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INDUSTRIAL GROWTH AND THE THEORY OF RETARDATION: PRECURSORS OF AN ADAPTIVE EVOLUTIONARY THEORY OF ECONOMIC CHANGE

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Introduction

The invitation to contribute to this conference in honour of Richard Nelson and Sid Winter has provided me with a welcome opportunity to return to one of my abiding concerns, the theory of industrial growth. Indeed, the central concern of this paper is the dynamics of economic growth under the rules of restless capitalism, in which the consequences of multiple and uncoordinated innovative activities are strongly ordered by market processes to produce patterns of growth and development in the economy and its framing institutions. The central theme of this world view is that growth is fuelled by sequences of technical, organisational and institutional changes creating and absorbing new areas of productive activity and consumption into the economic structure. The social is as important as the economic in understanding this dynamic and decline of activity is as important as expansion of activity in understanding the contours of development. This is a theme which is central to the Nelson and Winter project as first fully articulated in their An Evolutionary Theory of Economic Change, and one which reflects a modern concern with a more systematic understanding of the process of creative destruction (Schumpeter, 1944). However, it is a perspective that contrasts sharply with modern growth theory, endogenous or otherwise. For a macro approach has averaged away not only the facts of the uneven incidence of growth and technical change across sectors it has also hidden from view the very processes by which changes in technique come to have their economic effects. In the Nelson and Winter picture, by contrast, growth is very much bottom up but to see it entirely in this light is as damaging as to see it only in top down fashion. Rather, the aggregate structures and patterns that emerge at higher levels of the economy create important feedback effects to shape the underlying processes of microevolution of technique, organisation and institution. This inherent complexity of the interaction between technical progress and economic growth in modern economies means that simple categorisations of the growth process will be difficult to find. My conjecture is that Nelson and Winter have it right, the best way to make progress is to see this interaction as an adaptive evolutionary process, a triple process of variation, selection and development. Evolutionary theory is naturally growth theory but it is the diversity in rates of growth within appropriately defined populations that is the focus of attention. The question is ‘Why growth rates differ and vary over time?’ not ‘Why are the uniform and invariant?’. With diversity in growth comes structural change and the mutual determination of those growth rates such that the rates of growth are emergent phenomena arising from replication and interaction. This evolutionary view locates growth within market processes and the framework of institutions that defines modern capitalism, it emphasises the open nature of competition within these frames, and it gives innovation, in the broad, pride of place as the primary stimulus to the growth and development of economies.

There are many varieties of evolutionary growth theory but the variant that I explore here is based on the theory of niche formation and exploitation and I shall use these ideas to explore some precursors of this evolutionary perspective on growth. For it turns out that prior to the Keynesian revolution and Harrod's formulation of modern growth theory in the late 1930s, there was in place a rich empirical and theoretical literature on the problem of secular economic change, a literature that posed the problem in terms of the nature of innovation and the development of technology. This literature has at least four main branches of which three are firmly in the economics literature. First, is the line of analysis established in Schumpeter's Theory of Economic Development, with its emphasis on the introduction of new forms of economic activity and their spread within the economy. An ecologist would readily recognise this as a model of speciation and competition for economic niches. Secondly, we have the detailed, empirical investigation of Simon Kuznets and Arthur Burns on secular trends in real output and the so-called retardation hypothesis at the level of individual industries. Thirdly, and in a quite different tradition, the argument of Allyn Young to the effect that the link between technical progress and economic change was a deeper reflection of the Smithian argument on the extension of the division of labour. That is to say, the rate of progress is closely connected as cause and effect with the rate of growth of the market. All of these contributions lie firmly within the economics discipline. The fourth contribution is from a different domain and it concerns the background debate on 'laws of growth' arising from within the emerging discipline of mathematical ecology but which had much wider implications for the study of industry and the economy. Lotka's treatise Elements of Physical Biology, published in 1924 provided the definitive statement of this literature, and there evolution is defined in terms of the redistribution of the components of a system, that is, as structural change. Taking all of these strands together connects the argument on economic growth with a central topic in ecology, namely, the way in which a new species grows into its environmental niche. The insight here is that the dynamics of growth are governed by two considerations, the intrinsic rate of increase of the species (r) and the carrying capacity of the species in the environment (K) (Roughgarden, 1979; Slobodkin, 1980). This, so called $r-K$ theory is undoubtedly crude and mechanistic but it can be developed and applied in a variety of ways, which lay bare the essential features of the secular growth process of economic activities. Anderson (1994) and Saviotti (1996) have applied these ideas to a modern formulation of the question of economic growth. My purpose is to retrace the argument back to its origins in the 1930s in the work of the 'retardationists', Kuznets and Burns in particular. In the process we shall develop an economic interpretations of carrying capacity and intrinsic rate of increase so that their characterisation is not arbitrary but relates to the dynamics of the market process.

Growth and Retardation in Progressive Economies

In his comprehensive review of modern economic growth Abramovitz (1989) identified structural change and a tendency towards retardation in the growth of output as two salient empirical generalisations about the process of economic growth. Structural change is, of course, a necessary reflection of diversity in the growth rates of different activities. In any ensemble that activity that grows more rapidly than the ensemble average will increase in relative numerical importance in that ensemble. Retardation, however, is a different phenomenon, the systematic tendency for rates of growth of specific entities or their ensemble to decline with the passage of time. To anyone brought up on the economics of uniformly expanding economies, whose structure cannot change over time and whose rate of growth is constant, neither of these propositions will have much resonance. Yet they are central to the literature to which Abramovitz is referring, in particular to the work of the two principal retardation theorists, namely A.F. Burns and S. Kuznets[1]. Both authors are concerned with the measurement and explanation of secular or long time movements in the volume of economic activity. Both emphasise that the introduction of new activities and the disappearance of old activities are an intrinsic part of the development of capitalism. Accepting that the modern economic system is 'characterised by ceaseless change', neither could proceed with an aggregate analysis of growth nor accept the idea of uniform progress in all branches of activity.

Let us begin with A.F. Burns detailed study of American economic growth in the period 1880-1937. Like other empirically minded scholars, Burns gathered a great deal of evidence to establish that a central feature of modern economic development is the diversity of growth rates of output across different sub-sectors and industries in the economy. What might

[1] Abramovitz (1989), pp. 12-13, 30-31 and 90.

appear to be smooth progress of production and trade in the aggregate hides a considerable diversity of experience. It is interesting to note that Burns takes Gustav Cassel, and by implication modern growth theorists, to task for conceiving of a regularly expanding economy precisely because this necessarily rules out the mainspring of economic growth, namely an uneven incidence of technical and organisational change. His list of diversity creating factors has a thoroughly modern ring to it: new commodities; new raw materials; changes in methods of production; new methods for the recovery of waste products; changes in forms of industrial organisation; increases in the number of uses of given materials and in the number of materials put to a given use; and, finally, the emergence of what he calls learning products and style goods. In sum, Burns claims that "These changes have resulted in an increasing divergence of production trends for they have served to stimulate or depress but to an unequal extent, the development of various industries" (p. 63). Furthermore, what makes an economy progressive is not diversity *per se* but a positive skew to the distribution of growth rates[2].

Simon Kuznets had independently explored the same themes (1929, 1954) and from a broadly similar perspective. He stated the problem clearly as follows,

> 'As we observe various industries within a given national economy, we see that the lead in development shifts from one branch to another. A rapidly developing industry does not retain its vigorous growth forever but slackens and is overtaken by others whose period of rapid development is beginning. Within one country we can observe a succession of different branches of activity in the vanguard of the country's economic development, and within each industry we can notice a conspicuous slackening in the rate of increase' (Kuznets, 1929/1954, p. 254).

Of course, the long secular movements of the shares of agriculture, industry and service sectors in total output provide confirmation at higher levels of aggregation of the enduring presence of growth rate diversity and structural change. As do the shifting rural-urban balance of the population, changes in working hours and changes in the pattern of household consumption. Indeed the long swing of develop ment must have been marked by as much

[2] Glenday (1938) applied Burns' method to long production series for eight UK industries and found consistent evidence of retardation.

change of preferences as change of industry[3]. As Pasinetti (1981) rightly concluded, it is the presence of structural change which makes it impossible to conduct the analysis of growth by macro economic methods alone[4&5].

However, the unevenness of growth experience is only part of the picture. For both Burns and Kuznets focused upon a further regularity in the process of restless growth, namely retardation, the persistent tendency of growth rates to decline over time from the inception of the industry. Their explanations of retardation are remarkably similar, emphasising population growth (a minor element), foreign competition, interindustry relations of competition and complementarity and, of vital importance, technical progress. Indeed, for both Kuznets and Burns, it is retardation in within industry rates of technical progress, which is the chief explanation of retardation in rates of output growth. Moreover, their theories of technical progress are essentially the same, an industry being created by an invention, or complex of innovations which offers scope for a myriad of improvements of ever decreasing importance. A view beautifully and subsequently expressed by Hicks (1977) who wrote in terms of the 'economic children' that follow the original invention. A sequence of initial inventions creates new activities and a potential design space to explore the possibilities latent in the new concepts and so provides the fuel to maintain a trajectory of technical innovation over time. This is a theme familiar to all evolutionary minded scholars and students of innovation (Dosi, 1982; Georghiou, *et al*, 1984).

It is fair to say that while the broad outlines of the Kuznets/Burns theories are clear, a number of important details are not. In attempting to clarify the various elements it is clear the three major and distinct mechanisms are involved.

[3] For some interesting commentary see Baumol *et al* (1989, chapter 3).
[4] Pasinetti (1981), p. 65. It is a point with which Schumpeter would have heartily agreed. See Schumpeter (1939), p. 43-44.
[5] If s_i is the share of industry i, in a constant price weighted measure of industry output, then in a small interval of time, $\Delta s_i \approx s_i(g_i - g)$, g_i being the growth of the volume of output for industry i, and g being the growth rate of the aggregate. The contribution which i makes to a constant average growth rate, $s_i g_i$, changes as $\Delta(s_i g_i) = s_i g_i (g_i - g) + s_i \Delta g_i$. Obviously, a fast growing sector need not have much effect on the aggregate growth rate since, typically, fast growth corresponds to the early life of the industry where its share is also small. See Kuznets (1971, ch. 8).

The first concerns the dynamics of demand for a new product, or, more precisely, the dynamics of preference formation in which users learn to assign positive value to a new commodity. If micro foundations are to be found for such a process they will not be concerned with rational allocation in the presence of given knowledge but with a process of learning in which established patterns of behaviour are disrupted. Following the practice of modern evolutionary economics this process is perhaps best visualised in terms of the mutation of decision rules as new areas of consumption space are opened up and explored (Cross, 1983; Metcalfe, 2001). Our knowledge of these preference formation processes is, to say the least, sketchy, although the empirical evidence in favour of some form of adaptive learning process is strong (Cowan, Cowan and Swann, 1997). As a general rule, it is to be expected that rates of learning will depend on the current pattern of individual consumption and how the new good, or, for that matter, service, fits in this context and upon observations of the consumption experience of others. Similar issues apply to the development of demand for new industrial goods

The second mechanism concerns the growth in capacity to supply a new commodity, a mechanism in which profitability plays a central role as source of capital and as stimulus to investment and entry and, indeed, disinvestment and exit from industry when necessary. Placing the profit mechanism at the heart of the growth process necessarily does the same for the processes of price and cost formation. Diversity of growth is closely connected to diversity of profitability, and retardation in growth to retardation in rates of profitability. Under the rules of capitalism, one cannot possibly comprehend growth in the application or consumption of new goods without taking account of the central role of profitability in developing the capacity to supply.

The final mechanism involves the development of the technology with product improvements extending existing or opening up new areas of demand and improvements in the production process reducing unit production costs. Yet it is clear that the Kuznets/Burns explanation of the slackening of technical progress is focussed too much on the supply side of the problem. Schmookler, for one, argued for a demand side interpretation of retardation in terms of a declining elasticity of market demand, and some recognition needs to be given of the interrelation between the two blades of the scissors. Such a deeper sense of understanding is provided in the contemporaneous work of Allyn Young (1928) who, drawing on roots in Smith and Marshall, articulates the view that the extension of the market causes and is caused by the exploitation of technological opportunities. We shall suggest below that this is precisely the insight needed to capture the link between retardation of output growth and the slackening of the rate of technical change.

Taken together, the three processes, demand oriented learning, the accumulation of capacity and the rate of technical progress, provide the basis for an ecological dynamic of industry growth wholly appropriate to restless capitalist economies. Each one interacts with the others and all three are firmly located within the market process so that the nature of their interaction depends on that process of market co-ordination.

Growth Curves and Ecological Niche Theory

A major weakness of many of the empirical studies of modern industrial growth, including those of Kuznets and Burns, is that they are essential curve fitting exercises without a clearly articulated theoretical basis in the three mechanisms outlined above. At best they establish important regularities in growth behaviour and provide a potential basis for trend forecasting. Moreover no one growth curve is necessarily to be preferred to any other, and there are a wide variety of such curves available (Tingyan, 1990). In fact, there is a fundamental difficulty behind any growth fitting exercise, namely that observed growth is a joint outcome of a dynamic process and possible changes in the parameters of that dynamic process. What is observed in fact is an envelope of a sequence of growth curves each one contingent on given and different parameter values (Metcalfe and Cameron, 1988). Thus, a logistic process may drive the dynamics of a given industry, for example, without the outcome being a logistic curve. The secular time trend of itself does not establish the properties of the underlying processes. Obviously, there is no point squabbling over the merits of alternative growth curves unless one also has a clearly articulated theory of changes in the parameters of the growth process[6].

[6] For valuable discussion of the competing alternatives, see Antonelli *et al* (1992), Stoneman (1983) and Mahajan and Peterson (1985). The pages of the journal Technological Forecasting and Social Change are a rich source of empirical studies using different growth curves. One of the classic early references based on the logistic curve is Fisher and Pry (1971).

Some help in these matters is provided by ecological theory. In seeking to explain the changing balance between different species in the natural world ecologists have developed the concept of the niche, a limiting space within which a given organism can survive, and a dynamic of how this space is filled. The development of this apparatus need not concern us here, suffice it to say that it involves a distinction between the carrying capacity of the niche for a species (K) and the intrinsic rate of increase of the species in an unlimited environment (r). Hence the appellation, $r - K$ theory (Lotka, 1924/1956; Roughgarden, 1979; Slobodkin, 1980; Kingsland, 1985; May, 198x). What is interesting for us is that the origins of this approach are also to be found in the 1920s and 1930s. The ideas, which were in the air at exactly the time that Kuznets and Burns formulated their theories of industrial growth, are, to all intents and purposes, sophisticated yet unintended versions of $r - K$ theory. The niche is the analogue to the market and the intrinsic rate of increase is reflected in the dynamics of consumer learning, accumulation and technical progress. To explore this claim further we need a more explicit formulation of the foundations of the industrial growth curve.

In the following analysis, we have settled on the Gompertz process, largely because of its convenient properties in explicating the role of key economic elasticities and incorporating time dependent changes in the environment of the industry[7]. To remind the reader, the Gompertz curve, the integral of the Gompertz process, is an asymmetric sigmoid curve with an influence point at approximately 37% of the carrying capacity or long run value of the dependent variable[8].

Secular Expansion and the Gompertz Process

In economic ecology, the analogue to speciation or mutation is innovation. So we begin with the introduction of a new product with its own process of production that is introduced into the prevailing market environment. This product has certain fixed performance characteristics relative to the other products with which it is in competition, and at a price $p(t)$, all other prices being given, the long-run level of demand is given by

[7] In previous papers, Metcalfe (1981) and Metcalfe and Cameron (1988), I have explored similar theories using the logistic process. But this process is rather clumsy as a basis for treating time dependent shifts of the kind explored here.

$$Y(t)_D = n(t) = \eta_0 p(t)^{-\alpha} \tag{1}$$

α being the elasticity of long-run demand. This long run notion of demand describes the situation that would prevail when the evolutionary process has run its course. Notice carefully then, that this is the long-run level of demand when all learning of preferences has been completed, so that actual demand is always less than this long-run level. The Gompertz process postulates that this learning process can be summarized by the following differential equation

$$\frac{d}{dt}\log Y(t)_D = \beta[\log n(t) - \log Y(t)_D] \tag{2}$$

so that $Y(t)_D$ approaches $n(t)$ asymptotically over time. At a given price there is a given niche that is filled at a rate determined by this learning process. Now, if, as is highly likely, $p(t)$ is also changing over time, it is apparent that the actual path of demand growth need not follow a Gompertz curve, although it is generated by a Gompertz process. A theory of industrial growth in which the product price is arbitrarily determined is obviously unsatisfactory, we therefore need a theory of how the price of a new commodity is determined and how it changes over time. To internalise price formation within the growth process we require a statement of the supply side, in particular, of the growth of capacity to supply the expanding market. The view we take here is that firms set the price relative to unit costs in order to finance growth at a particular rate, so that capacity growth is proportional to current profitability. The investment analogue to the demand side learning process is

$$\log p(t) = \kappa \frac{d}{dt}\log Y(t)_s + \log h(t) \tag{3}$$

Where, $d/dt \log Y(t)_s$ is the growth rate of capacity. The coefficient κ will depend upon rules about the funding of investment, on the capital requirements per unit of output and on the conventions determining the rate of depreciation. To begin with, we let the industry have a constant level of unit cost,

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[8] c.f. Windsor (1932), Prescott (1922) and Peabody (1924) for early discussion and application. The logistic curve is symmetric around an influence point which corresponds to half the carrying capacity. The Gompertz curve was first proposed for actuarial purposes in 1825!

$$h(t) = h_0 \qquad (4)$$

Holding $p(t)$ constant (3) also integrates to give a Gompertz curve for the secular growth of productive capacity, a process in which profit drives investment. It follows that for any arbitrary $p(t)$ we have two Gompertz curves giving different paths for demand and capacity. Naturally, such unbalanced market situations are not likely to characterise the secular trend of the industry unless it is a small economy with $p(t)$ fixed by world market conditions. Hence, the obvious step is to require capacity (output) and demand to grow in step with the price adjusting to bring this about. We call such a secular path a balanced path. Combining (2) and (3) by setting $Y(t)_D = Y(t)_s = Y(t)$ and taking account of (1) and (4), we find that this balanced process satisfies the equation

$$\frac{d}{dt}\log Y(t) = B[\log K - \log Y(t)] \qquad (5)$$

where the coefficients B and K are given by

$$B = \frac{\beta}{1 + \alpha\beta\kappa} \quad , \qquad \log K = [\log\eta_0 - \alpha\log h_0]$$

and $\qquad Y(0) = Y_0 .$

Each of the parameters B and C combines together the economic influences on the growth process, in terms of learning and long run demand, investment and long run costs of production, in a clearly identifiable way. These coefficients are not arbitrary but reflect in a precise way the underpinning market process. Now the surprising feature of this balanced path is that it is also a Gompertz process even though the price of the product and the scale of long run demand are varying endogenously over the process of secular expansion. For future reference it is useful to let $\log Y(t) = x(t)$ so (5) can be written as

$$\frac{dx}{dt} + Bx(t) = B\log K$$

which integrates to give

$$\begin{aligned} x(t) &= e^{-Bt}\left[x_0 + B\int_0^t e^{Bt} \log K dt \right] \\ &= e^{-Bt} \log Y_0 + \log(Y_0 / K)e^{-Bt} \end{aligned}$$

Whence we have the equation for the Gompertz curve

$$Y(t) = e^{\log K} e^{\log(Y_0 / K)e^{-Bt}} \tag{6}$$

with $Y(\infty) = K$ and $Y(0) = Y_0$. Output increases along the balanced secular path, tracing a sigmoid curve with the inflexion point when $Y(t) = K / e$. As far as the balanced growth rate is concerned we have

$$g_y(t) = \frac{d}{dt}\log Y(t) = \frac{dx}{dt} = -B\log(Y_0 / K)e^{-Bt} > 0$$

while the rate of retardation is given by

$$\frac{d}{dt} g_y(t) = B^2 \log(Y_0 / K)e^{-Bt} < 0$$

Now the interesting aspect of this is that we have isolated the retardation phenomena without having to introduce technical change, other than that implied by the foundation of the industry, *pace* Burns and Kuznets. Our dynamics are driven by the interaction between learning and capacity expansion and there is no technical progress subsequent to the initial innovation. Retardation is a consequence of creating and filling the niche according to the rules of learning and capacity accumulation.

Solving for the path of prices, as a function of current output we find

$$\log p(t) = [\kappa B \log K + \log h_0] + \kappa\beta \log Y(t) \tag{7}$$

Clearly, $p(t)$ declines over time, and always falls relative to the unit cost level h_0. Since profits and growth are so closely linked, it follows automatically that retardation and a squeeze on profit margins are two sides of the same coin. This, of course, mirrors Schumpeter's famous depiction of profits as 'at the same time the child and victim of development' as he put it profit is 'related to the creation of new things, to the realisation of the future value system' (1934, p. 154).

We have referred already to the ecological parallels to our secular growth process, and here it is appropriate to interpret K as the carrying capacity of the industry and B as its intrinsic rate of increase. Notice that K is not dependent upon the two primitive rates of increase, β and κ, while B is dependent on the long-run demand elasticity, α. Figure 1a should help in the interpretation of these remarks.

The carrying capacity K is determined in familiar fashion by the long-run co-ordination of supply and demand (equations (1) and (4)) but this is only the asymptotic outcome. The price output combination coincides with neither the long-run cost curve nor the long-run demand curve but follows a trajectory such as that indicated by the locus $a-a$ in Figure 1a. In fact, the greater is β relative to κ, the closer will this locus lie to the demand curve D, rather than the supply curve H. In the limit, if β is infinite, instantaneous learning, the trajectory coincides with D while if κ is zero, no capital constraints on capacity expansion, the locus coincides with H. Different values of the long-run elasticities give different values for B and K. As the reader can readily establish, a higher value of the demand elasticity is associated with a lower value of K and a greater value of B. For completeness, Figure 1b plots the growth rate of output $g_{Y(t)}$ against the logarithm of output to indicate the pattern of retardation, as output expands to fill the long-run niche. Thus, output, capacity, demand, price and unit costs develop jointly to define the balanced expansion for the industry. Following Hicks (1977) we can say that the establishment of the new industry has provided an impulse to growth, a potential which is capitalised upon by investment and consumer learning.

I need scarcely stress the very limited nature of this exercise. At most it provides a first cut at a complex problem, a basis for separating out the different contributions of the dynamic elements and the long-run supply and demand elasticities. But much is missing. There is no explicit treatment of entry and exit as influences on capacity expansion, despite the evidence pointing to their importance in the process of secular growth (Klepper and Simon, 1994). Nor can there be unless firms with different costs and/or product variations are allowed to co-exist and compete within the process of secular expansion. With different firms, the coefficients B and K become averages, dependent on the composition of the industry and drift over time as competition concentrates output on lower cost, higher quality firms. Nor do we allow for competitive and complementary interactions between this and other industries[9]. Finally, foreign trade has escaped our net, an omission, which obviously needs to be remedied. Nonetheless, we claim to have a good starting point for such developments, and before we turn to one such extension some remarks on departures from balanced expansion are in order.

Balanced expansion is clearly a strong requirement, for entrepreneurs to keep capacity growth in exact step with demand growth would require a considerable degree of foresight and a tranquil environment. But like Harrod's famous warranted growth rate, the balanced rate is the rate consistent with the decision rules of firms and consumers and, therefore, provides the consistency requirement from which further analysis can be developed. We can interpret his balanced path as equivalent to Kuznets's primary trend of production. Now while the rules adopted in relation to pricing and investment behaviour can well tolerate small departures or self-correcting cyclical departures from balanced expansion, the secondary trend, they are not likely to cope with major shocks which are bound to lead to a fractured process of secular change. Figure 2 illustrates what might occur in the face of an unforeseen reduction in demand or an unforeseen increase in costs. The immediate consequence of which is to create excess capacity in the industry and to reduce the long-run niche to K. Up to time t_1 expansion is balanced but the shock drives output, $\log Y_2$, below capacity, $\log Y_1$, and destroys the basis for ongoing investment until demand has grown again to fully absorb capacity. From then on balanced expansion can resume but directed towards a new niche which reflects the changes long-run fundamentals. Thus the path $a-a$ is fractured and ultimately resumes as the path $b-b$. Similarly, an unforeseen increase in demand will generate a capacity shortage and a price above its balance value. Growth is again fractured until the capital stock has caught up with market demand.

[9] A point emphasised by Kuznets and Burns. But see Metcalfe and Gibbons (1987) for such a treatment in the logistic case.

It is one thing to consider the effects of exogenous shocks, which fracture the growth process and may be identifiable with the aid of econometric techniques that isolate breaks in trend. It is quite another matter to work through the effects of changes in the determinants of the growth process. Here there are an immense number of possibilities and we focus attention on the case of an exponentially growing environment, for which the Gompertz framework has a number of distinct advantages.

<u>An Exponentially Changing Environment</u>

Neither Kuznets nor Burns assumed that growth took place within a stationary environment, changes in the competitive relations between commodities and in production costs were central to their arguments. Yet our initial exposition was based on the assumptions of a given demand curve and a given cost curve for the industry, reflected in the two constants η_0 and h_0. This we now remedy. As far as demand is concerned, we should instead expect that the long-run curve alters at a rate which reflects the growth of total income and the income elasticity of demand for the new commodity and the influence of competitive and complementary relations with other commodities. Similarly we can allow technical progress to reduce unit costs. This we do by initially assuming a constant proportionate rate of cost reduction. Thus instead of relations (1) and (4) we have

$$n(t) = \eta_0 e^{n_1 t} p(t)^{-\alpha} \tag{I}$$

and

$$h(t) = h_0 e^{-h_1 t} Y(t)^{-\varepsilon} \tag{IV}$$

In (I) n_1 is the exponential rate of growth of demand and its value reflects the impact of changes in preferences and growth in per capita income. In (IV), h_1 is the exponential rate of cost reduction and ε is the elasticity of unit cost with respect to output. Now the technical progress function embodied in (IV) is precisely a version of the famous Verdoorn Law, in which the rate of technical progress is linked to the rate of growth of the market. This is the theme laid out by Young (1928) in his formulation of the growth process and confirmed subsequently in countless empirical studies. It is also the theme that Kaldor built on in his technical progress function. Now the force of this is to make the rate of cost reduction increase with the rate of growth of the market and so make the expansion of the market expand the market yet further. As Knight put it growth in capitalism is a 'self exciting process'.

The new equation for the balanced process is

$$x(t) = \log K_0 + e^{-Bt}\left[\log Y_0 - \log K_0 + A\right] + G\left[t - \frac{1}{B}\right] \qquad (8)$$

where $\log K = \frac{1}{1-\alpha\varepsilon}\left[\log \eta_0 - \alpha \log h_0\right]$, $G = \frac{(\eta_1 + \alpha h_1)}{(1-\alpha\varepsilon)}$, and $A = \frac{G}{B}$.

These coefficients have a precise interpretation. B is the intrinsic rate of increase of the industry, G is the rate of growth of the long run market niche, and K_0 is the initial value of that niche. For market co-ordination to be possible it is necessary that $\alpha\varepsilon < 1$. Otherwise, we cannot define the long run niche for the industry.

For large t it is clear that $\log Y(t)$ tends toward $K(t)$, growing exponentially at rate G. This growth rate is higher the higher is the growth rate of demand and the faster the rate of cost reduction. It is also clear that $Y(t)$ no longer follows a Gompertz curve although a Gompertz process determines its path. In fact, the path of $Y(t)$ is now given by

$$Y(t) = \left[e^{\log K_0} e^{(\log Y_0 / \log K_0)e^{-Bt}}\right][\phi(t)] \qquad (9)$$

where $\log \phi(t) = Ae^{-Bt} + G(t - 1/B)$.

This is different from (6) in two respects. The niche K is replaced by its initial value K_0, and the first bracket, which is a Gompertz curve with K_0 as its upper asymptote, is multiplied by the modifying function $\phi(t)$, which increases without limit over time.

The long-term dynamics are thus determined by the increase in the niche for the industry, which in turn reflects the interaction between technical progress and the growth in demand. In fact it is easy to see that the long-run niche grows according to

$$\log K(t) = \frac{1}{1-\alpha\varepsilon}\log(\eta_0 - \alpha h_0) + Gt \tag{10}$$

If the market niche is growing at an exponential rate, it makes sense to enquire how $Y(t)$ grows relatively to the ever increasing value of this niche. Is there a sense in which output catches up, relatively speaking, to fill the niche? Subtracting (9) from (8) we have

$$\log\frac{Y(t)}{K(t)} = e^{-Bt}\left[\log(Y_0/K_0) + A\right] - A \tag{11}$$

which, is a clear and perhaps surprising result. It is the ratio of output to its growing niche value which follows a Gompertz curve towards an upper asymptote with value e^{-A}. That is, $\log[Y(t)/K(t)]$ tends towards the ratio G/B, the natural growth rate of the niche divided by the intrinsic growth rate of the industry (Figure 3). In answer to our question it follows that the niche is progressively but not completely filled, $Y(t)$ never catches up with $K(t)$, and remains further away the greater is G relative to B. The reason for this is not difficult to fathom. Since the industry tends towards a constant, positive growth rate, the price can never fall into equality with unit costs as it did in the case of a stationary environment, a positive profit margin is always needed to finance growth at the long-run rate. But this excess of price over unit cost exactly prevents output fully filling the niche. In this it reflects an argument familiar in ecology. In a changing environment, the long-term values of a species are not determined by carrying capacity alone but by this in relation to the intrinsic rate of increase. Since the ratio $Y(t)/K(t)$ follows a Gompertz curve it follows automatically that its rate of increase is subject to retardation. In this relative sense retardation is confirmed even though output ends up growing exponentially.

Whether this implies that $Y(t)$ is also subject to retardation is not readily apparent, for while the growth of the niche is positive and constant, $Y(t)$ is necessarily increasing relative to $K(t)$ as we have just established. It turns out that we have three possibilities, namely, retardation, acceleration or a constant growth rate for the output of the industry. The clue to this puzzle is found by recognising that $g_y(t)$ is a monotonic function of t. Hence to establish whether or not we have retardation it is enough to compare $g_y(0)$ with its limiting value $g_y(\infty)$. Now,

$$g_y(t) = -Be^{-Bt}[\log Y_0 - \log K_0 + A] + AB \qquad (12)$$

so $$g_y(0) = -B[\log Y_0 - \log K_0] > 0$$

and $$g_y(\infty) = AB = G$$

If $g_y(0) > g_y(\infty)$ then we have retardation in $Y(t)$ even in this exponentially growing environment, while conversely, $g_y(0) < g_y(\infty)$ gives acceleration of the industry growth rate. As shown in Figure 4, the growth rate of $g_Y(t)$ can follow one of three paths depending on the comparison between the ratios G/B and $\log(Y_0/K_0)$. From (12) the condition for retardation is

$$\log\left(\frac{C_0}{Y_0} > \frac{G}{B}\right)$$

When the growth rate of the market niche is small relative to the intrinsic rate of increase of the industry and when the initial niche is large relative to the initial scale of output then we can expect retardation in the growth rate. However, if the growth of the niche is high relative to the intrinsic growth rate of the industry, and/or the initial output of the industry is sufficiently close to the initial value of the niche then retardation will be replaced by acceleration. In the special case in which these two ratios coincide, the industry will grow at a constant exponential rate G, with the ratio $Y(t)/K(t)$ constant over time. Thus we have a very clear conclusion, rapid growth of the environment whether it be due to demand growth or technical progress can lead to acceleration of growth rather than retardation.

We can sum up the results of this exercise as follows. In an exponentially expanding niche, the ratio $Y(t)/K(t)$ tends to a positive limit, less than one, which is smaller the greater is the growth rate of the niche relative to the intrinsic growth rate of the industry. This suggests an immediate generalisation to the possible patterns of growth. If the niche is growing at a less than exponential rate, with the growth rate tending to zero, then $Y(t)$ approaches arbitrarily close to $K(t)$ for large t. If the niche is growing faster than exponentially with the growth rate increasing over time then $Y(t)$ falls ever further behind $K(t)$ and their ratio tends to zero for large t. Retardation of $Y(t)$ is certain in the first case, improbable in the second. Exponential expansion of the environment is an interesting case, the case which has dominated the theory of economic growth, but it is not the only interesting case. A niche which expands cyclically around a rising trend is clearly of interest as is the case of a niche which at some point begins to contract, perhaps due to the growth of rival industries. These and other cases are all amenable to analysis within the current framework. Rather than explore these further we ought to say a little more about the case of retardation in technical progress which formed the core of the Kuznets and Burns analysis.

Retardation of Technical Progress

We have already shown that neither technical progress *per se* nor retardation in technical progress is necessary to produce retardation in output. Of itself this indicates that the relationship between technical progress and retardation is more complex than either Kuznets or Burns imagined. Indeed, the only way to interpret their argument unambiguously is to assume that $Y(t) = K(t)$ and $p(t) = h(t)$, that is to say that the industry if fully adjusted to its long-run niche. Then output can only increase as the niche increases and one way to ensure this is to let technical change reduce long-run unit costs such that retardation in technology is translated into retardation in output.

However, the core of our argument has been that the introduction of a new technology creates a potential for change, which is only gradually realised under the triple pressures of consumer learning, capital accumulation and technical progress. Our industry is always away from its long-run niche and once this is allowed we have found that technical progress at a constant rate can be associated with acceleration in the rate of growth of output. Correspondingly, a varying rate of technical progress, which is initially rapid, although declining, may first produce acceleration in the output growth rate before it produces retardation[10]. But there is another clear consequence of the Verdoorn Law interpretation of technical progress. Namely that retardation of the rate of cost reduction is a result of retardation in the rate of growth of output. The line of causation is reversed as Schmookler argued but not through the mechanism that Schmookler invoked.

Thus we may conclude that the emphasis which Kuznets and Burns placed on retardation in rates of technical progress as the cause of retardation in rates of output growth was misplaced.

Conclusion

This has been a brief exploratory essay on the nature of economic growth, reinforcing what we consider to be two of the most important of the stylised facts, namely, diversity of growth and retardation of growth. From this follows structural change and the need for the continual development of new industries, new impulses, if aggregate growth at a more or less constant rate is to be sustained. The ecological distinction between carrying capacity and intrinsic rates of increase have helped us clarify the nature of the impulse to growth and the way in which this potential is exhausted. In this the central contribution of technical progress is to create new impulses which are then capitalised upon by the central economic mechanisms of consumer learning, investment in capacity expansion and post innovation improvements in technology. As the economy grows more complex, the scope for creating new impulses will surely increase but how this works is surely another story.

[10] The reader can readily check this by assuming the following Gompertz function for the time path of unit costs, $\log h_0(t) = \log h_* + \log(h_0 / h_*)e^{-h1t}$ where h_0 is the initial cost level, h_* is the long-run costs level and h_1 is the intrinsic rate of progress. If h_1 is large and h_0 is considerably greater than h_* it is easily established that output growth will experience acceleration before retardation sets in.

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In so doing, we follows a long tradition of work in industrial growth on the theory of growth retardation. It is to this that we turn first. Nonetheless by concentrating on problems of limited scope we can hope to increase our understanding of the technical change and growth interaction. This is precisely our task here, to consider the dynamics of growth in a single industry, an industry created by a technical innovation. In the process we shall find that the problem is formally similar to

Table 1 summarises Kuznets' data divided into four cohorts of growth experience since 1880. They show very considerable change in output shares reflecting very substantial differences in growth rates. Thus while the output of group A (13 industries) increase by a factor of 169, that of group D (9 industries) increased only by a factor of 4. Within these groups there are even more outstanding variations. In group A, for example, automobile and related industries grew by a factor of 589 from a share of 3.2% to a share of 19.4% over the whole period. The data end in 1948 but it is not difficult to imagine how the table might look if extended to more recent times, with the emergence of the micro-electronics, information, air transport and pharmaceutical sectors as foci of very rapid growth.

$$h(t) = h_0 Y(t)_s^{\varepsilon} \qquad (4)$$

where $h(t)$ is the long-run unit cost level and ε is the (inverse) elasticity of long-run supply, the chief determinants of which will be supply conditions in primary factor markets and in the supply of intermediate goods. Treating this supply elasticity as a given is clearly unsatisfactory but it will serve for present purposes.

Long-run stability of the market requires 1 should be less than $\alpha\varepsilon$, and we assume this to be the case.

A higher value of supply elasticity (lower value of ε) is associated with a higher value for both B and C.