientation of medical research, universities can still offer significant knowledge to firms. Hence, firms enter into joint research ventures with universities.

(c) In *electronics* the situation is different. The knowledge base is moving even faster, and academia rarely has the competence to offer advanced knowledge, except at the very early stages of inventive activity, if a talented creative person happens to be "in place". This is true despite the fact that major technology areas in electronics are general in application and extremely abstract and advanced in any academic sense. As a consequence, basic research, technological development as well as market implementations take place in the firms. Frontier knowledge is typically "tacit", since receiver competence is lacking.

For the purposes of this essay it is enough to observe that we are talking about an observable, ongoing activity in large business corporations. Our hypothesis is that the organization of the learning process is what determines the long-run survival of firms.

3.4 Global Economies of Scale in Knowledge Accumulation and Use -- the International Market as a School

The economic value of a firm's knowledge endowment depends on its ability to compete (earn a profit) in a market where prices and costs are determined by the best performers. Critical industrial knowledge can rarely be purchased in the market without hiring the group of people in which the requisite talent is embodied. The only other way to acquire it is to develop it internally. Whichever way it is done, a successful outcome can only be determined through a test in the market and learning through competition. If it does not work, one goes back, modifies one's product, and tries again.

Since the market value of knowledge diminishes as soon as a competitor comes up with a "new idea", firms have to be in the market continuously to learn. Since the industrial knowledge base against which an advanced producer has to test his own competence for all practical purposes is global, a sophisticated producer of today is handicapped if he cannot scan his international business environment continuously.

The effects of scale here are large. If a firm comes up with a new element of knowledge, a ready, global marketing network makes its investment pay off fast. If the firm is large and fails to obtain information about its competitors' success, the negative impact on its profit is large.

The economies of scale in R&D and product development resulting from an international marketing network of foreign subsidiaries have already been documented (see Eliasson 1987a, Eliasson-Bergholm-Horwitz-Jagrén 1985). The scale needed for efficient knowledge use is much more important in world markets characterized by technological product competition than it was in basic industries.[11] The only way to achieve the necessary scale and technology is through building an international group that gives efficient access to the international pool of knowledge.

Only a large international firm can establish separate research facilities in all viable technological environments, and those environments are to an increasing degree located in foreign countries. Only a large international firm can complement its technology base through acquisitions, when it fails to develop the same technology inhouse or does not find it profitable to do so. And as the IBM example on PBX switching shows, the acquisitions also require a particular organizational competence to become a success.

This links back to the problem of concentration discussed in section 1. Advanced industrial nations have to exploit joint economies of scale in product development, manufacturing and distribution to reach productivity levels that make it possible to pay the high wages (and taxes) of wealthy nations. This leads to heavy concentration of production to a small number of integrated production systems in small but advanced industrial nations like Sweden (see Figure 1).

This, in turn, makes these nations exposed, since one advanced producer that fails in the learning process may rock the whole national economy. A global product development - production - marketing - educational organization is the only viable insurance against such risks, since it gives the firm access to *the global pool of international, industrial know-how.*[12]

The accumulation of industrial knowledge in the modern firm -- the educational process -- is fundamentally global and occurs through active market participation and confrontation with the internationally best competitors. If a company is protected from that competition, it is also shielded off from its most valuable learning experience.

4. MICRO-MACRO DYNAMICS -- CLOSING THE ECONOMIC SYSTEM

4.1 The Elements of a Growth Theory

There are four kinds of information processing: (1) *creation of new knowledge*, (2) *coordination*, (3) *filtering*, and (4) *education and knowledge transfer*. See Table 3. *Creating new knowledge* is the innovative and entrepreneurial side of economic activitiy. The organizing mode for the flow of activities determines the efficiency of *coordination*. *Filtering* determines the choice of activities, technology and also, as we have pointed out, the organizing modes for both innovative activity and for coordination.

Knowledge accumulation and transfer, finally, constitute the art of doing and improving upon the earlier three jobs. The more efficient this activity, the larger the knowledge leverage exercised on the other activities. In traditional economic analysis and particularly in growth analysis, the effects of all four information activities are lumped together under the headings of technical change or economies of scale. There is only one way of separating them, i.e., to go down to the micro level to understand how economic growth occurs.

The first two elements of economic activity are well represented by the great names in economics: Joseph Schumpeter (1912) for upgrading in the form of unpredictable entrepreneurship, Adam Smith for specialization, scale and coordination, and Knut Wicksell for coordination of investment through a capital market in disequilibrium. Finally, room has to be made for Keynes, since no macroeconomic growth process will become effective without a balanced demand feedback through income formation. All this is illustrated in Figure 3. Item (3) includes the choice of market or organizational regime.

The quality of all three activities is affected by the fourth "knowledge" endowment. John Stuart Mill (1848) made the knowledge base of industrial activity the key factor behind economic growth. His point was then almost totally disregarded for more than a century (also see Abramowitz 1988). Except for discussions of knowledge creation as a kind of disembodied capital accumulation I have seen little written on the know-how associated with organized selection and filtering of people, ideas and projects through markets and within hierarchies that draw large resources and constitute the essence of the creation and transfer of industrial knowledge in all advanced economies.[13] Knowledge is not simply one of these other asset categories. It permeates all activities in the sense that machines and labor hours have no value if the knowledge or quality factor is missing. But information processes based on knowledge are also value-adding activities. Marketing adds directly to value added, and capital accumulation occurs through R&D spending. But in addition to this, any organization engaged in dynamic competition also has an endowment of "knowledge capital" that makes it a competent upgrader of all other knowledge-based activities. That ability, in turn, has to be carefully upgraded, and so on. Knowledge cannot easily be quantified. It is a transient ("tacit") feature, normally vested in a small group of people, But the activity as such draws significant resources.

In the experimentally organized economy, heterogeneous knowledge is applied to specialized work processes, generating productivity advances at the micro level that are essentially unpredictable. The distinction between the experimental and the plannable economy -- as we have defined it -- refers to the possibilities of explicit,deterministic modeling of this economic process. In the experimentally organized economy a sizeable stochastic element is associated with the outcome of knowledge accumulation and transfer such that the art of technological upgrading and of coordination become essentially unpredictable in the longer term.

Table 5 Modeling the knowledge-based economic growth process

(1) *Exploitation of business opportunities*	
- creating unpredictable innovative behavior	Joseph Schumpeter (1912)
(2) *Dynamic coordination*	
- of specialized production flows	Adam Smith (1776)
- of investment through disequilibrium capital market	Knut Wicksell (1898)
- through demand feedback	John Maynard Keynes (1936)
(3) *Filtering, competition* (choice of organizational mode)	
- minimizing the loss through	
- non-entry of potential successes maximizing the exit of failures	
(4) *Education, knowledge transfer*	John Stuart Mill (1848)

Note: Cf. Table 3.

It should be observed, however, that one does not need a stochastic model to produce stochastic behavior. Many simple, non-linear deterministic models exhibit unpredictable and seemingly stochastic behavior. More complex non-linear models will normally exhibit phases of "chaotic" behavior, such that not even the most advanced econometric models (estimated on output data from such non-linear models) will be able to generate reliable predictions of model behavior in the next phase.[14] The Swedish micro-to-macro model that I will use as intellectual design for my final argument exhibits such properties. (Also see Day 1982, 1983, and Hanson 1985.) This family of mathematical models illustrates the deterministic origin of stochastic processes and, hence, should be useful in economics. If simple models like those used by Day produce phases of chaos at their levels of aggregation, then richly specified micro-based macro models exhibiting "diversity of structure" are needed to generate the stable macroeconomic behavior that we observe (see Eliasson 1984c). A simple way of expressing this would be to say that the law of large numbers applies. However, at various lower levels of aggregation, phases of unpredictable (chaotic) behavior are likely to occur now and then. This is the essence of my experimentally organized economy. I interpret my earlier argument as a behavioristic microeconomic rationale for such behavior, which can be observed in a full-scale micro-based macro model of the Swedish economy (Eliasson 1987b).

4.2 Technology and Entrepreneurship -- Exogenous Upgrading

The micro-to-macro theory that I use as a prototype design for the experimentally organized economy introduces technology change as the result of investment in R&D (innovation, technical information use). The firm processes market information to upgrade the value of its products.[15] Depending on the character of R&D, great success may occur with low probability, or mediocre technology improvements occur with high probability (Winter 1984). Technology enters the production system through the upgrading of labor and capital productivity in new investment vintages whose volume is determined endogenously at the firm level (see Carlsson 1988). A new investment vintage with superior but unpredictable technical specifications can either operate as an independent producer in the market (entry) or mix with the existing production system of the firm (investment). Both entry and investment are moved by profitability expectations. All agents (firms) in the market operate according to preset decision rules representing their particular, limited knowledge about themselves and their environment (bounded rationality). As we will see below, successful entrepreneurship involves the creation of temporary monopoly rents at the expense of earlier rent holders. The introduction of new technology (competitive entry) may change market conditions (prices) such that old firms are competed out of business (exit). Thus this M-M theory includes the necessary filter conditions for the variable player game of dynamic competition, free technological entry (entrepreneurship) and unrestricted exit (creative destruction), that we are studying.

4.3 Market Behavior of Producers -- Coordination through Endogenous Price and Quantity Setting

Firms compete simultaneously in three markets: in the *capital market*, where rate of return requirements are set; in the *labor market* where wages are set; and in the *product market* where product prices are determined.

Agents process market information through three intelligence or expectations functions. They offer a volume and a price in each market consistent with their profitability targets and watch competitors act similarly. As market arbitrage develops, they learn and revise their market offers. As a rule, these offers are kept consistent with profitability targets, but there are ways of modifying profit targets. Firms are not price takers. The key notion about the endogenous nature of price and quantity setting of individual firms is that ex ante price and quantity offers are revised as the firm learns from the ongoing market process, and that all individual offers together make the market process move forward.

This defines the market process as the joint activity of all agents pursuing their own profit motives. The individual action of all agents would, however, not be coordinated if the action of single agents is not bounded somehow.

4.4 Technological Competition in the Experimentally Organized Economy -- the Bound

Since the output of economic activities in advanced, growing economies is predominantly service and quality oriented, the limit to economic growth of any importance is human ingenuity, not raw materials and physical capacity to produce. Innovative activities generate the industrial growth process. What keeps innovative activity and application of know-how from leading to excessive concentration of production and market power in all industry? The answer lies in the economics of distribution. Industrial know-how has a permanent technological effect, but its economic value (to its owner) depends on the technological process of competing innovators that steadily enter the market, forcing bad producers out of business. Technological competition leads to what Schumpeter called *creative destruction*. The competing away of economic rents by new innovators bounds the wealth accumulation process of individual firms. Learning through dynamic competition is an efficient way of distributing (through its effects on market prices) innovative rents from temporary monopolies to consumers, thus containing the rent accumulation process and excessive market concentration (see Eliasson 1986a).

4.5 Dynamic Multimarket Coordination -- the Invisible Hand

Coordination in the classical general equilibrium model occurs through the Walrasian auctioneer, who collects data and passes out trial prices in an iterative manner until all markets are cleared. This is traditionally assumed to be a costless and timeless procedure -- the ideal price controller at work. The trick is to assume a timeless and costless intermediator of information, a prior assumption that almost completely controls the outcome of the analysis.

In the dynamic multimarket setting of M-M theory, each agent informs himself by reading off both price and quantity signals as the market exchange goes on. This is time consuming and costly and subject to frequent failures. Trade always takes place before anything resembling "equilibrium" has been attained. The actual learning that takes place normally modifies the behavior of agents.

No agent is ever fully informed in the experimentally organized economy. Time and information-gathering costs are often prohibitive. Since the disequilibrium market process generates unreliable signals, attempts to obtain full information can be self-defeating and may even disrupt the economy (Eliasson 1984). Hence the nature of the self-regulating forces in the M-M economy is along the lines of Smith's invisible hand, not the abstraction of Walras' auctioneer.

Dynamic multimarket interaction complicates market coordination, as does the innovative process. The latter we know already from general equilibrium theory (Fisher 1983). However, the innovative process is what drives the entire economy. Thus a dynamically efficient growth process has to be able to absorb unpredictable innovative behavior at the micro level but still be able to coordinate prices and quantities dynamically so that price distortions and insufficient demand situations do not occur, except temporarily.

This is where the theory of chaos comes in nicely. Chaos originates in non-linear systems which do not exhibit the conventional convexity properties needed to achieve static equilibrium. The Swedish micro-macro model (Eliasson 1985) is such a non-linear system. Any non-linear system can be approximated by a linear system plus a residual term of component factors. Let us pick one linear "approximation" of the Swedish micro-to-macro model or any non-linear system that mathematically is a general equilibrium model with all the required equilibrium properties. We solve for the equilibrium point and then -- using conventional Taylor expansions of the non-linear model around that point -- determine the component residual factor at some level of precision. Let us now try to move the non-linear model towards the static equilibrium of its linear approximation.[16]

The non-linear system exhibits "chaotic" properties if the "residual terms" expand without limits in positive or negative directions when the non-linear model is "moved" closer to the static equilibrium of its linear approximation. Hence, such non-linear models will always operate out of equilibrium, in the simplistic sense of static theory, and the market coordination problem will be very different from the one perceived from the classical model, including its modern versions exhibiting asymmetric information.

4.6 Insufficient or Excess Demand through Distorted Prices

If prices are not flexible enough, markets do not clear. Temporary excess demand or excess supply situations occur. If there is a bias in the relative upward and downward mobility of factor prices, inflationary pressures are present, and they become stronger, the faster aggregate demand grows.

Analogously, in order to contain inflation, policy makers may hold down aggregate demand growth. Hence, if relative prices do not adjust, demand may be insufficient to drive the profitable supply response that installed capacity and innovative output make possible.

The final outcome called macroeconomic growth in output, hence, depends on a delicate balance between the driving forces and the balancing, self-regulating forces. The commercial technological potential, determined by the knowledge base, including its distribution and creation, and the incentive system drive the economy. Market prices and administrative coordination provide the balancing forces. However, the choice of administrative system and market regime, i.e. the institutional rules of the economy, is knowledge-based. Even though not explicitly explained, this approach to economic theory makes knowledge the ultimate determining factor behind economic growth. We have avoided the full explanation by positing the existence of a global business opportunity set and locally bounded, asymmetrically distributed knowledge as the limiting factor. As a consequence, the entire economic system always operates well below its potential. What reins in economic growth is the institutional organization of the socio-economic system that regulates both the knowledge creation and the balancing forces. But this institutional organization is part of the "memory" or the tacit knowledge base of the economy which is gradually improved as the economic process goes on. What we have now finally made clear is that this knowledge base controls the entire information processing system through markets and hierarchies of the economy. The macroeconomy is organization (micro) based and the organization determines the macroeconomic performance of the economy.

4.7 What Does This Mean for Growth Theory?

The ultimate conclusion from the above reasoning concerning the experimentally organized economy is that at some level of disaggregation, policy makers, like managers of a firm, will have to *give up control.* The reason is not only complexity or non-transparency in the Hayekian (1945) sense. Since practically all production activities consist of more or less knowledge-intensive information use, *unpredictable technical change occurs in the efficiency of using information itself*, and, with a high leverage effect, in the efficiency by which knowledge is accumulated and transmitted through the organization.

But to assume predictable technical change, even stochastic generation of technical change (cf. Futia 1980), means assuming away the basic proposition of this paper. The only way to achieve some form of micro-level predictability is to restrict entry of new technology as is systematically done in the public sectors of Western industrial nations and in the "planned economies" of the East and -- I have to add -- in classical economic theorizing at Western universities. This hampers the innovative process, reduces competition and conserves economic structures. Economic behavior becomes more predictable but the factors that engender economic growth of real economies are blocked.

Therefore, modeling economic growth requires understanding the nature of all forms of information and knowledge-using activities. Dynamic micro-macro theory is needed. It appears that control of the economic process can only be exercised at fairly high levels of aggregation. If macroeconomic growth is the desired ultimate outcome of policy control, this is perfectly all right. The implications of this for economic theory and policy are, nevertheless, formidable. Not only is the traditional economic measurement system severely affected by unpredictable quality change, something economists have long recognized, but in a non-equilibrium model, neoclassical welfare analysis can no longer be used.

4.8 A Note on Economic Measurement

The measurement problem arises out of the difficulty of measuring *quality of output*. The capacity "installed" to produce quality of output has two dimensions, namely the distributional one associated with the rate of return, and the welfare, output, dimension. On the input side we cannot measure knowledge capital well. On the output side we cannot measure the volume of quality produced well. Technological competition through quality hence has a strongly disruptive effect on economic measurement. We have suggested that these two intangibles are what really matters for supply. Thus, the modern industrial nations may be entering a phase when the most important and the most rapidly growing inputs and outputs -- knowledge and quality, respectively -- are not measured at all. Our economic sensors will only be able to pick up a noisy reflection of the ongoing "hidden" production process, namely a positive return to these unmeasurable quantities reflected in an above-normal return to measured capital. Knowledge capital then operates like the financial gearing ratio. In a profitable firm, a lot of cheap external finance gears up returns on total assets as they accrue to owners through the rate of return on equity. This is a typical "scale" effect. Similarly, invisible general business talent -- like invisible finance know-how -- gears up the return on measured assets, making observers of economic things sometimes believe that the reason is a technology embodied in the physical capital. An excess return over standard costs of capital occurs. In certain forms of productivity measurements, these excess returns show up as total factor productivity growth. If instead a hypothetical knowledge capital is defined, and if the residual is allocated to that capital input, total factor productivity growth -- and the shifting of the production function -- would be reduced or eliminated. If that knowledge could be measured, e.g. through accumulating its reproduction value, it would be possible to measure, in a conventional fashion, the return to that knowledge capital.

NOTES

1. This theory is still purely static variations on the classical model. Cf. Albrecht-Axell-Lang (1986) who suggest that "limited markets" in a search theoretic model may give interior solutions even with increasing returns to scale. Similar "scale explanations" have also been offered for intra-industry trade (see e.g. Helpman 1984). This is a puzzle only for minds shaped in general equilibrium trade theory. For two countries with identical factor endowments, and hence no Heckscher-Ohlin comparative advantage, increasing returns to scale may generate trade. The reason: because of scale economies, each nation will specialize on a subset of products and import the rest. Standard equilibrium trade theory, however, only generates 0/1 results from this setting, that is full specialization (concentration) and offers no explanation how. To understand such specialization you need a dynamic, micro-macro theory of the kind we are offering in this paper, that not only explains the specialization effects that occur because of scale but also the nature of the ongoing competitive market process (see last section and Eliasson 1985c).

2. Also see Romer (1987).

3. Cf. the wider notion of "economies of scope" (Teece 1980) and Dahmén's "Development blocks" (1950; see also his essay in this volume).

4. An IUI study is currently under way.

5. Measurable in the sense of being itemized in the cost accounts of at least large firms.

6. *Explained in English* in Eliasson (1986a).

7. The ε excess profit factor in Eliasson (1988c, p. 188).

8. A general discussion of this can be found in Eliasson (1988a).

9. Carlsson (1980) has demonstrated that this allocation and coordination function within firms and between firms accounts for more than 50 percent of total factor productivity growth as estimated "disembodiedly" on a standard macro production function.

10. When all listed factors in the production function introduced in the earlier section have been paid their marginal costs, a difference between value added and total costs, representing the return to assets over the market interest rate, remains. As shown in Eliasson (1985, 1987b) this difference relates directly to total factor productivity change. However, this excess return could also be said to be a return to the unspecified innovative or organizing knowledge input of entrepreneurs or owners. If properly accounted for, disembodied total factor productivity change would vanish.

11. As distinct from technological competition through process upgrading that characterizes the literature on technological competition and industrial targeting. See Krugman (1982, 1983, 1984) and Eliasson (1987a).

12. There is a parallel but essentially erroneous argument about the same problem that is often heard from engineering school sources, that is also reflected in the modern literature on industrial targeting. It derives directly from the general equilibrium based industrial organization tradition. The argument is (1) that the innovator should be protected from foreign competition until he has geared up the scale and become competitive in international markets. This erroneously implies that innovative activity is a purely local process. The second (2) part of the argument is that the advanced industrial nation needs a domestic full coverage technology base, implying an academic such base and the possibility that such a base can be designed and organized locally even though the elements of knowledge needed make up a very large number. This argument is fundamentally wrong -- at least in my experimental economy. I will not develop this argument further in this context. See further Eliasson (1988b).

13. Before Mill, however, economists paid keen attention to the knowledge factor behind national economic performance, e.g. Westerman (1768) in attempting to understand why Dutch and British industries performed at twice the Swedish productivity level in comparable production activities.

14. Hence, "rational expectations" in its only palatable formulation will not hold, namely that agents *eventually learn* so that full information in some sense emerges. Compare the strange assumptions needed for "rational expectations equilibrium" in the so-called *learning models* of Blume-Easley (1982), Bray (1982), Jordan (1985) and see the discussion of Frydman (1982). Also see Eliasson (1988a, pp. 178-180).

15. What I present is a brief sketch of the general M-M theory presented in Eliasson (1985, 1988c). Note, however, that the actual M-M model implemented econometrically and used for numerical illustrations is much cruder in design. The innovation process of the firm, in particular, is exogenous, and learning is strictly for coordination purposes. New technology enters through exogenous improvements of productivity associated with new investment (see Carlsson 1988). However, each firm, and the economic system as a whole is equipped with a *memory*, which determines the rate of knowledge accumulation and guarantees a path dependent economic process. What is needed (and modeled but not programmed into the model, Eliasson, 1985) is a productivity enhancing process of the firm determined by investments in R&D, the latter being also endogenously determined.

16. This is identical to trying to push the factors of the Swedish M-M model towards 0 from above or from below through increased competition. See Eliasson (1984, 1988c, and in particular 1985, pp. 332 ff.), where an attempt in this direction was made, even though I was not then aware of "chaos" in the above mathematical sense.

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