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Technological Unemployment

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Abstract

This paper investigates the effect which technological progress has on the short and long-run employment of labor, on household welfare, and on aggregate output. Two types of technological shocks are considered and compared--improvements in product quality and improvements in labor productivity. I use a simple two-sector dynamic framework wherein households maximize utility and firms maximize profit, but training new employees involves increasing marginal cost to the firm.

The analysis shows that an improvement either in the quality of a good or in labor productivity can cause temporary "unemployment" (captured by a decrease in equilibrium labor employed). I show that the degree of temporary unemployment depends on three key factors: the size of the technological shock, the extent to which households view products as substitutes, and the degree to which labor released from the competing industry is substitutable for that needed in the new industry. With either type of innovation, household utility rises, but some people temporarily lose their jobs, and in this sense the technological change may not be recognized as progress--at least in the short run. Innovations to product quality are also shown to produce long-run aggregate output effects which generally differ from those generated by the standard neoclassical production enhancement.

Adopting specific utility and production functional forms, the model is simulated to show numerically the effects of each type of technological progress on short and long-run (steady-state) employment under various conditions (significance of innovation, elasticity of product substitutability, and degree of labor substitutability). The analysis lends support to Schumpeter's thesis that "progress unstabilizes the economic world" and furthermore that "it is particular innovations which carry a given [business] cycle."

1. Introduction

In his 1939 book, Business Cycles, Joseph Schumpeter went to great effort to illuminate the various types of unemployment which he understood that a capitalist economy might exhibit. He distinguishes neatly between structural, cyclical, and other forms of unemployment, but emphasizes most importantly, the phenomenon of "Technological Unemployment."[1] A seeming contradiction in terms, Schumpeter adopts this lexicon to underscore the fundamental force which he saw as behind most business cycles in a capitalist economy. Indeed, Schumpeter emphasized that

> "Basically, cyclical unemployment *is* technological unemployment. ... Technological unemployment ... is the essence of our process and, linking up as it does with innovation, is cyclical by nature."[2]

The present paper explores the issue of technological unemployment--interpreted as the dynamic replacement of old jobs with new ones due to technological progress. Specifically, I explore the effects on aggregate employment, output, and welfare of two types of technological progress--improvements in product quality and advances in production technology. Emphasis is on innovations in product quality because it is felt that the effects of this type of progress are generally understated and are more central to Schumpeter's theme of "economic evolution."[3]

Additionally, I emphasize the role played by three economic factors--significance of technological advancement, degree of product substitutability, and degree of labor substitutability--in determining the extent and duration of the jobs' recession caused by

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[1]Altogether, Schumpeter mentions eight types of unemployment (which he capitalizes so as to formally name)--Normal, Structural, Vicarious, Disturbance, Secondary, Cyclical, and Depression--as well as Technological Unemployment. See Business Cycles, p.511-17.

[2]See Business Cycles, p.515.

[3]Schumpeter referred to business cycles as the "Contours of Economic Evolution." See Chapter IV., Business Cycles.

technological change. Is the product innovation a major one (is it chewing gum, for example, or the computer)? To what degree is the product innovation a substitute for existing ones (is it the telephone, for example, or the parachute)? And are the skills of labor released from the old industries similar to those needed in the new and emerging ones (the automobile, for example, versus the fax machine)? These are the issues which I highlight and attempt to untangle.[4]

Previous studies of product innovation/quality ladders include Romer (1990), Segerstrom (1990), Cheng and Dinopoulos (1991), Grossman and Helpman (1991a, 1991b), Aghion and Howitt (1992), Dinopoulos (1993), and Lai (1993). Unlike their work, this paper follows in the spirit of Schumpeter to emphasize and empiricalize technological unemployment in lieu of product cycles. To simplify the analysis, I take innovation as exogenous, following the setup of Shleifer (1986). Contrasting Shleifer (1986), I consider a demand-side quality enhancement in addition to a supply-side cost reducing technological improvement. Innovation is assumed to result in a higher quality of the existing product rather than the introduction of new goods (Stokey, 1988). The resulting employment cycles can lend support to the microeconomic empirical studies of Davis and Haltiwanger (1990). The two sector adjustment framework is a simplification of Matsuyama (1992); and the accompanying technological unemployment can be regarded as a complement to the theory of

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[4]Although the automobile was clearly a major innovation (see footnote 7), it was not one which resulted in massive *immediate* aggregate employment effects. Early motorcars were very similar in construction to the existing carriages. William Durant, founder of General Motors (Durant's Folly), had previously been in the carriage business and simply transferred most of his existing workers into the production of horseless carriages--their assembly skills being highly substitutable for those needed for the new product. Thus, at first, the development of the automobile did not bring with it massive job losses elsewhere. It was not until later--with the development of an extensive roads network and the trucking industry--that the automobile resulted in major job losses in the economy. These were experienced in such industries as railroads, blacksmithing, etc.

The fax machine, though perhaps not as major a product innovation as the automobile, clearly represents the type of innovation which has immediate impacts on existing jobs. Direct substitutes for the service provided by the fax machine are the mail industry (particularly express mail) and teletype. The emergence of the fax industry required programmers, electronic engineers, and software designers; but, affected by the mail and teletype businesses, were truck drivers, mail sorters, and typists.

involuntary unemployment, as in Akerlof (1981) and Foster and Wan (1984).

The key findings are as follows. First, an improvement in product quality is shown to cause a greater short-run reduction in employment the greater is the improvement in product quality. Second, the *extent* of disemployment caused by product innovation is directly related to the degree which households view products as substitutes. The more substitutable is the innovating product for existing ones, the more an improvement in one product reroutes demand to the improved product and from the competing one, causing unemployment in the existing "stagnant" industries. Third, the *duration* of unemployment depends directly on the degree to which labor skill requirements are substitutable across the emerging and existing industries. The less homogeneous are labor skill requirements across industries, the higher are labor training costs, and the more slowly will emerging firms add new employees. Workers out of a job thus go unemployed for longer when the skills of labor in the declining industries do not match well those needed in the emerging ones.

Technological progress bears welfare gains both in the short and long run, and the larger is the technological progress, the greater are the welfare gains. However, innovation's full welfare gains are realized only after labor has been trained and fully assimilated into the new tasks. The seeming paradox here, of course, is that the greater is the technological progress, the greater will be the improvement in households' long-term "standard of living," but the *worse* will be the short-run unemployment effects. In short, patience is required in order to reap the full benefits of innovation and the "creative destruction" which it brings.

Finally, the behavior of an aggregate output "index" tells two entirely different stories, depending on whether the technological shock is quality, or output, enhancing. Measured aggregate output rises both in the short and long run when progress occurs in the form of production technology; but measured aggregate output actually *falls* in the short run when that progress instead occurs in the form of product quality. This happens despite the fact that the effect on household welfare is identical for the two types of progress. Aggregate output indices are thus naturally prone to misinterpretation, and can easily give misleading signals concerning the extent to which society's welfare has advanced. Parallel but different forms of technological progress will sometimes be manifest as an economic "boom" yet other times as a temporary recession.

The paper is organized as follows. Section 2 gives a brief historical motivation based on Schumpeter's insights into economic evolution. Section 3 presents a simple two-sector optimization model. Firms in two separate industries maximize profit, and households maximize utility by choosing among leisure and the two types of consumption goods. Product quality and labor productivity are both subject to random technology advances in specific goods or industries. Such advances carry possible employment effects due inherently to the heterogeneous nature of labor skills required to work in the two industries. In essence, labor cannot move costlessly between the two industries but must be trained at some positive and increasing marginal cost in order to be assimilated into the acquiring firm. Section 4 specifies a particular household utility function as well as particular production functions for each of the two products which satisfy the conditions for optimization set out in Section 3.

In Section 5, the full economic model is calibrated and prepared for sensitivity analysis, which is performed in Section 6. Section 6 considers two types of technological progress--improvements in product quality and improvements in labor productivity--and compares the dynamic impact on employment, aggregate output, and welfare of these two forms of technological progress. I conduct exercises to determine the sensitivity of the employment response function to variations in both product substitutability and labor substitutability. As hypothesized, the degree to which individuals view the two products as substitutes and the degree to which labor is substitutable are both powerful factors in governing the degree to which technological change brings short-run unemployment. The paper concludes with some suggestions for further research.

2. Historical Motivation à la Schumpeter

What is economic "growth?" How does growth happen, how can we observe it, what are growth's fundamental causes, and what are its effects? These are difficult questions. But Joseph Schumpeter, writing most clearly in his works Capitalism, Socialism, and Democracy and Business Cycles had keen insights into these issues. To Schumpeter, the essence of growth was *change*.

> "The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets, the new forms of industrial organization that capitalist enterprise creates." Capitalism, Socialism, and Democracy, p. 83.

Indeed, Schumpeter emphasized that an economy doesn't literally "grow," it *evolves*--continuously recreates itself--as people seek naturally and unceasingly to improve their standard of living.

> "The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process." Capitalism, Socialism, and Democracy, p. 82.

> "The changes in the economic process brought about by innovation, together with all their effects, and the response to them by the economic system, we shall designate by the term Economic Evolution." Business Cycles, p. 86.

To Schumpeter, progress was the primary driving force behind the free enterprise business cycle.

> "It is by no means farfetched or paradoxical to say that

'progress' unstabilizes the economic world, or that it is by virtue of its mechanism *a cyclical process*." Business Cycles, p. 138.

> "It is, after all, only common sense to realize that, but for the fact that economic life is a process of incessant internal change, the business cycle, as we know it, would not exist." Business Cycles, p. 138.

Moreover, Schumpeter saw the duration and depth of the business cycle as a function of the *particular* innovations which the economy absorbed.

> "All we can thus far say about the duration of the units of [the business cycle] and each of [its] two phases is that it will depend on the nature of the particular innovations that carry a cycle." Business Cycles, p 143.[5]

And to drive home this point, Schumpeter added

> "Individual innovations imply, by virtue of their nature, a 'big' step and a 'big' change. A railroad through new country, i.e. country not yet served by railroads, as soon as it gets into working order upsets all conditions of location, all cost calculations, all production functions within its radius of influence; and hardly any 'ways of doing things' which have been optimal before remain so afterward."[6] Business Cycles, p. 101.

Economic history is replete with examples of how product innovation or invention reroutes demand from existing products to improved or emerging ones, in the process destroying old jobs and creating new ones.[7] The automobile, the computer, plastics, etc.--all

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[5] See also Schumpeter (1928) and (1935) for a discussion of the issue of economic change, and the inherent instability of capitalism.

[6] See Capitalism, Socialism, and Democracy, p 101.

[7] In practice, the distinction between product invention and product innovation is an illusive if not impossible one. The automobile, for example, first appeared on the streets of France in 1769, but was steam powered, difficult to control, and prone to frequent accidents. Early internal combustion engines used gun powder as their source of explosive propulsion, but proved entirely ineffective. It was not until science had reached the stage where refraction, the gasoline carburetor, the battery, the distributor, and other components were reasonably perfected that the motorcar was practically accessible to consumers. This occurred around the turn of the century (1901-1903)--the era which most people would associate the with the "invention" of the automobile. A more careful look, however, clearly reveals that this was a period of

eventually had major unemployment effects. Table 1 documents briefly the phenomenon of technological unemployment.

Table 1
Technological Unemployment

New Product	*Labor Needed*	Old Product	*Labor Released*
Automobile	Assemblers Designers Road builders Petrochemists Mechanics Truck drivers	**Horse/carriage** **Train** **Boats**	Blacksmiths Wainwrights Drovers Teamsters RR workers Canalmen
Airplane	Pilots Mechanics Flight attendants Travel agents	**Train** **Ocean liner**	RR workers Sawyers Mechanics Ship hands Boilermakers
Plastics	Petrochemists	**Steel** **Aluminum** **Barrels/tubs** **Pottery/glass**	Miners Founders Metalworkers Coopers Potters Colliers
Television	Electronic engineer Actors Reporters Electricians	**Newspaper** **Theater** **Movies** **Radio**	Reporters Actors
Computer	Programmers Computer engineers Electrical engineers Software designers	**Adding machine** **Slide rule** **Filing cabinets** **Paper**	Assemblers Millwrights Clerks Tinsmiths Lumberjacks
Fax machine	Programmers Electricians Software designers	**Express mail** **Teletype**	Mail sorters Truck drivers Typists
Telephone	Electronic engineers Operators Optical engineers Cellular technicians	**Mail** **Telegraph** **Overnight coach**	Postal workers Telegraph operators Coach drivers
Polio vaccine	Chemists Lab technicians Pharmacists	**Iron lung**	Manufacturers Attendants

significant product innovation, but not literally invention. With this in mind, the table presented here can arguably be justified as examples of product innovation--quality improvements--represented and modeled in terms of the framework presented in this study.

3. The Model

This section sets out the basic framework for analyzing the issue of technological unemployment. There are two types of decision-making units--households and firms. Households maximize utility and firms maximize profit. Government is explicitly excluded from the framework, but clearly could be included to perform such acts as "protecting jobs" (providing unemployment compensation, for example, or in some other way regulating labor's transition from one industry to the other). Additionally relevant, government could be conceived to administer a program of retraining labor, say, through a tax and transfer scheme. Here, I do not consider such roles for government, but focus attention exclusively on the roles played by the substitutability between goods and substitutability between labor in affecting the magnitude of unemployment caused by technological progress.

A. Households

I begin by setting out the problem faced by households. Households are assumed to value consumption (c) and leisure (ℓ), each of which is viewed as a normal "good." In order to consume, households must work. In each period, households are endowed with one unit of time, the fraction L of which households choose to spend working and the fraction $\ell = 1 - L$ of which households choose to spend in leisure. The household's problem, therefore, is to maximize utility by choosing between leisure and consumption subject to prevailing prices and wages.

For simplicity, I assume that households maximize periodic utility

(1) $U = U(c, \ell)$,

where U_c, $U_\ell > 0$; U_{cc}, $U_{\ell\ell} < 0$; and $U_{cc}U_{\ell\ell} - U_{c\ell}^2 > 0$.[8] Admittedly, an extension to lifetime utility maximization may offer additional insights. But, in order to be interesting such an extension would have to allow for the endogenous evolution of technology or the endogenous accumulation of human capital, which would likely prove intractable in the present two-sector optimization framework.

Household consumption is assumed to occur in the form of services derived from two types of products--X and Y--viewed by households as substitutes. That is, households do not directly value products themselves, but rather they value certain intrinsic services, or characteristics, embodied in and provided by products (Lancaster, 1966). Essentially, for example, households do not directly value horses, carriages, motorcars, planes, trains, boats, or elevators, but rather they value the transportation services which these products provide.

I assume that consumption services may be aggregated according to the function

(2) $c = c(X,Y,A)$,

where c_X, $c_Y > 0$, and c_{XX}, c_{YY}, $c_{XY} < 0$.[9] That is, products X and Y are assumed to be substitutes in providing consumption services, and have positive but diminishing (or at best constant) marginal returns in terms of the consumption services which they provide.[10]

Note that X and Y measure the quantity of the two products consumed and the

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[8]For a dynamic optimization framework with a much simpler treatment of productivity enhancement see Matsuyama (1992).

[9]For purposes of exposition, I have dropped the time (t) subscripts throughout the presentation of the model. Thus all variables should be thought of as pertaining to period t, with the exception duly noted later when the new notation (,-1) is introduced to denote a one period lag.

[10]Actually, I rely only on the assumption that the two products are weak substitutes. That is, $c_{XY} \leq 0$.

variable A is a technology-related product quality measure which governs the mapping of product quantity into consumption characteristic space.[11] By assumption, A is exogenous but increases from time to time to reflect an improvement in one of the products in terms of the consumption services which it provides. As a shorthand, I refer to this type of technological shift as an improvement in product "quality," as perceived by households. For exposition, I assume that X is the product whose quality improves. An improvement in the quality of product X is modeled as an increase in A together with a concomitant increase in $c(\bullet)$ and c_X/c_Y , so that advances in quality increase total consumption services, as well as the marginal services which households derive from product X relative to those of Y.[12] Mathematically, $c_A > 0$, and $c_{XA}c_Y - c_Xc_{YA} > 0$.

This formulation of household consumption and utility is essential to the scope of the model because it allows us to consider the type of technological progress which gives rise directly to an increase in the *demand* for one product vis-a-vis another. The dynamic effects of technology shocks which are immediately output-demand-enhancing (product quality shocks) may differ from those which are immediately output-supply-enhancing (productivity shocks) and should be considered. (The latter of these has been investigated by Schleifer (1986)).

Households may work in either or both of the two industries--X or Y--but are assumed to be indifferent between the two when faced with equal wages. Moreover, labor is assumed to be freely mobile across the two industries. These assumptions imply that

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[11]See Lancaster (1966) for a fuller explanation of this approach.

[12]On the surface, the distinction between different goods and a single good of differing quality may seem illusive or contrived. However, it is not, but is central to the issue of "product" definition, measurement, and aggregation required to calculate aggregate output indices. Section 6 contains a discussion of this issue.

household labor supply will act so as to equalize the wage rate across the two jobs.

For simplicity, I eliminate the need for money in the model by allowing the product Y to serve as the numeraire. That is, wages, prices, and profit are all measured in terms of units of product Y. The price of Y is 1, the price of X is ρ, wages are ω per unit of labor supplied, profit in the Y industry is π_Y, and profit in the X industry is $\rho\pi_X$ --all measured in terms of the Y commodity.

A fiscal overview recounts that households purchase the two types of products, earn income from working in the two industries, and receive the profit from each of these industries ($\pi = \pi_X + \pi_Y$). Maximization of household utility subject to the budget constraint thus gives the first order conditions

$$(3) \qquad c_X(X,Y,A) = \rho c_Y(X,Y,A),$$

$$(4) \qquad U_\ell(c,\ell) = \omega U_c(c,\ell)\, c_X(X,Y,A), \textit{ and}$$

$$(5) \qquad \omega L + \pi = \rho X + Y,$$

which are satisfied by choosing X, Y, and $\ell = 1 - L$, given ω, ρ, and A. These three equations define the optimal relationship between household's demand for product X, demand for product Y, and supply of labor, as functions of the wage rate, the relative price of X, and product quality.

B. Firms

I now model the production side of the economy.

Typically in analyses of employment and production, the firm is assumed able to adjust its input of labor instantly and costlessly, apart from labor's normal wage costs. Implicit in this formulation is the notion that the hiring and firing of labor involves symmetric costs and savings to the firm--simply wage costs. Evidence, however, clearly points to the contrary.[13] Firms clearly oftentimes fire quickly and in large quantities (layoff) while hiring slowly and in small, incremental, quantities. This behavior suggests firms face some asymmetry in their underlying profit function when faced with an inequality between labor's real wage cost and its marginal productivity.

Here, the setup departs from conventional production analyses in order to consider the interaction between labor substitutability and technological change in generating unemployment. Specifically, firms are assumed to incur positive and increasing marginal training costs for hiring new workers, but no concomitant costs for layoffs. This assumption should be viewed as merely a special case of the general condition where employee marginal training and severance costs are both increasing, but not equal. An inequality between labor's real wage and its marginal productivity thus will evoke one magnitude of response on the part of the firm when that difference is positive, but an altogether different one when it is negative.

There are two industries--X and Y--each producing one type of good with only one factor of production--labor. Physical capital is excluded as an input in order to focus attention on the role played by labor heterogeneity in determining the employment impact of technological change. In addition to labor, technology is assumed to play a major role in affecting the degree of output. For simplicity, I assume that production technology is of the Harrod neutral type, so that it proportionately affects firm's production at all levels of labor input.

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[13]News headlines prove and constantly reprove this point. Layoffs of 74,000 at General Motors, 25,000 at IBM, and 27,000 at Boeing, 33,000 then another 50,000 at Sears, etc., are all examples of a familiar and repeated market phenomenon. Job losses often tend to come in torrents. On the other hand, news headlines such as "6,000 Jobs Added at Home Shopping Network," or "Microsoft Hires 26,000 New Workers." are rarely, if ever, seen. New jobs seldom make the daily news precisely because they *don't* come in sudden bursts, but in trickles that are overshadowed by the torrents of layoffs. Nonetheless, as the employment data show, on balance and over time the economy clearly creates more new jobs than it destroys.

Production in each of the firms is assumed to require industry-specific labor skills. Those skills are assumed to be costlessly held by households up to the level at which they worked in the previous period. As households increase their employment in each of the industries, they must undergo additional (industry-specific) training in order to be productive. This training occurs at the beginning of the first period of additional work, at some positive and increasing marginal cost to the firm.[14] Such training makes new labor fully productive and indistinguishable from pre-existing employment.

These assumptions imply the following production and profit relationships for firms in each of the two industries:

$$(6) \qquad \pi_X = BX(L_X) - \frac{\omega}{\rho}\left[L_X + \max\{T(\Delta_{L_X}), 0\}\right], \textit{ and}$$

$$(7) \qquad \pi_Y = NY(L_Y) - \omega\left[L_Y + \max\{T(\Delta_{L_Y}), 0\}\right],$$

where, X', Y' > 0; X", Y" < 0; T', T" $\geq$ 0, and $\Delta L_X \equiv L_X - L_{X,-1}$.

The function $T(\Delta L_X)$ accounts for the presence of training costs in the X industry when $\Delta L_X > 0$. The magnitude of T'($\bullet$) presumably varies inversely with the substitutability between labor skill requirements in the X industry and those in Y. For the case where labor skills are perfectly homogeneous, T($\bullet$) = T'($\bullet$) = 0; thus nested in the general labor framework described here is the narrow, more traditional one. Parallel relations hold for the Y firm; thus for compactness I will henceforth exhibit only those relations which pertain to

[14]Here, the labor training feature is modelled directly as type of labor cost which the firm must bear in hiring new workers. Alternatively, the labor training feature could be modelled as affecting productivity of pre-existing workers in the firm during the time which they must train new employees. The choice between these two approaches in not critical to the results of the model since either a decline in employee productivity or an increase in employee cost will affect the firm's employment decision comparably.

firm X.

For simplicity, I assume that firms maximize periodic profit. Following this objective, firm X chooses to hire an amount of labor which satisfies the condition

$$(8) \qquad X'(L_X) = \frac{\omega}{\rho}[1 + \lambda],$$

$$where\ \lambda = \max\begin{cases} T'(\Delta_{L_X}) & for\ \Delta_{L_X} > 0 \\ 0 & for\ \Delta_{L_X} \leq 0 \end{cases}$$

this requirement being determined mathematically by maximizing π_X as expressed in equation (6).

Note that $\lambda(\omega/\rho)$ reflects the firm's marginal cost of hiring or firing workers, apart from standard wage costs. $\lambda = 0$ for $L_X \leq L_{X,-1}$, indicating no severance costs to firms as workers are laid off; but $\lambda = T'(\bullet) > 0$, and $T''(\bullet) > 0$ for $L_X > L_{X,-1}$, reflecting positive and increasing marginal training costs to firms when new workers are hired. This type of asymmetry in employment adjustment can capture the stylized facts presented in the microeconomic evidence of Davis and Haltiwanger (1990).

In effect, λ measures the degree of substitutability of labor between the two industries. If production in the X industry, for example, involves skills similar to those in industry Y, then retraining costs would be small as would λ. An example of this is the early automobile industry vis-a-vis its predecessor, the carriage industry. Labor skills required to assemble carriages were very similar to those required to assemble the early motorcars, and thus the transition of labor from the former industry to the latter one was a fairly easy one, requiring relatively little training costs.

Conversely, if production in the X industry requires skills unlike those in Y, then retraining costs would be high as would λ. This case describes, for example, the emergence of the computer industry, which required programmers and electrical engineers, but directly impacted the typewriter, adding machine, slide rule, filing cabinet, and paper industries where few of the needed new labor skills could be found.

Finally, I assume that equilibrium prevails in the labor market. In other words

$$(9) \qquad L = L_X + L_Y .$$

Thus, unemployment is not expressly considered. Admittedly, the framework at hand is not factually authentic in two ways. First, the economy here will exhibit no literal *un*employment as a result of shifts in technology--only *dis*employment, as reflected in a decrease in the equilibrium amount of household employment. In other words, *each* household bears the disemployment equally, and must spend some fraction of their time in retraining. A more descriptively accurate framework would allow for literal unemployment--unequally across households and at least temporarily--as a result of the technological progress.

This labor setup is intended to imitate a situation where some households have been traditionally employed in the production of one type of product, but then face layoffs and industry "downsizing" as progress reroutes the demand for that product to new or improved products. As a result, some fraction of those households would then need to undergo retraining and transition into jobs in the expanding or emerging new industries, and the economy would exhibit temporary unemployment as a feature. The current framework is not designed to illustrate such a disequilibrium feature; however, it alternatively captures household employment effects through reductions in the equilibrium amount of individual household labor employed. The simplifications used, thus primarily aid tractability with little compromise to the basic goals of the analysis.

4. Specification and Parameterization

This section prepares the full economic model for calibration. For households, a specific utility function is chosen, and for firms, specific production functions are chosen which satisfy the conditions for optimization set out in section 2. These functional forms are then parameterized in order to explore the dynamic nature of employment, aggregate output, and welfare in response to shifts in technology. Particular attention is paid to three parameters--those which signify product quality, product substitutability, and labor substitutability--as viewed by households and firms in consumption and production of the two goods.

A. Households

Consider first the household sector. Conforming to equations (1) and (2), and using $\ell + L = 1$, households are assumed to maximize

$$(10) \quad U(c,\ell) = U_{max} + M\frac{c^{\beta}}{\beta} - z\frac{L^{\phi}}{\phi},$$

$$where \;\; c = c(X,Y,A) = AX + \frac{QY^{\alpha}}{\alpha},$$

and $L = 1 - \ell$, with $\beta < 0$, and M, Q, U_{max}, $\phi > 0$. These conditions are satisfied by households choosing X, Y, and L.

Before solving the maximization problem, it is useful to review the properties of the utility function. Note first that this utility function comprises two elements--leisure and composite consumption services, c. $U_c = Mc^{\beta-1} > 0$, $U_{\ell} = zL^{\phi-1} > 0$, $U_{cc} = M(1-\beta)c^{\beta-2} < 0$, $U_{\ell\ell} = -z(\phi-1)L^{\phi-2} < 0$, and $U_{cc}U_{\ell\ell} - U_{c\ell}^2 = Mz(1-\beta)(\phi-1)c^{\beta-2}L^{\phi-1} < 0$, so that each of the conditions set out earlier for U(•) is satisfied so long as $\phi > 1$, given that $\beta < 0$ and M, z >

0. Also, $U_{c\ell} = 0$, so that, by construction, consumption services and leisure are separable. The parameter β the degree to which the marginal utility of composite consumption services diminishes as households enjoy more consumption (diminishing faster for a higher β), and ϕ reflects the degree to which the marginal utility of leisure falls as individuals work less (falling faster for a higher ϕ).

The composite consumption services function has the properties $c_X = A$, $c_Y = QY^{\alpha-1}$, $c_A = X$, $c_{XX} = 0$, $c_{YY} = (\alpha-1)QY^{\alpha-2}$, and $c_{XY} = 0$, which satisfy the conditions for $c(\cdot)$ set out above so long as A is positive and $\alpha < 1$. Note that $c_X/c_Y = (A/Q)Y^{1-\alpha}$, and the condition $c_{XA}c_Y - c_Xc_{YA} = QY^{\alpha-1} > 0$ is also satisfied, so that an increase in A causes an increase in $c(\cdot)$ together with a concomitant increase in and $c_X(\cdot)/c_Y(\cdot)$. Improvements in the quality of product X raise total consumption services, as well as the marginal consumption services which households derive from product X relative to that of Y.

In sum, $\beta < 0$ and all other parameters--α, ϕ, A, U_{max}, M, Q, and z--are assumed to be positive, with the added restrictions that $\alpha < 1$ and $\phi > 1$. The variables X, Y, and L are all naturally non-negative and $L \leq 1$. A utility upper bound of $U = U_{max}$ holds as X, $Y \rightarrow \infty$, with $L = 0$. However, $U = U_{max}$ is not feasible because households must work ($L > 0$) in order to consume ($c > 0$).

Subject to these conditions, households maximize utility when

$$(11) \quad AY^{1-\alpha} = \rho Q, \text{ and}$$

$$(12) \quad zL^{\phi-1}c^{1-\beta} = MA\left(\frac{\omega}{\rho}\right),$$

given the household budget equation (5).

Two parameters in particular--A and α--play a central role from households' perspective of the economy. First, the parameter A directly governs the mapping of product

X into consumer services. Both total consumer services and the marginal services which households derive from product X (relative to Y) are higher for higher values of the parameter A. Thus A is the parameter whose intended role is to reflect the per-unit quality of A. By assumption, A is exogenous but increases from time to time to reflect an improvement in product X in terms of the consumption services which it provides.

Note that the parameter α reflects the degree to which households view the two products as substitutes. By construction, $\alpha \leq 1$, a low α reflects low product substitutability and a high α reflects high product substitutability, with $\alpha = 1$ as the case where households see X and Y as perfect substitutes. The size of the parameter α is hypothesized to be of key significance in determining the employment effect of a shift in technology.

Defined by (11), (12), and (5) are the demand for X, the demand for Y, and the supply of labor as functions of the relative price of X, the wage rate, and the parameters of the model. These relations constitute three of the equations which must be met in order for the economy's equilibrium to be optimal, from the standpoint of households.

B. Firms

I turn next to specification of the production sector. Firms in industry X are assumed to make products according to the production function

(13) $$X = BL_X^{\gamma} ,$$

but face training costs for new workers (when $L_X > L_{X,-1}$) according to the relation

(14) $$T(\Delta_{L_X}) = \tau(L_X - L_{X,-1})^{\delta} .$$

By construction, all of the parameters are presented as non-negative. The parameter $0 < \gamma < 1$ reflects the returns to labor in the X industry, the magnitude of B reflects the level of production technology in X, and (ω/ρ), together with the parameters τ and δ, jointly determine the cost of training $L_X - L_{X,-1}$ new employees. Note that $\lambda \equiv T'(\bullet) = \delta\tau(\Delta L_X)^{\delta-1} > 0$ and $\lambda' = T''(\bullet) = \delta(\delta-1)\tau(\Delta L_X)^{\delta-2} > 0$ must hold in order to reflect a positive and increasing marginal training cost. Thus $\tau > 0$ and $\delta > 1$ are the parameter requirements necessary to model a situation where--because labor must be trained--the marginal cost of adding a unit of employment exceeds simply the wage cost (ω/ρ).

With these restrictions in mind, profit of the X firm in period t can thus be written as

$$(15) \quad \pi_X = BL_X^{\gamma} - \frac{\omega}{\rho}\Big[L_X + \max\{\tau(\Delta L_X)^{\delta}, 0\}\Big],$$

with the understanding that the last term of this expression is zero for the case of layoffs ($L_X \leq L_{X,-1}$). Maximization of the periodic profit function gives

$$(16) \quad B\gamma L_X^{\gamma-1} = \frac{\omega}{\rho}\big[1 + \lambda\big],$$

$$\textit{with } \lambda = \begin{cases} \delta\tau(L_X - L_{X,-1})^{\delta-1} & \textit{for } L_X > L_{X,-1} \\ 0 & \textit{otherwise} \end{cases}$$

where the solution to this relation is the optimal amount of labor for the X industry to employ in the current time period.

Two parameters in particular--τ and δ--play a central role in the production sector of the economy. First, the parameter τ models directly the cost of assimilating new labor into X's work force. The larger is τ, the lesser will be the amount of new labor which firm X hires in response to a reduction in labor's wages (ω/ρ) or an increase in labor's productivity (B). It is also worth noting that for the case of $\tau=0$, the demand for labor may be expressed in the traditional closed-form solution $L_X = [\gamma B(\rho/\omega)]^{1/(1-\gamma)}$. For $\tau = 0$, labor skills are homogeneous across industries, labor in either industry is perfectly substitutable for that in the other, and workers may move directly into the production of X with no training cost to firms. Thus nested in the general case where employee training costs are potentially present is the special case where they are not.

Note, finally, that the influence of training costs disappears in the steady state. As new labor is hired, labor's marginal product declines, reducing the firm's incentive to further increase employment. Eventually, enough new labor will be added to the firm to where labor's marginal product has fallen to simply real wage cost, and the steady-state equilibrium level of employment will be attained where L_X equals $L_{X,-1}$. The higher is τ (and the closer is δ to 1) the greater are these training costs, presumably, thus the slower will firms add new employees and the longer will be the adjustment to steady state equilibrium.

The setup for industry Y is assumed to be similar to that of X. Firms in industry Y are assumed to make products according to the production function

$$(17) \quad Y = N L_Y^{\eta} \ ,$$

and face training costs when hiring new workers. By design, however, the analysis does not consider shocks of the type which lead the Y firm to hire additional labor. All advances in technology considered are presumed to lie in the X product, and are of the type which result in an excess supply of labor and layoffs in the Y industry. Thus, the Y firm's demand for labor can be expressed simply as

$$(18) \quad L_Y = \left[\frac{\eta N}{\omega}\right]^{\frac{1}{1-\eta}} \ .$$

The parameter η reflects the returns to labor and N represents the exogenous and unchanging level of technology in the Y industry.

5. Calibration

To solve the model, it is necessary to choose values for each of the parameters, U_{max}, Q, M, β, γ, η, and δ, as well as the quality and production technology parameters, A and B, the product substitutability parameter, α, and the labor training cost parameter, τ. Table 2 summarizes the values selected for each of the key parameters.

Table 2

Fixed Parameters

β	ϕ	γ	η	δ	N
.3	1.1	.7	.7	1.1	80

Parameters which Vary for Sensitivity Analysis

α	τ	$\hat{A}$	$\hat{B}$
0.5	5	0.5	0.5
0.8	10	1.0	1.0

Consider first the production parameters γ and η, which reflect labor's share of the production of X and Y, respectively. There has been a considerable amount of research on the issue of the returns to labor. The most commonly accepted value for the U.S. is probably around .72, determined from the post-WWII data and reported by Citibase. In this study, I use $\gamma = \eta = .7$ as an reasonable estimation. Additionally, I treat labor's share in the production of X as equal to that in the production of Y so as to center attention on other parameters--A,B, α, and τ--and not on variations in labor's share across industries, which is not pivotal to the issue at hand.

Consider next the parameters β and ϕ. As noted earlier, the parameter β reflects the degree to which the marginal utility of composite consumption services diminishes as households enjoy more consumption, and ϕ reflects the degree to which the marginal utility of leisure falls as households take more leisure. In the context of the present study, therefore, these parameters govern the extent to which households will take technological progress in the form of additional leisure as opposed to consumption. That is, an increase in the quality of X or in the productivity of labor in the X industry will each allow households to enjoy more utility through consumption at the same level of total time worked. The optimizing response of households in this situation would be to work less, and if β is large or ϕ is small, then households will tend to more sharply reduce their supply of labor in response to an advance in technology than they would otherwise.

In short, households will take the benefits of technological progress more in the form of leisure and less in the form of consumption when β is high and ϕ is low. Understanding the role played by these parameters, and given that this consideration is not central to the issue at hand, I calibrate the model (choose joint values for β and ϕ) such that steady-state equilibrium employment tends to be affected relatively little by advances in technology. This is accomplished, specifically, by choosing $\beta = .3$ and $\phi = 1.1$, although other combinations of these parameters would do just as well.

One key parameter which must be specified is α. As stated earlier, α reflects the degree to which households view the products X and Y as substitutes in the provision of consumption services. The larger is α, the greater is the substitutability between X and Y, and, in the limit, as α approaches one, households view the two goods as perfect substitutes. In order to conduct the sensitivity analysis, I utilize two values for α. These are .5 and .8.

Other parameters which require specific attention are the technology parameters A and B. The initial values of these parameters play no important role in any cardinal sense, and I specifically begin with A = 1, and B = 80.

Variables which require specific attention are L, L_X, and L_Y. According to evidence presented by King, Plosser, and Rebelo (1988), the fraction of total time which households spend working tends to fall close to .20.[15] Here I use the figure L = .20, and construct the initial steady state such that $L_X = .04$ and $L_Y = .16$. That is, firm X is modelled as the relatively small employer as compared to firm Y. Consistent with this initial equilibrium and the values of the other parameters selected, notably α (which will be varied for purposes of sensitivity analysis), I set Q = M = 1, initially, but must forego choice of z and N in order to secure $L_X = .04$ and $L_Y = .16$ as the initial equilibrium.[16] Additionally, in conducting the sensitivity analysis (in particular, as the parameter α is varied) it is necessary also to readjust Q and M so as to comply with the first-order conditions for household utility maximization given by equations (11), (12), and (5) at the desired initial steady state $L_X = .04$, $L_Y = .16$.

The two other key parameters which must be specified are τ and δ. These parameters play no role in determining the steady-state values of the endogenous variables, but play a crucial role in governing the extent to which technological change has temporary effects on employment, output, and utility, in particular. The values for these parameters are admittedly somewhat arbitrary, and therefore I desire to err on the side of being

[15]Essentially, this value is determined by dividing the total number of hours worked per year by households (excluding commuting time, breaks, vacations, holidays, sick leave, etc.) by total hours available to households (24 times 365).

[16]The specific values of N and z are unimportant, and must be allowed to be free parameters in order to maintain the first order conditions for household utility maximization as I keep $L_X = .04$ and $L_Y = .16$ while α is varied.

conservative, if possible, concerning the degree to which employee training is a significant cost of production. The value chosen for δ is 1.5. In order to conduct sensitivity analysis, two different values of τ are alternatively used--5 and 10. The upper value of $\tau = 10$ represents the case where employee training costs are highest.

In order to gain some perspective on how high training costs are for $\delta = 1.5$ and $\tau = 10$, consider the case where the X firm increases its level of employment by 50% in one period. Presumably, this would be a very large increase for the typical firm.[17] Starting at an employment level of $L_X = .04$, and for $\delta = 1.5$, $\tau = 10$, a 50% increase in labor employed by the X firm involves training costs of approximately 3% relative to those of normal wage costs. Given that labor's marginal product should equal its real wage (at the previous level of employment, $L_X = .04$), this could be equivalently viewed as a 3% decrease in the marginal productivity of existing employees while they train those newly hired. Such effects do not seem unreasonably high and, indeed, likely understate those typically experienced.

6. Sensitivity Analysis and Implications

In this section, I subject the model economy to technological progress of two types--improvements in the quality of product X and advancements in productivity in the X industry. The goal is to analyze and compare the dynamic impact on equilibrium employment, household welfare, and aggregate output when progress occurs.[18] Central to this

[17]The relative number of employees which a firm finds expensive to hire may conceivably be a function of firm size. That is, it may be relatively less expensive for small firms to add 10% to their work force than for large firms, or vice versa. This feature is not modelled here.

[18]Typically, product innovation does not immediately bring its period of greatest job destruction (or welfare gains). The first (gasoline-powered) automobile on the streets of America appeared around the turn of the century, but had its greatest effects on employment beginning in the mid-to-late 1920s (see footnotes 5 and 7). The television was "invented" in 1926, atomic power in 1931, the computer in 1946, and DNA was

effort, I conduct exercises varying both the product substitutability and labor substitutability parameters (α and τ), as well as the degree and type of technological progress, in order to analyze the sensitivity of employment, welfare, and aggregate output to these economic factors.

Panels 1-3 summarize the results of the experiments conducted.[19] Four different cases are analyzed and considered in terms of their effects on employment, welfare, and aggregate output. These are

Case 1: $\hat{A} = 0.5$ and 1 when $\alpha = 0.5$ and $\tau = 5$;

Case 2: $\hat{A} = 0.5$ and 1 when $\alpha = 0.8$ and $\tau = 5$;

Case 3: $\hat{A} = 0.5$ and 1 when $\alpha = 0.8$ and $\tau = 10$; and

Case 4: $\hat{B} = 0.5$ and 1 when $\alpha = 0.8$ and $\tau = 10$.

Panel 1 demonstrates graphically the dynamic behavior of employment, panel 2 highlights effects on household welfare, and panel 3 focuses on the behavior of aggregate output for each of these four cases. Each panel begins with an initial steady state where $L_X = .04$, $L_Y = .16$, and $L = .20$, with corresponding values for household welfare and aggregate output.

Of primary interest are the employment effects of technological progress.[20] Four main

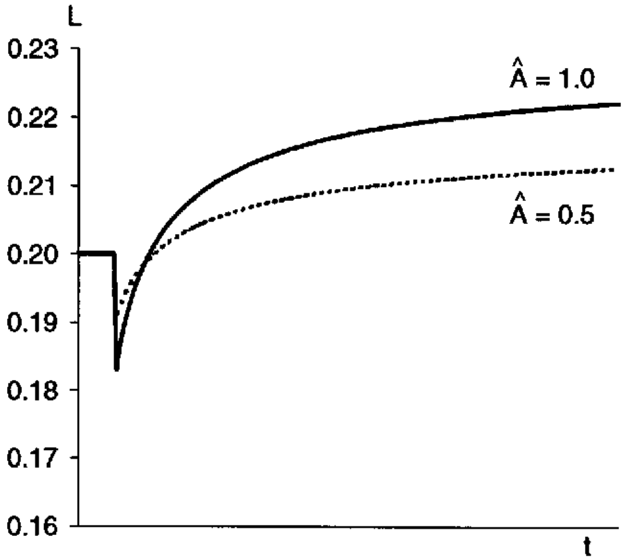
discovered in 1953, but each did not have its major employment effects until decades later. In short, the gestation period from invention (innovation) to full market power is often quite long and unpredictable. The reader, therefore, should not be mislead into inferring that the simulations conducted here describe with a high degree of accuracy the specific dynamic response of employment and the business cycle to product innovation.

[19]The specific equations utilized in the simulation are (11), (12), (16), and (18), imposing the condition of equilibrium in all markets.

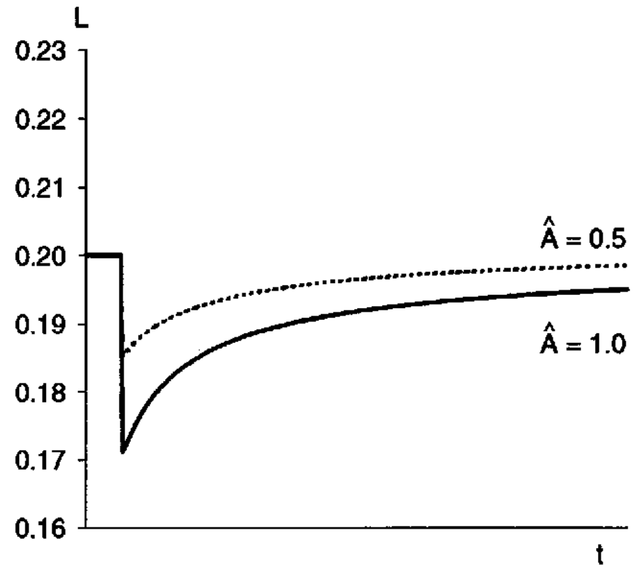
[20]Not discussed here are the long-run effects on leisure taken which technological progress allows households to afford. This is admittedly an important issue, and one which deserves more attention. History shows that the average workweek has declined from 66 hours in the late 1800s--an average of six days a week, eleven hours per day--to 55 hours per week by the first part of the 1900s, and to 40 hours a week by the 1950s. These effects are not explicitly considered here.

Panel 1: Effects on Employment

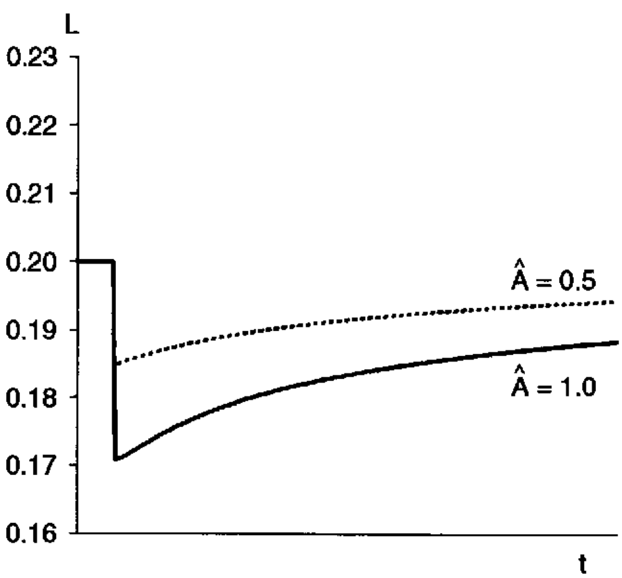
1a: α=0.5, τ=5



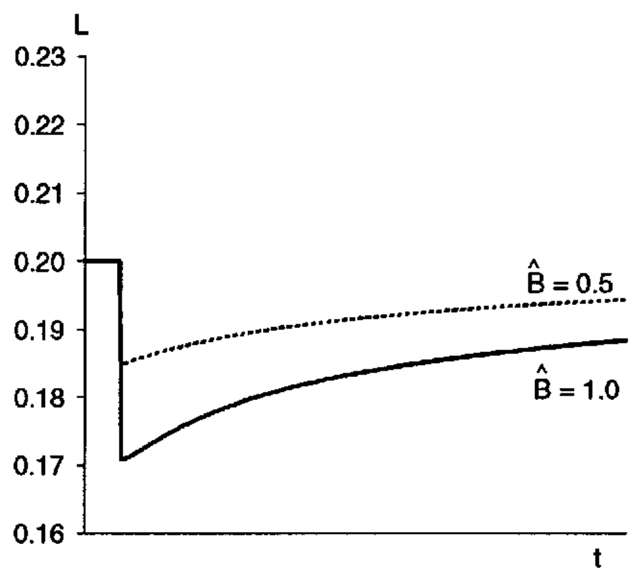
1b: α=0.8, τ=5



1c: α=0.8, τ=10

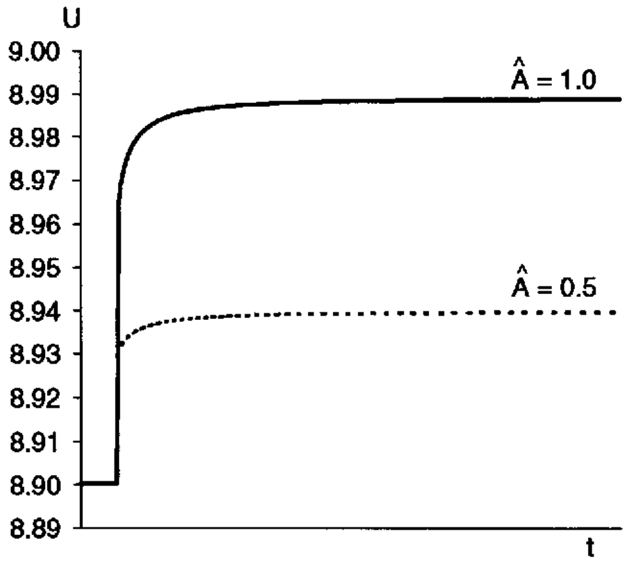


1d: α=0.8, τ=10

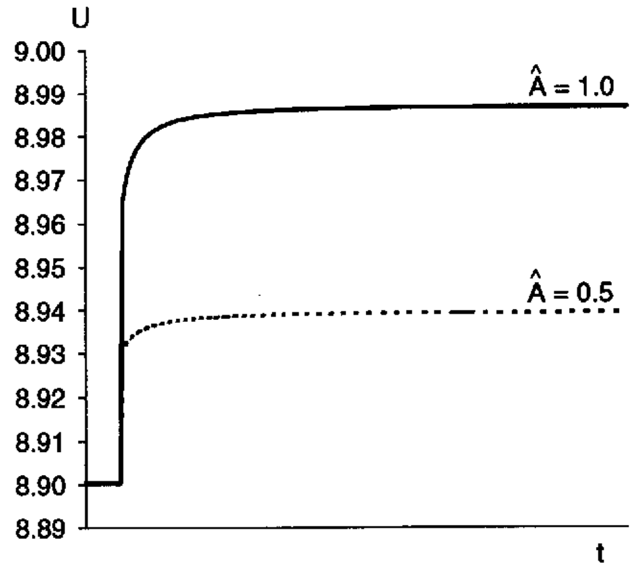


Panel 2: Effects on Welfare

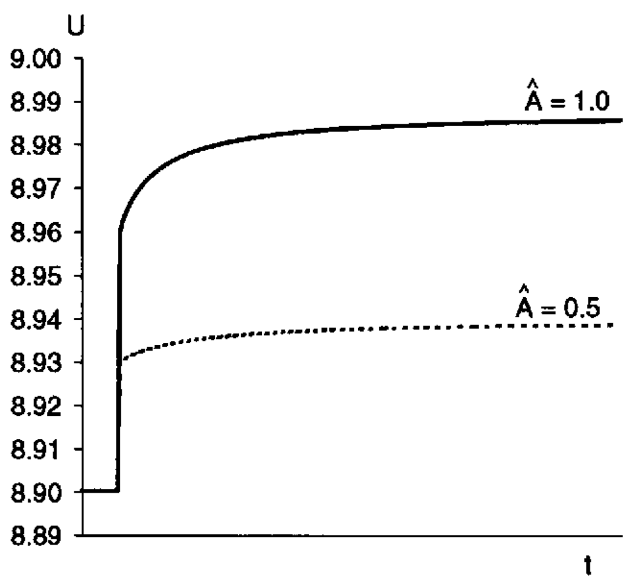
2a: α=0.5, τ=5



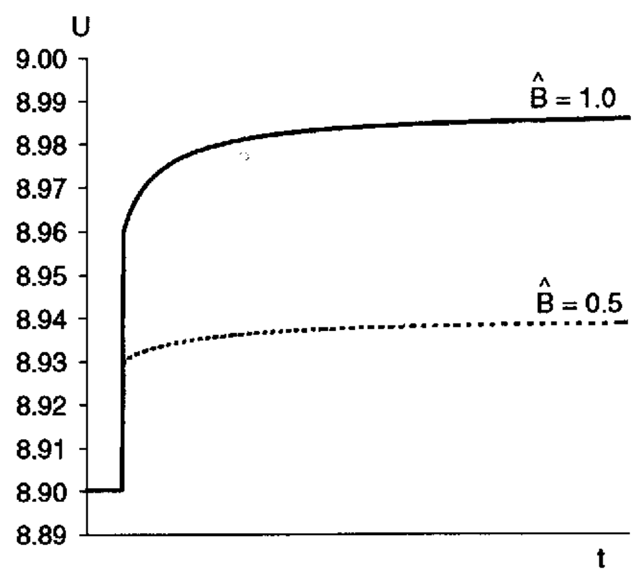
2b: α=0.8, τ=5



2c: α=0.8, τ=10

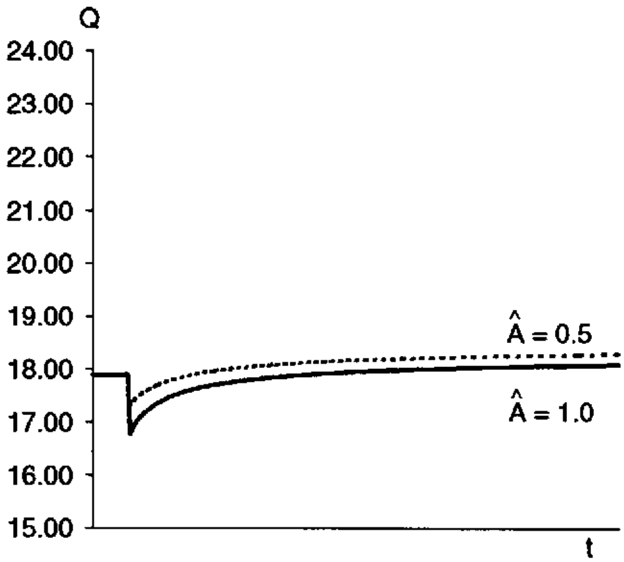


2d: α=0.8, τ=10

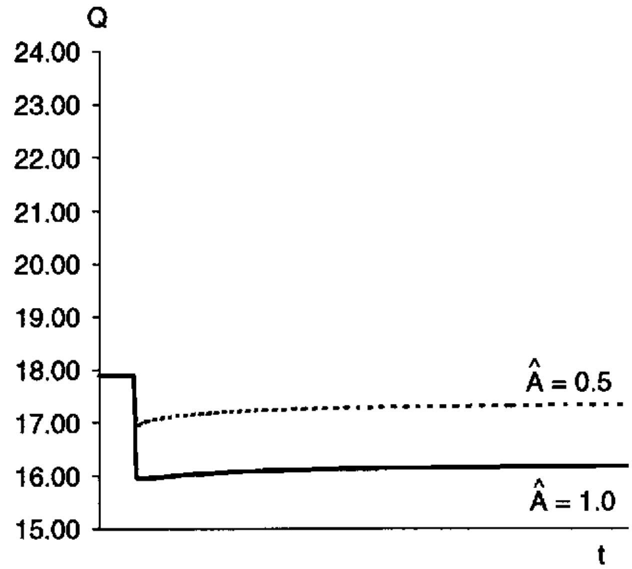


Panel 3: Effects on Output

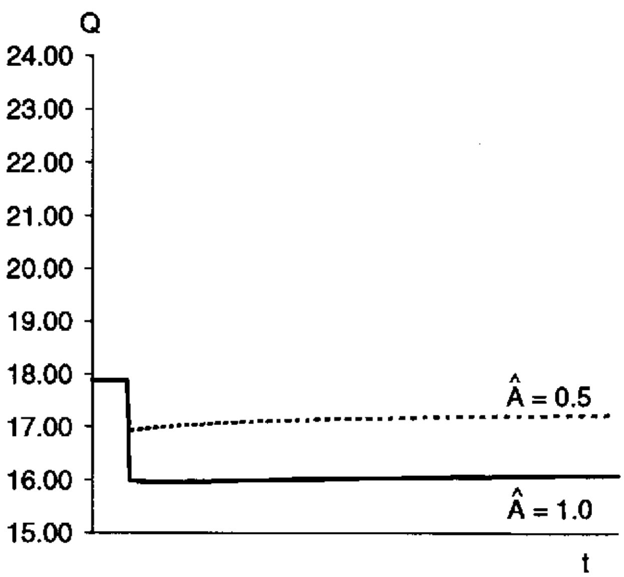
3a: α=0.5, τ=5



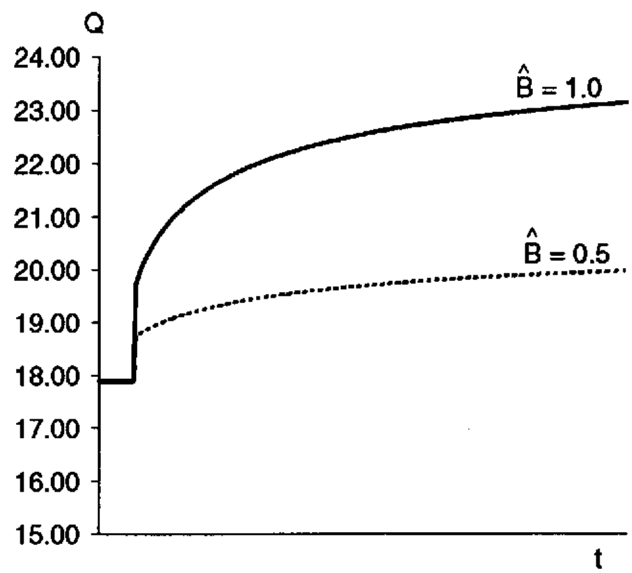
3b: α=0.8, τ=5



3c: α=0.8, τ=10



3d: α=0.8, τ=10



results should be noted from Panel 1. First, an improvement in product quality is shown to cause a greater short-run reduction in employment the greater is the quality improvement. As shown in Charts 1a, 1b, and 1c, the temporary disemployment effect of $\hat{A} = 1$ exceeds that of $\hat{A} = .5$, so that progress and job layoffs go hand-in-hand. This conclusion also holds with regard to advances in production technology (Chart 1d). Indeed, equal advances in product quality and production technology ($\hat{A} = \hat{B}$) have identical effects on household employment (Charts 1c and 1d).

Note, second, that the *extent* of disemployment caused by an improvement in the quality of one of the products is directly related to the degree which households view products as substitutes (the magnitude of α). As a comparison of Charts 1a and 1b reveals, for $\alpha = .8$ employment falls by more in response to an improvement in product X than when $\alpha = .5$. This conclusion holds identically for concomitant advancements in production technology, although I do show this result here.

These results support the hypothesis that product substitutability is one of the main factors governing the degree to which technological progress brings temporary job destruction. Economically speaking, this conclusion follows because the more substitutable are X and Y in terms of their provision of consumption services to households, the more an improvement in one product reroutes demand to the improved product from the competing one; the more the relative price of good Y falls; and the more the level of real wages in the Y industry increase, forcing firms in industry Y to cut back on employment.

Note, third, that the *duration* of disemployment depends directly on the degree to which labor skill requirements are substitutable across the two industries (the magnitude of τ). As a comparison of Charts 1a and 1c reveals, for $\tau = 10$, employment recovers more slowly than when $\tau = 5$ in response to an improvement in product quality. This conclusion also holds identically for advancements in production technology, although I do show this result here.

These results support the hypothesis that labor substitutability is one of the main factors governing the degree to which technological progress brings temporary "unemployment." Such results are reasonable and, indeed, should be expected because the higher are labor training costs--particularly marginal training costs--the more slowly will firms add new employees. Workers out of a job thus go unemployed (below fully employed, as defined by the eventual new steady state) for longer when the skills of labor in the declining industries do not match well those needed in the emerging ones.

Pertaining lastly to the issue of employment effects, some separate attention is owed to the two types of technological progress--improvements in product quality and advances in production technology. As Charts 1c and 1d reveal, these two types of progress bear identical employment effects when of equal magnitude. And, as discussed above, when subjected to the other economic considerations (variations in α and τ), advances in product quality and production technology have parallel effects on employment. Schumpeter was perhaps more right than he knew when he credited "the new consumers' goods, [and] the new methods of production" alike for the problems caused by the "perennial gale of creative destruction." As I shortly show, however, these two types of progress diverge sharply in terms of their effect on measured aggregate output.

Consider next the welfare effects of technological progress. As Panel 2 shows, technological progress bears welfare gains both in the short and long run. The curves for $\hat{A} = 1$ all lie above those for $\hat{A} = 0.5$ (Charts 1a - 1c), indicating that the larger is the technological progress, the greater are the welfare gains. This result also holds for the case of productivity advancements, which, indeed, yield welfare effects identical to those of quality improvements, if occurring of the same magnitude ($\hat{A} = \hat{B}$).

Note next the role played by product substitutability in influencing households' welfare gains. As a comparison of Charts 1a and 1b shows, the welfare path for $\alpha = 0.5$ lies everywhere above that for $\alpha = 0.8$, indicating that the less is product substitutability (i.e., the more unique are the individual products), the greater are both the immediate and long-term gains from improvement in product quality. This result also holds for advancements in production technology, although, again, it is not demonstrated here.

Labor substitutability also clearly affects the household welfare paths, and in a predictable way. Technological progress releases labor from "old" and stagnant industries for use in the "new" and emerging ones, but that labor generally must be trained because its skills are not suited for being fully productive in the new jobs. The greater is the dissimilarity in labor skill requirements between the old and new industries, the greater are firms' marginal labor training costs, the slower will innovating firms add new employees, and the slower will households realize the welfare gains from technological progress.

Innovation tends to occur in particular industries or particular products, which requires that labor be optimally reallocated. Innovation's full welfare gains are thus realized only after labor has been trained in the new tasks. Emerging firms will eventually add many (if not most) of the disemployed labor caused by product or production innovation, but generally find it too costly to hire and train all of the "surplus" labor overnight.

The seeming paradox here, of course, is that the greater is the technological progress, the greater will be the improvement in households' long-term "standard of living" (welfare), but the *worse* will be the short-run unemployment effects. Innovation in particular products raises the value of labor *in all industries*, which renders some portion of labor in old industries too expensive, thereby causing layoffs in those industries, and releasing labor to work in the innovating and emerging industries. The more unique are products (the less substitutable products are in providing consumption services to households), the more that technological progress will bring long-term welfare gains but short-term employment losses to households. And the more dissimilar are the labor skill requirements in the innovating industries for those in the competing ones, the slower will be the welfare gains from technological progress. In short, retraining and patience are required in order to reap the full benefits of innovation and the "creative destruction" which it brings.

Consider finally the aggregate output effects of technological progress. Because national economic "bean counters" tend to measure society's progress in terms of aggregate output (perhaps because of an inherent difficulty in measuring welfare or product quality), I construct here an aggregate output index, Q, defined as $\rho X + Y$, and track the behavior of that output index in response to the two types of technological progress. To conform with standard practice in aggregating output, I hold (relative) prices constant and value the variations in X and Y at ρ prevailing in the initial steady state.

Two main results should be noted from Panel 3. First, and most important, note that the aggregate output index tells two entirely different stories depending on whether the technological shock is quality or output enhancing. As a comparison of Charts 3c and 3d demonstrates, aggregate output is measured as rising (Chart 3d) both in the short and long run when progress occurs in the form of production technology; but measured aggregate output actually *falls* in the short run when that progress instead occurs in the form of product quality. This happens despite the fact, as shown earlier, that the effect on household welfare (Charts 2c and 2d), is the same for the two types of progress.

This is an important point to note because it shows that aggregate output indices are prone to misinterpretation, and can easily give misleading signals concerning the extent to which society's welfare has advanced. Parallel but different forms of technological progress ($\hat{A} = \hat{B}$) will sometimes be manifest as an economic "boom" ($\hat{B} > 0$) yet other times as a temporary recession ($\hat{A} > 0$). Economic policy-makers focusing on aggregate output may unwittingly find themselves content when progress occurs in the form of advances in production technology, but tempted to intervene (say, to protect jobs) when progress occurs in the form of a better product. This point is made particularly relevant, I believe, by the fact that product quality is difficult to measure, whereas simple quantity is not.

Additionally, aggregate output will appear to fall further and be more stubborn to recover the less substitutable are existing products for the innovating ones, and the less substitutable are labor skills in the existing industries for those in the emerging ones. Again, the information embodied in an aggregate output index may be so difficult to decipher as to render the index virtually useless.

7. Conclusion

Lately, much attention has been focused on the endogenous aspect of economic growth. Examples include Romer (1986), Lucas (1988), Grossman and Helpman (1991), and Aghion and Howitt (1992). Their work on endogenous growth has concerned three main issues: (i) knowledge and human capital spillovers as they enable economy-wide increasing returns to scale, (ii) an explanation of the nature of the dynamic process which leads to product evolution, and (iii) product cycles and creative destruction.

The focus of this paper is not on the endogenous aspect of economic growth, but rather on the role of demand and supply side technological innovations in generating employment cycles. For future research, it will be interesting to incorporate the R&D sector developed by Aghion and Howitt (1992) to determine endogenously the evolution of economy-wide technology. Such an extension will enable us to examine the issue of growth and cycles, focusing primarily on the labor market, instead of on the financial market. (For the latter see Stiglitz (1993) and King and Levine (1993)).

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