Real Wages, Business Cycles and New Production Patterns

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ABSTRACT. In contrast with most conventional business cycle models, empirical data show no clear correlation between real wage movements and output and employment. This paper presents a model, largely based on concepts presented by Joseph Schumpeter, in which economic growth and the business cycle are triggered by endogenous real "shocks" to technology. It suggests that the speed and magnitude by which technological "shocks" spread throughout the economy determine whether the resulting changes in real wages will be pro- or counter-cyclical.

1. Introduction

Business cycle models constructed from both classical and traditional Keynesian analysis typically predict that wage and output fluctuation will have a strong negative correlation (Fischer, 1977; Keynes, 1935; McCallum, 1989). In contrast, most modern real business cycle (RBC) models predict a high degree of positive correction between average productivity and hours worked (Christiano and Eichenbaum, 1992; Greenwood, Hercowitz, and Huffman, 1988; King and Plosser, 1994; King, Plosser and Rebelo, 1988a, b; Prescott, 1986; Simkins, 1994). This result is largely derived from the assumption that cyclical changes are caused almost exclusively "by exogenous shocks to technology" (Christiano and Eichenbaum, 1992; Cogley and Nason, 1995), typically depicted as shifts in productivity.

Most empirical studies have found, however, that no clear correlation exists between real wage movements and output and employment (Dunlop, 1938; Lucas, 1981; McCallum, 1989; Tarshis, 1939; Sargent, 1987). For example, Abraham and Haltiwanger examined most of the prominent real-wage- business-cycle studies and, after correcting for compositional and measurement biases, could find no long-term pattern of pro- or counter cyclicality in the data, although since 1970 real wages have tended to be somewhat procyclical (Abraham and Haltiwanger, 1995). Clearly, a new approach to the broad subject of real wages, growth, and business cycles is warranted.

This paper will present a model in which growth and the business cycle are both triggered by real "shocks" to technology that are derived wholly from endogenous sources. It will suggest that the extent and rapidity by which the technological "shocks" spread throughout the economy determine whether the resulting changes in real wages will be pro- or counter-cyclical. Much of the analysis underlying the model is drawn from ideas presented by Joseph Schumpeter (1939, 1983).

2. Technology and information

It seems evident that information is intimately connected with the existence of order, or structure. Clearly, if any aspect of reality is characterized by total disorder, or chaos, in the sense that no coherent pattern or structure about it may be identified, no description of it at any time can predict its state at any future time. This implies that information requires the existence of a pattern that is preserved or invariant to change. Patterns may be represented as a set of components that are linked to form a coherent system. Patterns may also describe the evolutionary process in structures that undergo some type of deterministic change, in which the elements that define the structure in one period are linked to new elements in subsequent periods.

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In this paper, technological efficiency will be closely linked to *active information*, a term introduced by the late physicist David Bohm (Bohm and Peat, 1987; Bohm, 1980). Bohm defined active information as a pattern superimposed over a field of energy to harness that energy for some purpose or end.[1] The relatively little energy needed to maintain the pattern serves to control (or "amplify") a larger output of energy (Bohm and Peat, 1987, p. 157). As Bohm says:

> The basic idea of active information is that a form, having very little energy, enters into and directs a much greater energy . . . acting to 'inform,' or put form into, a much larger energy (Bohm and Peat, 1987, p. 93)

Following Bohm, we will define information as any pattern that molds, forms, or shapes a set of components or objects in order to direct and amplify a source of energy. This concept will be extended to define technology as any pattern of information that is superimposed upon a source of energy to control or harness it for useful purposes. The "technological pattern" of control in a specific production function is constructed from an array of implements, devices, and machines that are coupled to channel energy into productive tasks.

3. Information, machines, and control patterns

We will represent a machine as a pattern of components that are linked to form an interactive system that controls an energy flow. The components form a pattern that harnesses or changes the direction, motion, or intensity of a flow of energy, such as a crank attached to a rotating shaft changing circular to vertical motion. A vector whose elements represent the magnitude and direction of an energy flow describes the input and transformed-energy output of a component. The output is then further changed by the next component to receive this energy. In this way, the components of the system "communicate" with each other and, in the process, channel and control energy. For example, the system of intercommunicating components found in the modern computer amplifies small inputs of energy in order to control much larger energy flows through selection of protocols that couple it to one or more external energy sources, such as a printer or production processes.

The evolutionary process of pattern improvement

This model will explore the evolutionary process of two types of control patterns, one type representing production processes, the other consumer products. Typically, each pattern consists of an array of components that are linked to form a system. Some of the components in a system may be single structures each with a unique shape; other components may themselves be comprised of patterns of sub-components.

Production processes typically contain a series of linked components and subcomponents that direct a flow of energy through the system to transform a set of inputs in such a way as to increase their value, as determined by customers. Similarly, consumer products contain patterns of components that are used by consumers to achieve a valued purpose or objective. In both cases patterns are used to control the flow of energy toward specific goals, and therefore represent "active information."

When a new pattern is developed, it typically contains a new array of linked components that differ substantially from existing technological patterns, and which therefore provides a "discontinuous change" from those patterns. As a result, the new pattern renders many of the components of the existing pattern obsolete and must be replaced either by entirely new components, or by modifications of existing components. The process through which these changes occur is driven largely by trial-and-error experimentation, in which entrepreneurs develop new product versions, and then, from the consumer acceptance or rejection of these versions, develop improvements on these patterns. Each improvement increases the total sales of the new pattern, and reduces the sales of existing product patterns for which the new product is a substitute. Although the trajectory of this process is inherently characterized by uncertainty, eventually the final form of the product pattern emerges, and the uncertainty at each successive step ultimately approaches zero.

In many cases, a specific pattern may be applied in a variety of very different production processes by coupling it with other patterns. For example, the waterwheel shaft may be coupled with a cam, which is then connected to a rotating shaft and hammer to crush ore, or to a bellows to drive blast furnaces. In many cases, the components of the coupled systems, including the initial one, may need to be modified for optimal introduction of the control pattern. The undershot waterwheel, for example, which was most suited for processing metal ores in mountainous areas of medieval Europe, required substantial changes in the shape and number of blades used in the wheel. We will consider control patterns that can be represented through homologous transformation matrices that represent similar or identical patterns, even though their physical components might differ.

The extent to which a specific control pattern may be employed in different uses and production processes depends upon the number of other control patterns with which it may be combined and on the extent to which the form of its components may be modified or reshaped for specific uses. In most cases a central control pattern, or what we will call a "technological driver" of change, which David (1990) designates as a "general purpose engine," performs the basic transformation or change in the pattern and which is coupled to other implements that further refine and direct, or control, the flow of energy. For example, levers, bearings, and gears that are attached to an eccentric cam (the control driver) together open and close the valves that regulate the flow of steam into a piston. The result of this new pattern is to: (1) reduce the variety of another machine or process to which it may be coupled, or (2) generate an entirely new type of output by performing a new type of task, or (3) perform a task on an entirely new material, such as aluminum instead of iron.

Once successfully introduced, however, a new control pattern results in evolutionary improvements in the components of the production systems that employ it, either by making them more precise, with reduced variability, by modifying them is such a way as to permit them to couple with other components, which may result in improved final products. The result is a greater likelihood that new versions of the original pattern will be formed (from new components) and may be implemented in an increasing number of productive systems.

In an analogous way, a new consumer-good control pattern contains a new technological driver that allows consumers either to achieve a new goal, or, in Schumpeter's terms, a new "want," or to attain a new objective more effectively, perhaps with lower opportunity cost. The initial version of this product typically consists of new combinations of existing products, which, since they were designed for entirely different patterns, in their present form may not couple, or "communicate," with optimal effectiveness. This new product will then undergo an evolutionary process in which many of the original components will be modified or refined, or, in some cases, coupled with entirely new other components, each of which improves the efficiency to consumers of the new product pattern. The evolutionary paths taken by the typewriter and the personal computer provide useful examples of this process (Utterback, 1994).

4. The emergence of discontinuous new patterns

Although the flow of new innovative production patterns tends to diminish even in a dynamic economy during periods of contraction or stagnation, incremental changes and alternations on existing products and processes still occur. At some point, however, these incremental innovations make possible the development of a new production pattern of control, largely by entrepreneurial new firms willing to assume the risks involved.

As Schumpeter has pointed out, when such a new technological control pattern emerges in an economy, it initially will be embodied in a combination of pre-existing machines and components (Schumpeter, 1983, p. 65). Once introduced successfully, the characteristics of the new product will undergo successive refinements, generally increasing the efficiency with which the components of the pattern communicate. Similar changes will occur in complementary products. These changes, in turn, will require changes in the machines or processes used to make all patterns and components.

The role of entrepreneurship

In this paper we will assume that entrepreneurial business provide the most important driving force behind the introduction of a new production process or product pattern. As Schumpeter and other pioneers in entrepreneurial theory, such as Israel Kirzner, have pointed out, the essence of the entrepreneurial function is to introduce products or production processes that are *discontinuous* with current practices in an industry (Kirzner, 1985; Schumpeter, 1983). Such change are not modifications of existing technologies and represent paradigmatic shifts that typically signal the birth of a new industry. The evidence shows that the majority of such innovations have been typically introduced by new business; although a few examples of discontinuous changes by existing large business enterprises may be found, they tend to be the exception (Aldrich and Fiol, 1994; O'Connor and Rice; 2001; Utterback, 1994; Veryzer, 1998).

Production control patterns

New technological control patterns disseminate throughout the economy s successive "waves" of change. First, the basic new control pattern spreads to other firms and market segments in an industry; second, the pattern is adapted by other industries; and finally, firms that produce complementary components, production equipment, and other inputs to the firms that implement the new pattern will introduce new or altered components and complementary products that are better adapted to the new pattern. These secondary changes often result in the development of new production system patterns.

When a new technological pattern is introduced by a production system, its use often generates bottlenecks and resource limitations that generate pressures for improvement in complementary products and processes. New production patterns will tend to be developed and introduced into these collateral processes. For example, when the horizontal loom was introduced in medieval Europe, its efficiency was severely limited by shortages of thread, which was still produced by manual means. The solution, of course, was the spinning wheel.

Many new production patterns result in increased production efficiencies that reduce product costs and prices; other result in improved products that are easier and simpler to use, or can be used in a greater variety of applications, often in complementary combinations with a wider variety of other products. Still other patterns result in a larger number of variations on each product. In general, technological advancements that increase economic growth increase the variety of products and, therefore, options or choices to consumers.

Increased growth expands the number of potential new combinations that can be produced with a new pattern and the number of applications in which it may be used. Increased output results from increased control over production processes, less waste, reduced number of production tasks, and, consequently, decreased production cycle time.

When the use of a new production pattern results in a greater potential variety of output, it tends to be introduced into other production systems, often initially by risk-seeking new, small businesses, in many cases in very different industries. Therefore, the initial success experienced by the new pattern causes it to be introduced in still other production systems. In general, the greater number of components that can be coupled with any device produced by the new pattern, the greater the number of potential production systems into which it may be employed.

Often, the dissemination of the new pattern causes "feedback" effects that result in additional refinements and variations of the original produce that expand its use.[2] For example, soon after Watt's steam engine was introduced, it was clear that its efficiency and performance would improve dramatically if the piston could be made to fit more precisely within the main cylinder. When Watt patented his engine, however, no technology existed to make cylinders sufficiently uniform to make such a fit possible. John Wilkinson was able to combine a new set of devices, including a boring tool connected to a set of gears and a guide bar linked to a rail transport system, all of which was powered by an early version of Watt's steam engine (Buchanan, 1992; Burke, 1979, pp. 175–176; Mokyr, 1990, p. 88). The result was a far more uniform bore, which made it possible to introduce steam power to an expanding array of uses, each of which combined the steam engine with other components and production patterns.

5. From uncertainty to new industry structure

The appearance of a new production pattern that may be coupled with many other production patterns throughout the economy triggers the development of new combinations of production patterns, new products, and new processes. These new possibilities, together with the turbulence caused by a wide array of feedback effects, tend to generate considerable uncertainty.

Uncertainty represents the extent to which disorder, or lack of clear pattern or structure, may be said to characterize a segment of an economy. For one thing, the new technology could develop along many different potential pathways, or "trajectories," each of which will be determined by improvements in components, as well as in collateral products, many of which remain to be developed. For another, as David has pointed out, firms are often slow to introduce a new control driver, or "general purpose engine," such as the dynamo, because, among other reasons, the difficulty of imposing the new technological pattern on the existing patterns embodied in production systems frequently requires substantial redesign of entire production systems. Furthermore, when the new technological driver is introduced into an existing, unmodified production system, the result is often organizational turbulence and reduced productivity (David, 1987, 1990).

In addition, the diffusion of the new technology depends upon "network externality effects" that conjoins the new technology "with other streams of technological innovation," or other production patterns (David, 1990, p. 356). These network effects increase the variety of uses of the control driver, which, as we will see, depends upon the introduction into new or existing production systems' complementary processes and patterns. On the other hand, the failures and successes that result from this often trial-and-error experimentation generate new information – new patterns, new structures – that select those patterns that meet with consumer acceptance and result in creating new wealth.

Thus, a new production pattern gradually emerges from the turbulence caused by waves of change that appear from the myriad of combinations and variations of new products and technologies that are continually being developed and tried in the marketplace. In a market economy, each component is tested for consumer acceptance, which serves as an "organizing principle" that fundamentally guides the often-chaotic process of change.

At some point, however, one dominant production pattern emerges as a market favorite. From a macroscopic perspective, the new pattern is an array of inter-industry linkages; microscopically it is a set of specific products, components, and production processes. The new overall pattern, in most cases, reflects the emergence of one or more new "dominant designs" in key consumer products (Utterback, 1994).

The new product, which, as Schumpeter noted, represents a set of features that are combined to form a novel pattern, also requires a new combination of production components and inputs. If the new product meets with initial success, the new pattern soon spawns imitators, who introduce variants of the initial product. These new products trigger the design and development of components, materials, and capital goods for use by the firms producing them.

Finally, the firms making products threatened by the new product variants typically will respond by introducing new, and presumably improved, versions of these products. As was true for the primary new product, design changes in existing products result in correlated changes in products and production processes by suppliers of components, materials, and capital goods.

6. Uncertainty and an evolutionary model

Next, we will examine in more detail the structure of the dynamic process through which new products and product variants are introduced. Let us assume that a new production pattern, Λ, is developed from a new and novel combination of existinproducts and production patterns. As we have seen, the early stages of the dynamic product innovative process are characterized by considerable uncertainty as to the characteristics of the products that will ultimately emerge to meet consumer acceptance – and to the technology that will be most suited to their production.

Clearly, uncertainty increases as the number of potential product variants, ν, that appear from Λ in any time period increase, and to the degree that no single product is clearly preferred by consumers. Patterns of consumer acceptance of the product variants that have been developed and put on the market by all businesses at any given time provides entrepreneurial businesses with information from which they will make further modifications on their products. As new product variants are placed on the market, these consumer patterns will undergo dynamic modification, which constitutes and evolutionary trajectory of consumer preferences through successive time periods.[3]

The new technological pattern, Λ, may represent a new consumer product, a new capital good, such as a steam engine or computer inventory program, or an entirely new production process that embodies a new technological structure, such as "just-in-time" inventory delivery. In many cases, a new production process often implies a change in product form, as when plastic molding replaces steel sheet molding. In other cases, a new process that results in increased productive efficiency will tend to reduce the price of the final product. In any case, in most cases a change in production will ultimately lead to some type of change in final product.

After a new technological pattern has been developed, it will typically undergo substantial modifications and shaping in the marketplace as it is subjected to consumer scrutiny and feedback. These modifications consist of developing alterations in the initial structure of the new pattern or finding and often adapting other patterns that are then coupled with it. Therefore, when the new pattern is introduced into the market, a number of firms, particularly new entrepreneurial firms, will develop products or production processes that employ variants of it. Product variants that succeed as well as those that fail in the marketplace provide feedback information that firms use to shape successive generations of further variants of the pattern.

In addition, in response to the threat to their market position that Λ has introduced, existing firms using the older technology, Φ, will introduce new and in many cases improved variants of their existing products. These factors, therefore, suggest that the introduction of any new product or production pattern will generate substantial levels of uncertainty in the marketplace.

Patterns of consumer acceptance of the product variants that have been developed and put on the market by all businesses at any given time provides entrepreneurial businesses with information from which they will make further modifications on their products. As new product variants are placed on the market, these consumer patterns will undergo dynamic modification. We will represent the entire evolutionary change of output for all products, including those using the new technology as well as those modifying products based on the older technology, as a sequence of difference equations.

Output transition functions

During each period, each jth firm will estimate the long-run annual sales potential of all product variants bases on the new technology, $Q^{(\Lambda)}$ and the share its current product variant will have of this total sales potential, $\xi_j^{(\Lambda)}$. Since the firms employing the new technology are continuously developing new products or product variants, both consumers as well as businesses are continuously learning about relative product feature preferences, both $Q^{(\Lambda)}$ and $\xi_j^{(\Lambda)}$ estimates will continuously change as new information is generated from the market.

Moreover, not only will firms continuously revise their estimates of their long run sales potential, but they will also develop correlated estimates of changes (negative or positive) of sales that will occur from period to period. In general, short run estimates are a function of three factors: (1) the percentage change in sales the firm has experienced over the last two periods, (2) the percentage change in sales for the entire new technology, and (3) the percentage changes in sales for each competitive product variants using the new technology.

Therefore, total output by each jth firm employing Λ in time t can be represented as its sales in $t-1$, plus an estimate of the change in their sales over the previous period. This estimate is given by term $\alpha_j(Q_{t-2}^{(\Lambda)} - Q_{t-1}^{(\Lambda)})$, where α_j is a parameter that is based on the firm's evaluation of the degree by which consumers prefer their current product variant over competitive products. This estimation is based largely on a comparison of the percentage change of their sales compared with the percentage changes in sales that other companies selling product variants using the same technology have experienced during these periods.

These concepts may be used to form two simple second order linear difference equations that represent the period-to-period changes in output both in the products developed from the new technology (Λ), and in those employing the existing technology, (Φ).

$$Q_t^{(\Lambda)} = \alpha(Q_{t-2}^{(\Lambda)} - Q_{t-1}^{(\Lambda)}) + Q_{t-1}^{(\Lambda)} \quad (1)$$

$$Q_t^{(\Phi)} = \beta(Q_{t-2}^{(\Phi)} - Q_{t-1}^{(\Phi)}) + Q_{t-1}^{(\Phi)} \quad (2)$$

Since products based on Λ are substitutes for products using the existing technology, Φ, changes in $Q^{(\Lambda)}$ are by definition inversely related to changes in $Q^{(\Phi)}$.

In these equations we are assuming that when one or more entrepreneurs put on the market products (or production process patterns) that incorporate the new technology, Λ, the new products will achieve some degree of consumer acceptance. In addition, a new pattern based on a new technology may spread to other firms in other industries who adapt the pattern to their products or production methods. In general, the more the pattern is diffused to other industries, the greater the magnitude of $Q^{(\Lambda)}$ in this model.

To the extent that consumers find products based on Λ preferable to those based on Φ, sales for the first will rise, at the expense of sales for the latter. Initially, however, uncertainty as to which new product patterns will be ultimately preferred will high as some customers prefer the new product, but others who try the product reject it, some of whom will try other variants.

A firm producing any basic or primary product, of course, purchases inputs, such as raw materials or components, from other firms. The firms producing these inputs, particularly components, for new products that are derived from a new and evolving technology face uncertainty that is derived from the overall uncertainty that characterizes the new industry. Therefore, the same patterns of change also apply to businesses that we supply inputs and raw materials to businesses employing the two different technologies. Thus, we have,

$$Q_t^{(c\Lambda)} = \alpha_c(Q_{t-2}^{(c\Lambda)} - Q_{t-1}^{(c\Lambda)}) + Q_{t-1}^{(c\Lambda)} \quad (3)$$

$$Q_t^{c\Phi} = \beta_c(Q_{t-2}^{(c\Phi)} - Q_{t-1}^{(c\Phi)}) + Q_{t-1}^{(c\Phi)} \quad (4)$$

In equations 3 and 4, $c\Lambda$ and $c\Phi$ represent all products that are inputs into products based on Λ and the older Φ technologies, respectively, including complementary products, components, and raw materials. Changes in these products undergo the same type of change and exploration as the primary products do, although here the changes are driven by, and in response to, the changes in the primary products.

Real wages in RBC model

Although many factors enter into the determination of real wages in an industry, considerable economic research over many years suggests several that are most significant. First of all, and most obvious, wages tend to be positively related to the marginal physical productivities achieved by workers in the various firms that comprise an industry. In addition, wages tend to be proportional to the monopoly profits that firms in an industry can achieve, and to the degree workers in an industry require specialized skills, and can therefore extract rent (Bound and Johnson, 1992; Dinopoulos and Segerstrom, 1999; Johnson, 1997).

Monopoly profits are related to the wealth created by the products and the production processes in an industry, and to the extent to which competition exists in the industry, which is, of course, reflected in the price business can charge. The degree of competition, of course, is a function of the extent to which close substitutes for each firm's products may be found. The demand curve for a new product or new variant of an existing product that has few competitors, and is highly preferred by customers over existing products, will have inelastic demand, resulting in significant monopoly profits, which can be extracted by workers as higher wages, provided the workers can gain power by possessing specialized skills in short supply (Lloyd-Ellis, 1999). An index of the relative value of a product is provided by, of course, the magnitude of cross elasticity of demand between a product and its nearest substitutes.

But wages paid to workers are also a function of the skills level, and training, of the workers (Berman et al., 1994; Juhn et al., 1993). If the technology employed to make the new product requires no new training or skills, the supply of workers will tend to be very large, and wages will tend to be low. To put it more exactly: the greater the degree of substitutability between workers in the new industry and other industries the less they will be able to extract any portion of the monopoly profits earned by the firms.

For new and innovative entrepreneurial firms, real wage determination is represented in equation 5:

$$\varpi_{\Lambda} = f_{\Lambda}[\hat{\wp}_{n}^{(\Lambda)}, \varepsilon_{\chi}^{(\Lambda, \Phi)}, (\Gamma_{\chi}^{(\Lambda, \Phi)})^{-1}] \tag{5}$$

where $f_{\Lambda t}$ is a positive function, and $\varpi_{\Lambda t}$ represents the average real wage of workers employed in businesses that use the new technology at time t.

In equation 5, $\hat{\wp}_{n}^{(\Lambda)}$ represents the average of marginal products for the n workers in Λ technology firms, where the number of workers is a positive function of $Q^{(\Lambda)}$. The term $\varepsilon_{\chi}^{(\Lambda, \Phi)}$ is the cross elasticity of substitution between the products employing Λ and those employing ϕ technologies. The greater this coefficient, the greater the monopoly power in Λ businesses. Finally, $\Gamma_{\chi}^{(\Lambda, \Phi)}$ is the average cross elasticity of substitution between the skills needed in Λ and Φ businesses for the number of employees in Λ businesses. The lower this number the greater the monopoly power (and the higher the wages) of workers in Λ businesses.

Using similar assumptions and notations, we may represent the real wage determination in firms that use existing technologies in equation 6:

$$\varpi_{\phi t} = f_{\phi t}[\hat{\wp}_{n}^{(\Phi)}, \varepsilon_{\chi}^{(\Lambda, \Phi)}, (\Gamma_{\chi}^{(\Lambda, \Phi)})^{-1}] \tag{6}$$

The same analysis may be applied to the determination of real wages for complementary products or inputs into the firms that utilize the new innovative technology.

When an innovative new production pattern appears in an industry, typically introduced by a new entrepreneurial business, its impact generates successive ripples, or "wavefronts" of uncertainty, along with further innovation and changes, that effect all firms, including those the new "technological driver" will ultimately replace. We may now trace the effects of the relationships specified in these functions by examining the trajectories that existing and new businesses will follow after the introduction of a new production driver.

7. Technological wavefronts

Successive and overlapping waves of change in output that result from the successful introduction of a new production pattern are illustrated in Figure 1, as projected by difference equations 1–4. Changes in $Q^{(\Lambda)}$ are represented in Figure 1 as the solid heavy line 1, entitled, "Products using new Tech Pattern."

If the new production pattern is introduced successfully and gains significant market success at the expense of existing firms, the initial uncertainty faced by the entrepreneurial firms that introduced it initially drops significantly. Existing firms that employ older production processes experience rising uncertainty, as their market shares decline. Their response, shown on line 3, "Products Using Existing Technology," is to improve their technology and often the features or quality of their products. If these changes are successful, the result is a decrease in uncertainty as to which products will win customer acceptance, which is reflected in a substantial recovery of sales after an initial decline. As the exiting firms modify and improve their production processes and products, the number of firms that employ the new production pattern typically declines as a result of the increased competition from existing firms.

However, firms employing the new production pattern will respond to the enhanced competition from the older firms by making still more refinements and improvements to their existing product and production patters. These improvements are met by further improvements by firms using the existing technologies, without, however, adapting the new process and technology (Utterback, 1994; Abernathy and Clark, 1985; Abernathy and Utterback, 1978). All attempts to improve existing and mature technological patterns inevitably encounter diminishing returns, as the history of technology amply demonstrates. For example, when faced with the technological threat posed by refrigeration technology, the substantial U.S. ice-harvesting industry during the 19th century responded with a series of process innovations, including the use of steam-power that for a while improved its productivity and competitiveness. Other examples can be found for consumer products, such s the introduction of the electric light bulb and lighting systems, which stimulated the competing technology of gas lamps to develop a sequence of innovations, such as the Welsbach mantle, which substantially increased the luminosity of gas lamps over that provided by electric light bulbs (Utterbach, 1994). Ultimately, however, existing patterns must succumb to the law of diminishing returns for further investment in any given technology.

Moreover, the new pattern undergoes refinements that increase the efficiency of its control process. These refinements are the result of changes in the products that are produced by other new and entrepreneurial firms that provide components and products that improve communication between the components of the new primary production pattern. These improvements in the new technology ultimately cause firms that employ them to replace the older processes.

The new production pattern sets in motion subsidiary or secondary waves of change in businesses that are supplying inputs to the initial, or primary, production processes. These businesses are compelled or encouraged by market pressures generated by the success and widening use of the new production pattern to create and introduce additional new production patterns in industries that are compatible with the primary pattern. This secondary wave of compatible changes in production processes is represented in line 2, "Products Complementary to New Tech Pattern," in Figure 1.

In addition, improvements in existing processes induce changes in many of the inputs used by firms employing the older production technology, as well as components and materials into the revised outputs of these processes, changes which are summarized in the line 4, "Products Complementary to Existing Technology." The effort, however, eventually fails, and the changes on existing processes are reduced to a very few.

We will assume that the development of new production patterns in upstream firms will lag somewhat behind the introduction of new patterns in final-produce firms downstream. In general, as

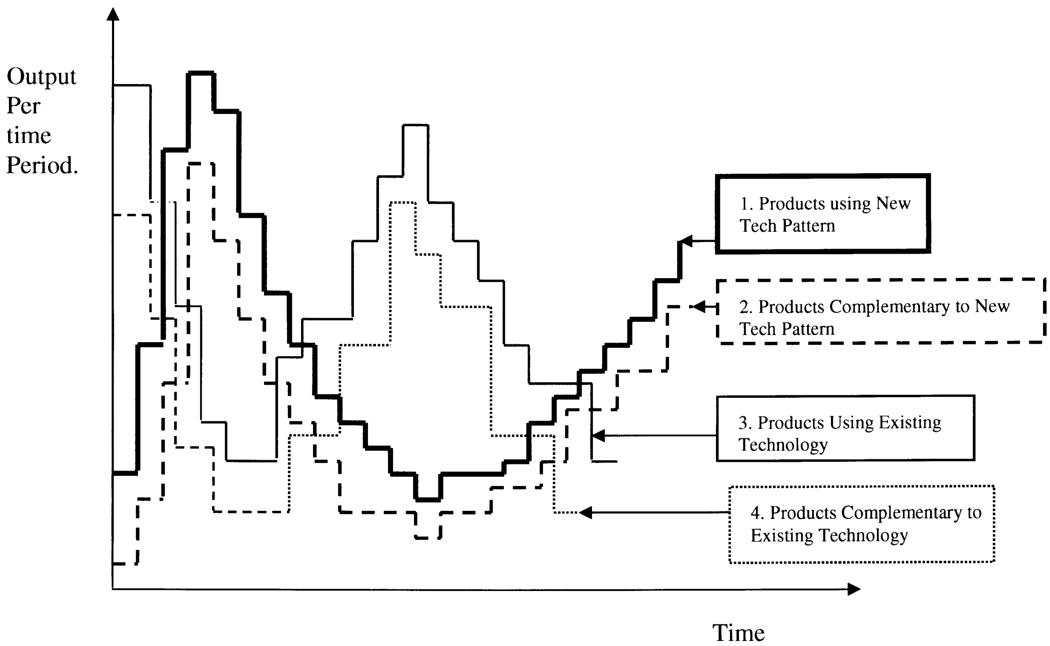

Figure 1. Real business cycle wavefronts over discrete time periods.

the new innovative productive pattern becomes dominant in firms throughout the downstream industries, and as new patterns emerge and become established in secondary, or subsidiary, industries, the magnitude of the wavefront cycles will gradually dampen and ultimately disappear, at which point a new equilibrium emerges.

9. Conclusion

The model presented in this paper suggests that when a new product or a production process pattern, Λ, results in more efficient production processes or product designs that are preferred by a significant number of customers, an "endogenous" technological cycle is triggered that results in a substantial increase in output for products based on it, and an economic expansion that is not induced by low real wages. Moreover, the increase in $Q^{(\Lambda)}$ is amplified if firms in many industries can adopt the new pattern.

The model identifies several of the most essential factors that can increase real wages through the expansion phase of the business cycle. First of all, if the successful new technology is a production process that embodies more effective control information, labor productivity will increase, which will, all other things being equal, tend to increase real wages. Second, if the new technology represent a new product that is preferred by a substantially large group of customers, perhaps because it offers them highly valued new choices or objectives, the initial firms that develop successful designs based on it will achieve at least temporary relatively high monopoly profits, some of which may be appropriated by labor.

If skills used in the new technology are highly differentiated from the skills employed by businesses using the earlier technology, and if the firms using the new technology achieve monopoly power, the cross-elasticities of product substitution, $\varepsilon_{\chi}^{(\Lambda,\,\Phi)}$, will be high, and if the cross-elasticities of labor skills, $\Gamma_{\Lambda}^{(\Lambda,\,\Phi)}$, is also high, workers will gain enough monopoly power to extract high real wages from the monopolistic rent earned by the businesses using the new technology.

Although many businesses that are unsuccessful at developing improved variants of the new technology will fail, this will not affect the real wage for those workers in the successfully growing new firms and industries. Workers already employed in the pioneering new businesses will have developed knowledge and skills that were honed during the time when a product design emerged from the initial chaotic conditions, and they will not be easily replaced. The result of higher returns to existing successful new technology firms and the reduction of employment in firms and processes that are replaced should increase the aggregate mean wage, and the magnitude of the cross-elasticity of their skills, $\Gamma_{\Lambda}^{(\Lambda,\,\Phi)}$, will be high, resulting in relatively high real wages.

As products and processes adapt to the new technological pattern, and if the new design pattern is introduced successfully into many production systems in many industries, the waves of change will spread broadly throughout the economy, both in the primary firms and in multiple layers of suppliers and firms making complementary products. In this case, the marginal labor productivity functions in many industries will shift outward substantially, and real wages and employment will move, in the aggregate, procyclically.

On the other hand, if new innovative process and technological patterns can not readily be transferred across industry boundaries, or if it does not trigger corresponding changes in suppliers, or other secondary industries, the innovations will have relatively little net effect. In other words, an increase in cyclical output that does not result in a large-scale adaptation of a new technological pattern that affects many industries, will most likely result in little or no significant increase in real wages throughout the economy.

Finally, if the new pattern causes a substantial increase in efficiency in all production functions that adopt it or its variants, the overall effect could be that initial increases on marginal labor product curves for the new industries are more than offset by large-scale subsequent decreases in declining industries, in which case real wages would tend to move counter-cyclically.

10. Summary

This paper presents a model that describes economic expansion as an endogenously generated pattern that represents a new product or a production pattern, which, as Joseph Schumpeter noted, typically embodies new combinations of existing products or patterns. If it is successful, the emergent new pattern replaces existing products, thereby constituting a "shock" that diffuses throughout the economy, producing a Real Business Cycle expansion. The initial success of the new pattern triggers an evolutionary sequence of changes not only in the new pattern, but in products and production patterns that are replaced by it, resulting is successive waves of expansion and contraction. It suggests that real wages will move either pro- or counter-cyclically, depending upon the level of skills needed by workers in the businesses that employ the new technology, the monopoly power attained by those businesses, and, above all, the strength and breadth with which the new pattern is incorporated into production systems throughout the economy.

Notes

[1] This is broader concept of information than that introduced by Shannon (Shannon and Weaver, 1948), who was concerned with the relationship between channel capacity and reliable transmission of messages.

[2] Such feedback loops constitute a type of "autocatalysis," which plays an important role in several models of "self-organizing" systems, in which order emerges from chaotic turbulence (Prigogine and Stengers, 1984; Jenner, 1989, 1991, 1994).

[3] This may be modeled as a succession of Markov matrices, where entropy of transition probabilities measures uncertainty (Jenner, 1966).

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