CRIC

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

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Introduction[1]

The central concern of this paper is the dynamics of economic growth under the rules of restless capitalism, rules under which multiple, uncoordinated innovative activities are strongly ordered by market processes to produce patterns of growth and development in the economy as well as in its framing institutions. The central theme of this worldview is that growth is created by sequences of technical, organisational and institutional changes that create and absorb new areas of productive activity and consumption into the economic structure. These developments arise from within the system, and they are grounded ultimately in changes in private knowledge and public understanding (Metcalfe, 2001b; Potts, 2001). Thus, capitalism is restless because knowledge is restless; there never can be any equilibrium in respect of knowledge and, consequently, the development of an economy is unpredictable and openended. The social and institutional dimension of knowledge is as important as the economic dimension to any understanding of this dynamic and the decline of activity is as important as is expansion of activity in mapping 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.* It reflects a modern concern to establish 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, organisation and institution are originated and come gradually to have their economic and social effects. Furthermore, this approach inevitably losses sight of how these processes of transformation shape the subsequent growth of practical knowledge and give to the growth of knowledge in general a powerful autocatalytic dynamic in which the solution of problems defines yet further problems. In the Nelson and Winter picture, by contrast, growth is very much bottom up but to interpret their argument 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 in their evolutionary framework create important feedback effects to shape the underlying processes of

[1] 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 and economic transformation.

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 operating at multiple levels. 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 they uniform and invariant?' Structural change follows from diversity in growth, and the mutual determination of those growth rates means that they are emergent phenomena arising from replication and interaction. As Pasinetti (1981) rightly concluded, it is the presence of endogenous structural change which makes it impossible to conduct the analysis of growth by macro economic methods alone[2].

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 *and consequence of* the growth and development of economies.

There are many varieties of evolutionary growth theory but the variant that I develop here is based on the theory of niche formation and exploitation as developed by evolutionary ecologists and I shall use these ideas to explore some economic precursors of this evolutionary perspective on endogenous growth. For it turns out that prior to the Keynesian revolution and Harrod's formulation of modern aggregate 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 this problem in terms of the nature of innovation and the development of technology. This literature has at least four main branches of which only the first three are firmly within economics. First, is the line of analysis established in Schumpeter's *Theory of Economic Development*, with its emphasis on the entrepreneur, new business formation and introduction of new forms of economic activity and their subsequent spread within an economy. An ecologist would readily recognise this as a model of speciation and competition for economic niches. The important aspect of Schumpeter's

[2] Pasinetti (1981), p. 65. It is a point with which Schumpeter would have heartily agreed. See

analysis is that it brings together stability in the capitalist *order* with instability in the capitalist *system*. The continuous transformations in economic form are associated with the creation and application of new combinations that arise from within the otherwise relatively more stable order of overarching institutions (Schumpeter, 1928). As he expressed the point,

> "… what we unscientifically call economic progress means essentially putting productive resources to uses *hitherto untried in practice*, and withdrawing them from the uses they have served so far" (*op.cit.*, p. 378, emphasis in original)

Anyone familiar with modern accounts of evolving systems will recognise in this quotation the importance of linking innovations to the introduction of non-average behaviours and the opening up of new spaces for economic activity (Allen, 2001). Since mechanical systems can only be analysed in terms of average behaviours and processes, one can see immediately the significance of Schumpeter's method as an early, if perhaps unwitting, exposition of evolutionary dynamics and a celebration of the significance of unrepresentative behaviour.

No doubt, the foundation of Schumpeter's model of capitalist development is to be found in his knowledge of industrial history. *Business Cycles* (1944), for example, contains a detailed account of how the first three decades of the 20th century were a period of enormous economic transformation both qualitative and quantitative. This period witnessed the creation of major new dimensions to economic space in terms of such activities as the production of automobiles and the complementary industries, the spread of electricity in home and workshop and the production of new synthetic materials (Sayers, 1950).

While Schumpeter provided new perspectives to comprehend the economic processes at work, it was the detailed empirical investigations of Simon Kuznets and Arthur Burns, on secular trends in real output and the so-called retardation hypothesis at the level of individual industries, that provided a more sharply focused empirical foundation to an innovation based account of growth. There ideas where explored further by Fabricant (1942) and, in the post war period, by Stigler (1947) and Gaston (1961. However, by then the aggregate orientation of growth theory was taking a firm hold and this second strand in our literature was rapidly passing into history. The third strand we find in a quite different and older tradition, the

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Schumpeter (1939), pp. 43-44.

argument of Allyn Young (1929) 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 advance of knowledge and thus economic progress is connected closely as cause and effect with the rate of growth of the market. All of these contributions lie firmly within the economics discipline and they singly and together form the basis for an evolutionary account of economic growth. Our 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 in the 1920s 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 he defines evolution in terms of the redistribution of the components of a system, that is, as structural change. This literature developed naturally into the analysis of a growth curves in different populations from which the extension to economic phenomena followed with ease (Prescott, 1922; Bratt, 1936; Vianelli, 1936; Windsor 1932)[3].

Taking all four strands together connects the analysis of 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; May, 1974; Kingsland, 1985; Renshaw, 1991). This so-called, r-K, theory is undoubtedly crude and oversimplified but it can be developed and applied in a variety of ways which lay bare the main features of the process of innovation based growth and transformation[4].

[3] Ultimately, it emerged again, in different form in the idea of an industrial, technological or product life cycle in the 1960s.
[4] Anderson (1994) and Saviotti (1996) are two very cogent expositions of an ecology of growth in the tradition explored here.

My purpose in this essay 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 interpretation of carrying capacity and intrinsic rate of increase so that their characterisation is not arbitrary but is related to the dynamics of the market process. It is clear that the literature I have referred to provides an endogenous account of economic growth. New knowledge defines new combinations, entrepreneurship introduces these new combinations into the space of economic activities, and those that pass the test of economic and social viability may spread further into the system attracting resources and demand and so enhancing or destroying the markets for existing activities. In the process, new knowledge is gathered, new opportunities emerge and so the process feeds on itself in autocatalytic fashion. However, there is no metric through which knowledge can be reduced to a scalar quantity. Knowledge is an ensemble not an aggregate, a union not a sum, and it is quite inappropriate to think of it as some homogeneous substance that has an independent macro economic existence. To think in these terms is to suppress the very processes that create growth through the opening up and exploitation of new economic spaces. This is the import of the work of Kuznets and Burns, and of Schumpeter and Young, to which we now turn.

Growth and Retardation in Progressive Economies

In his comprehensive review essay, Abramovitz (1989) identified structural change and a tendency towards retardation in the growth of output as two among eight 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 the relevant population. 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 our two principal retardation theorists, namely A.F. Burns and S. Kuznets[5]. Both authors are concerned with the measurement and explanation of secular or long time movements in the

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

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. Both understood that the evidence for retardation would depend on the level of statistical definition of an industry or sector, and that the broader the aggregate the more the evidence in favour of economic evolution will be suppressed. 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.

It is worth noting that the diversity of growth rates and the retardation of growth rates are closely connected as dynamic phenomena[6]. This we can see immediately if we define the growth rate of some aggregate of economic activities in the conventional way as $g = \sum s_i g_i$ where s_i is the share of the 'i'th component in the aggregate. Then it follows that the rate of change in the aggregate growth rate is

$$\frac{dg}{dt} = \sum \frac{ds_i}{dt} g_i + \sum s_i \frac{dg_i}{dt}$$

Furthermore, since $ds/dt = s_i(g_i - g)$ it follows that we can write this as

$$\frac{dg}{dt} = V_s(g) + R$$

where $V_s(g)$ is the variance of growth rates within the population and R is the averaged rate of change of the growth rates of the individual components of the aggregate. If R is negative we have retardation on average and if it is positive acceleration. Consequently, whenever the growth rate of the aggregate is constant, we must have retardation on average, and the average rate of retardation is numerically equal to (minus) the variance of the growth rates in

[6] 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 population. More generally, the difference between these two magnitudes is exactly the rate of change of the growth rate of the aggregate.

Let us turn now to the main issue and 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 commodities in the economy. What might 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 to task Gustav Cassel, and by implication modern growth theorists, 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 the factors that underpin the diversity of growth rates 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[7].

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).

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

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 development must have been marked by as much by change of preferences as change of industry[8].

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 the 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 that offers scope for a myriad of improvements of ever decreasing importance. Progress inevitably slackens unless there is some radical breakthrough in the foundations of an industry's methods as it becomes increasingly difficult to extract further improvements in performance. This is 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 stimuli to maintain a trajectory of technical innovation over time within the limits resident in these new concepts. This is a theme familiar to all modern evolutionary minded scholars and students of innovation (Dosi, 1982; Georghiou *et al.*, 1984). Kuznets and Burns where not the only scholars to explore these themes. Fabricant (1942) too found compelling evidence in the retardation of growth in American manufacturing output and employment over the period 1899 to 1939 although he worked in terms of broader commodity groups rather than the individual commodities that were the focus of the Kuznets and Burns studies. While Fabricant does not develop the logic of the retardation thesis, being content to echo the Kuznets/Burns line on technical progress, his study is valuable for its emphasis on structural

[8] For some interesting commentary see Baumol *et al.* (1989, chapter 3).

change and the shifting balance of employment within the overall growth of the economy. Fabricant is also clear in his assessment that technical change in the broad simultaneously creates employment and destroys employment. The emergence and exploitation of new fields of employment is a factor balancing the ebb of employment in mature and decadent industries (*op. cit*., p. 159). Subsequent studies after 1945 by Hoffman (1949), Stigler (1947) and Gaston (1961) further explored the empirical basis of the retardation theme in different bodies of industrial data but without any further development of the underlying theory. By then growth theory had taken its macro economic turn as the consequences of the Keynesian revolution where applied to long period problems. In all essentials, the picture of growth as an evolving transformation of an economy was lost in its entirety. The rekindling of interest in the knowledge of growth and the growth of knowledge makes its revival both timely and highly relevant to understanding the endogenous sources of growth.

It is fair to say that while the broad outlines of the Kuznets/Burns explanations of retardation and growth rate diversity are clear, a number of important details are not, and this lack of clarity may have contributed to the demise of their approach. In attempting to clarify the various issues, it is apparent that three major and distinct mechanisms are involved in their accounts. 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 utility 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 consumer learning in which established patterns of behaviour are disrupted. Following the practice of modern evolutionary economics this process is best visualised in terms of the mutation of decision rules as new areas of consumption space are opened up and explored (Cross, 1983; Metcalfe, 2001a). 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, albeit one that is embedded in wider social interactions, 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 upon observations of the consumption experience of others.

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 a stimulus to investment and entry and, indeed, disinvestment and exit from an 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 and opening up new areas of demand, and improvements in the production process reducing unit production costs. Retardation of technical progress was at the centre of the explanation of retardation of output. 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 and to the analogy of a technological opportunity as a given mineral vein to be progressively exhausted at a declining rate. For one this makes the rate of technical retardation exogenous with respect to the rate of output retardation. For another, this wholly neglects the demand side of the technical progress problem. It is only with the work of Schmookler (1966, 1972), that the Kuznets/Burns line of causation is questioned. Schmookler consistently argued for a demand side interpretation of retardation in terms of a declining price and income elasticities of market demand, and that retardation of technical progress is not to be found in the increasing cost of invention but in the declining value of invention (1966, p. 204). However, there is no need for these to be mutually exclusive explanations; a little Marshallian logic suggests that some recognition needs to be given of the interrelation between the two blades of the invention and innovation scissors. Such a deeper sense of understanding is provided in the work of Allyn Young (1928) to which we have already referred. Drawing on roots in Smith and Marshall, he 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 one possible link between retardation of output growth and the slackening of the rate of technical change. Of course, the scope of Young's argument was much broader than the linking of growth of market and technical progress *within* a single industry. What mattered was the reciprocal dependence between activities in which 'inventions' in one sphere initiate 'responses elsewhere in the industrial structure which in turn have further unsettling effect' (*op. cit.*, p. 532). For Young, as for Schumpeter, the idea of capitalism in equilibrium did not hold much appeal. Yet, it is sufficient for our purposes to explore the more limited version of Young's central theme and confine our attention to the sequences that flow from the creation of a new activity and its associated markets.

Taken together, demand oriented learning, the accumulation of capacity and the rate of technical change provide the basis for an ecological dynamic of industry growth wholly appropriate to an understanding of 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. How they interact and how they are linked to retardation is the focus of the rest of this paper.

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 single 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. Since the secular time trend of itself does not establish the properties of the underlying processes, 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[9].

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

[9] 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

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; May, 1974; Roughgarden, 1979; Slobodkin, 1980; Kingsland, 1985; Renshaw, 1991). Whilst this theory is undoubtedly crude and simpleminded 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.

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 long run size of the market, as determined by conditions of demand and cost, and the intrinsic rate of increase reflects 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, particularly technical progress[10]. To remind the reader, the Gompertz curve, the integral of the Gompertz process, is an asymmetric sigmoid curve with an inflexion point at approximately 37 per cent of the carrying capacity or long run value of the dependent variable[11].

Secular Expansion and the Gompertz Process

In economic ecology, the analogue to speciation or mutation is innovation, rather more precisely a radical innovation that creates a new line of productive activity. So we begin with

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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).

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

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

an innovation, the type that leads to a new industry built around a new product with its own process of production and introduces this 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

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

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, when consumer learning and the formation of preferences has ceased. Notice carefully that, since this is the long-run level of demand when all learning of preferences is complete, actual demand is always less than this long-run level. The Gompertz process postulates that this learning process be summarized by the following differential equation

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

hence, the actual demand level $Y(t)_D$ approaches $n(t)$ asymptotically over time. Here, the constant β dictates the rate of learning. At a given price, a given niche 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 need a theory of how the price of the new commodity is determined and how it changes over time. To internalise price formation within the growth process requires 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. As long as profitability is above the cost of capital the industry invests to expand capacity. What this price is will depend on investment requirements per unit of capacity expansion and the capital market condition that impinge on the flow of funds into the new industry. Firms have to learn the appropriate level of capacity and 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 captures, in a rough and ready way, rules about the funding of investment, the capital requirements per unit of output and the conventions determining the rate of depreciation. To begin with, we abstract from further technical progress and any elements of non-constant returns to scale and let the industry have a fixed level of unit cost, defined to include the normal return on investment,

$$h(t) = h_0 \tag{4}$$

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 finance and 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 together with the price adjusting to bring about the required co-ordination of the new market. We call such a secular path a 'normal path' and it provides a benchmark case against which to judge other possibilities. 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 normal, balanced process satisfies the equation

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

Where, the coefficients B and K are given by

$$B = \frac{\beta}{1 + \alpha\beta\kappa} \quad , \qquad \log K = [\log \eta_0 - \alpha \log h_0] \qquad \text{and} \qquad Y(0) = Y_0 .$$

Each of the parameters B and K 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 by which a new activity grows into its niche. Now the surprising feature of this normal path is that it also describes a Gompertz process even though the price of the product, profit margins and the scale of long run demand are varying endogenously over the process of secular expansion. It is useful now to define $\log Y(t) = x(t)$ so (5) can be written as

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

which, integrates to give

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

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, to fill the niche completely, tracing a sigmoid curve with the inflexion point where $Y(t) = K / e$. 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

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

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. The retardation 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, and it is clear that the rate of retardation declines at an exponential rate towards zero. Slackening of the rate of technical progress is not necessary to experience retardation of output. Solving for the path of normal price as a function of current output we find

$$\log p(t) = \log h_o - \kappa B \log(Y_0 / K) e^{-Bt} \quad (7)$$

Clearly, $p(t)$ declines over time, and always declines relative to the given 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' or, 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 normal price output combination coincides in general neither with the long-run cost curve nor with 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, and conversely. In the limit, if β is infinite, instantaneous consumer learning, the trajectory coincides with D while if κ is zero, no learning or financial constraints on capacity expansion, the trajectory coincides with H.

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 normal 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 that is capitalised upon by investment and producer 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. 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 we allow firms with different costs and/or product variations 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 they drift over time as competition concentrates output on lower cost firms. Nor do we allow for competitive and complementary interactions between this and other industries[12]. Finally, foreign trade has escaped our net entirely. 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 normal expansion are in order.

Normal expansion is clearly a strong requirement, if entrepreneurs are to keep capacity growth in exact step with demand growth this would require an ability to react instantaneously to discrepancies between demand growth and capacity growth and a tranquil environment. Like Harrod's famous warranted growth rate, the normal rate of secular expansion 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' 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 normal 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 that reflects the changes in 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 fractured again until the capital stock has caught up with market demand.

It is one thing to consider the empirical 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. In so doing we can focus on the question raised by Burns and Kuznets as to the link between retardation of output and retardation of technical progress.

Retardation, Technical Progress and Long-Run Demand Growth

The conclusion reached so far is that retardation is related to technical progress only in a very precise sense. It follows because the creation of the new activity opens up a new economic niche and the filling of that niche through consumer learning and capacity expansion produces the phenomena called retardation. No other notion of technical progress is required to produce this outcome. Yet this is only a partial statement of the Kuznets/Burns argument. Neither assumed that growth took place within a stationary environment, changes in the competitive relations between commodities, population growth and reductions in production costs were central to their arguments. How might these additional elements be incorporated in our depiction of a normal process and what implications would this have for the idea of

[12] A point emphasised by Kuznets and Burns. But see Metcalfe and Gibbons (1987) for such a

retardation? As far as demand is concerned, we might expect that the long-run curve shifts over time at a rate which reflects the growth of total income and the income elasticity of demand for the new commodity as modified by the influence of competitive and complementary relations with other commodities. To establish the basic issues we first replace (1) by (I)

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

Where, n_1 is the exponential rate of growth of the long run demand curve, its value reflecting the impact of changes in preferences and growth in per capita income on the demand for the new commodity. Take it for the moment as a given, positive parameter. Consider next the impact of ongoing technical progress throughout the growth process.

As we have already explained, in their analyses of retardation, Kuznets and Burns put great emphasis in the exhaustion of technical possibilities in the industry to explain why the rate of reduction in unit costs could only be expected to occur at a declining rate and thus induce retardation. Similarly, we have seen that Schmookler, in his critique of this supply side logic, argued that retardation in technical progress reflected limiting forces on the demand side of the industry as expressed through a declining elasticity of demand over time. Both positions have merits but what is needed is a form of explanation that makes the rate of technical progress an endogenous feature of the industry. Unfortunately, there is no immediately plausible and convincing way to invoke the idea of an endogenous technical progress function. However, the line of enquiry opened up by Allyn Young is one clear way forward. To do this we distinguish two elements in the industry rate of cost reduction at a point in time: a given rate of exogenous progress and an endogenous component that depends on the rate of extension of the market and thus output. We treat these as independent and additive and note that such a formulation is not unconnected to the Kaldor/Verdoorn representation of technical progress, linking this latter to investment in capacity and thus to the growth rate of output. No one should pretend that this is entirely satisfactory but neither is it an entirely misleading place to start the discussion of technical progress. Thus we write the following expression for the technical progress function

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treatment in the logistic case.

$$-\frac{d}{dt}\log h(t) = h_1 + \varepsilon g_s$$

where, h_1 is the exogenous rate of cost reduction and ε is the progress elasticity that chains together cost reduction to investment and investment to the growth of capacity. If we take this as a starting point then we can integrate the technical progress function to give (IV) in stead of (4) above

$$h(t) = h_o e^{-h_1 t} Y(t)^{-\varepsilon} \qquad \text{(IV)}$$

Unit costs are no longer constant and they are partly determined in the process of filling the niche. Notice that in making the rate of cost reduction increase with the rate of growth of the market we make the expansion of the market expand the market yet further. As Knight once expressed the matter, growth in capitalism is a 'self exciting process'. Others, Young and Kaldor included, would concur and see it as a cumulative process. It is a process of proper endogenous growth.

If we now incorporate (I) and (IV) in our process of normal expansion we can write this as

$$\frac{dx}{dt} = B[\log K + (n_1 + \alpha h_1)t - (1 - \alpha\varepsilon)x]$$

or as

$$\frac{dx}{dt} + B'x = B'[\log K' + Gt]$$

Where, the new coefficients are defined as

$$B' = B(1 - \alpha\varepsilon), \log K' = \frac{\log K}{1 - \alpha\varepsilon} \text{, and } G = \frac{n_1 + \alpha h_1}{1 - \alpha\varepsilon}$$

If a normal process is to be defined it is clear that we must impose the condition $\alpha\varepsilon < 1$ otherwise the long run niche can no longer be defined and the dynamics of normal expansion break down. Subject to this requirement, B' is the intrinsic rate of expansion of the industry, K' is proportional to the initial value of the niche K, and G is the long run rate of growth of the niche.

Integrating this non-autonomous relation, by parts as necessary, we have a new equation for the normal expansion process

$$x(t) = \log K' + e^{-B't}\left[\log Y_0 - \log K' + A\right] + G\left[t - \frac{1}{B'}\right] \tag{8}$$

where, $A = G / B'$, is the long run rate of growth of the niche divided by the intrinsic rate of expansion of the industry.

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

$$Y(t) = \left[e^{\log K'} e^{(\log Y_0 / \log K')e^{-B't}}\right]\left[\phi(t)\right] \tag{9}$$

where, $\log\phi(t) = Ae^{-B't} + G(t - 1/B')$, which for large t grows exponentially at rate G.

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

$$\log\frac{Y(t)}{K(t)} = e^{-B't}\left[\log(Y_0 / K_0) + A\right] - A \tag{10}$$

and this is a clear and perhaps surprising result. It tells us that it is the *ratio* of output to its growing niche value which follows a Gompertz curve towards an upper asymptote, and that the value of this long run ratio is 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 relatively 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, that of the niche, 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, and this excess of the normal price over the changing level of unit cost exactly prevents output fully filling the niche. In this regard, the process of industrial growth reflects an argument familiar in ecology. In a changing environment, the long-term population values of a species are not determined by carrying capacity alone but by this in relation to the intrinsic rate of increase of that population.

Is there still retardation of output growth? In one sense, yes. Since we have established that, the ratio $Y(t)/K(t)$ is described by a Gompertz curve it follows automatically that the rate of increase in this ratio is subject to retardation, whatever the rate of technical progress and whatever the growth rate of the market. In this relative sense, retardation is confirmed even though the niche is growing over time. However, this is not the meaning of retardation used by Kuznets and Burns, who focused their empirical and theoretical explanation on the absolute levels of output. To unravel the effect on the growth rate of the level of output we proceed in several steps.

From (8) we find the output growth rate to be

$$g(t) = -B'e^{-B't}\left[\log Y_0 - \log K' + A\right] + G \qquad (11)$$

from which it follows that

$$\frac{dg(t)}{dt} = B'\left[G - g(t)\right] \qquad (12)$$

As in the previous case, the trajectory of the growth rate remains monotonic with time but now there are three possible outcomes depending on the initial value of $g(0)$ relative to the growth rate of the niche, G. If $g(0)=G$ then the normal expansion path is one of constant exponential growth at this rate. If $g(0)<G$ then the growth rate accelerates over time to approach G asymptotically from below. Only if $g(0)>G$ will the industry experience retardation in the Kuznets/Burns sense, and this requires that the initial scale of the industry is sufficiently small relative to the initial niche. It follows that we can write the precise condition for retardation as

$$\log\left(\frac{K'}{Y_0}\right) > \frac{G}{B'} = A$$

The condition $Y_0 < K'$ is sufficient to ensure that the initial growth rate of the industry is positive and remains positive. For retardation to follow it is also necessary that, $Y_0 / K' < e^{-A}$, which is more likely the greater is the niche growth rate relative to the intrinsic growth rate of the industry. Expressing it differently, retardation occurs whenever the initial ratio Y_0 / K' is less than the long run ratio, e^{-A}.

The consequences of this for the Kuznets/ Burns approach to retardation and technical progress are as follows. First, take the exogenous rate of progress as given. If there is retardation (acceleration) of the output growth rate then there will be retardation (acceleration) in the rate of technical progress. The two rates of retardation (acceleration) are simultaneously determined. Indeed with h_1 given, the rate of retardation/acceleration in the rate of cost reduction is simply the progress elasticity multiplied by the rate of change in the output growth rate. Thus, as Schmookler, observed, the causation between technical progress and output growth can run both ways but not for the reasons that he invoked. The causation pattern is not a feature of a mature industry but of a dynamic industry finding its niche in the economy.

We can conclude that a given value of h_1 is neither necessary nor sufficient for retardation in the rate of growth of output. Secondly, and more subtly, if we compare (6) and (9) at the same value of the growth rate we find that the rate of retardation is smaller in the latter case than the former. A higher rate of exogenous progress, of the kind we have analysed, reduces the rate of retardation of output growth it does not enhance it, and this is precisely because a given rate of technical progress extends the market and so promotes faster output growth. Thus, it appears that retardation in the rate of exogenous progress, which would require the magnitude of h_1 to decline over time, would be associated with *retardation of the rate of retardation*, not with retardation itself.

Under what circumstances would it be correct to link retardation of technical progress directly to retardation of output growth? Reflecting on the argument shows that the link relates to a special case, namely when the industry has settled into its niche and is growing at the constant rate, G. For then it is readily seen that this growth rate declines as the exogenous rate of technical progress is reduced.

Thus, the relation between technical progress, the growth of the market and the rate of retardation is more complicated than either Kuznets or Burns foresaw, and this is so because of the fact that their analysis is of a ‘far from equilibrium’ kind. Their industries are new industries finding their place in the economic world, not established industries that have passed on to maturity. They are not industries that could be described as being in equilibrium although, of course, the activities of production and consumption are coordinated by market processes. Coordination leads to order, not to equilibrium Paradoxically, the link they claimed between output retardation and technical progress is only valid when their industries are ‘old industries’ that have been absorbed into their respective niches. Yet their principal insights remain valid. The process of innovation and subsequent economic adjustment requires a non-aggregative explanation of growth in which impulses to economic change lead to the joint occurrence of learning phenomena, investment and technical progress such that each of these can be labelled endogenous.

Conclusion

This has been a brief exploratory essay on the evolutionary, adaptive nature of economic growth, reinforcing what we consider, along with Abramovitz, 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 distinctions between carrying capacity and intrinsic rates of increase have helped clarify the nature of the impulse to growth and the way in which this potential is exhausted. In this account, the central contribution of technical progress is to create new impulses which are capitalised upon by the central economic mechanisms of consumer and producer 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 another story. To follow this line further requires far more attention to be given to the experimental dimensions of a capitalist market economy. The conditions under which new business conjectures are generated and translated into innovations, must be at the centre of this story, as must the vital property of market institutions that they encourage and facilitate challenges to established economic positions. This really is a story of restless capitalism and it is to the great credit of Kuznets, Burns and their followers that they were able to develop a framework for a theory of endogenous growth that begins from these essential features of modern capitalism.

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Figure 1a

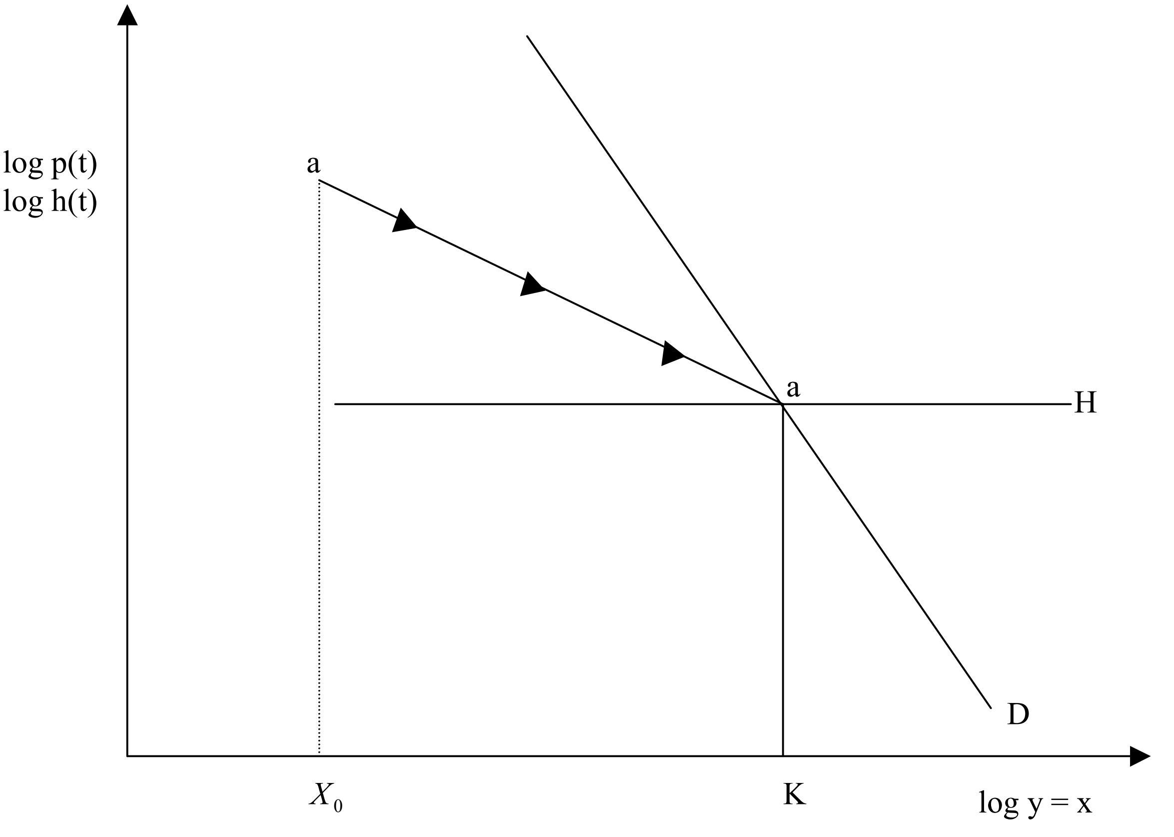


Figure 1b

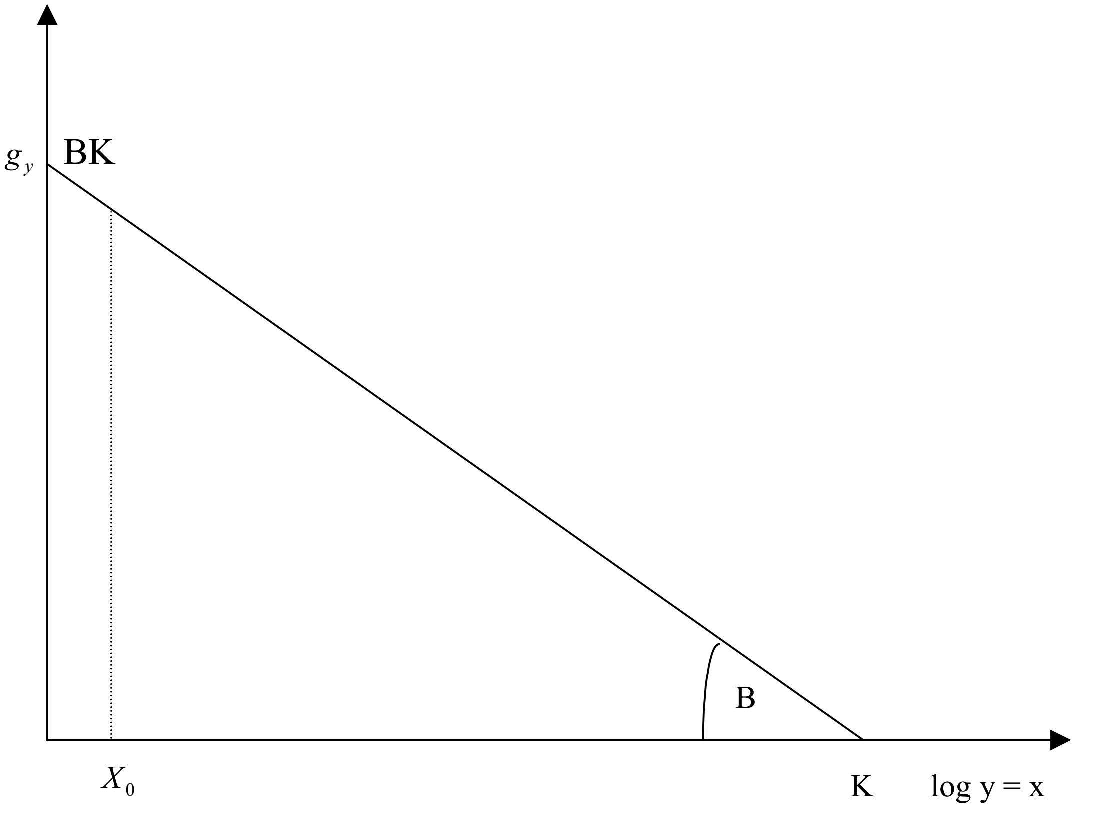


Figure 2

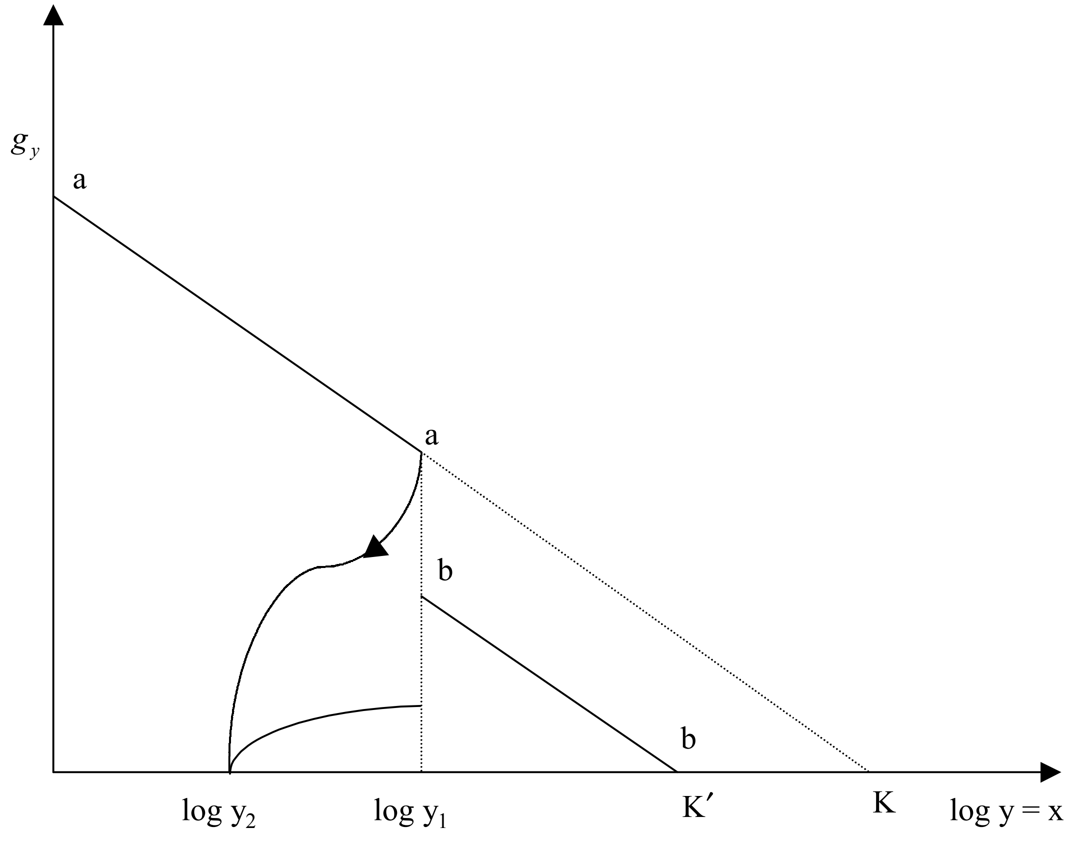


Figure 3

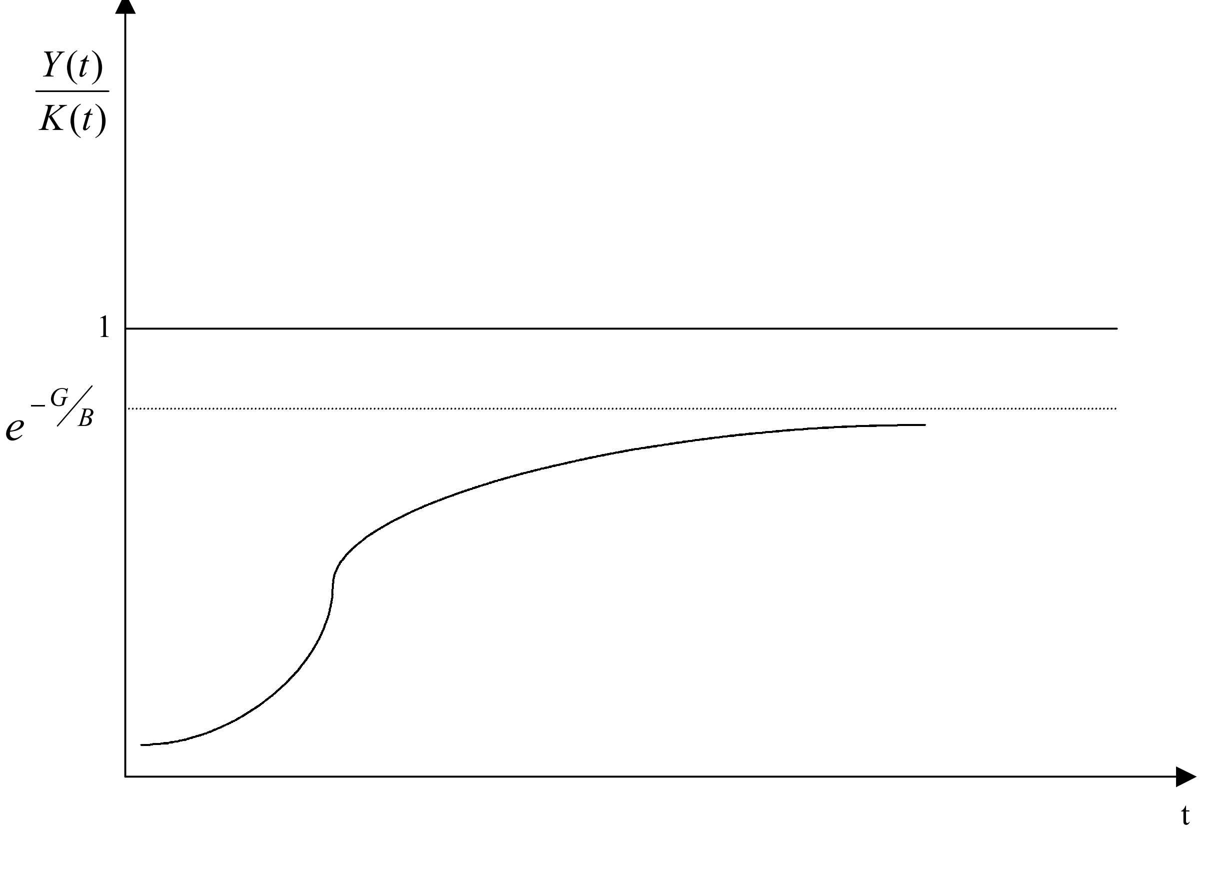
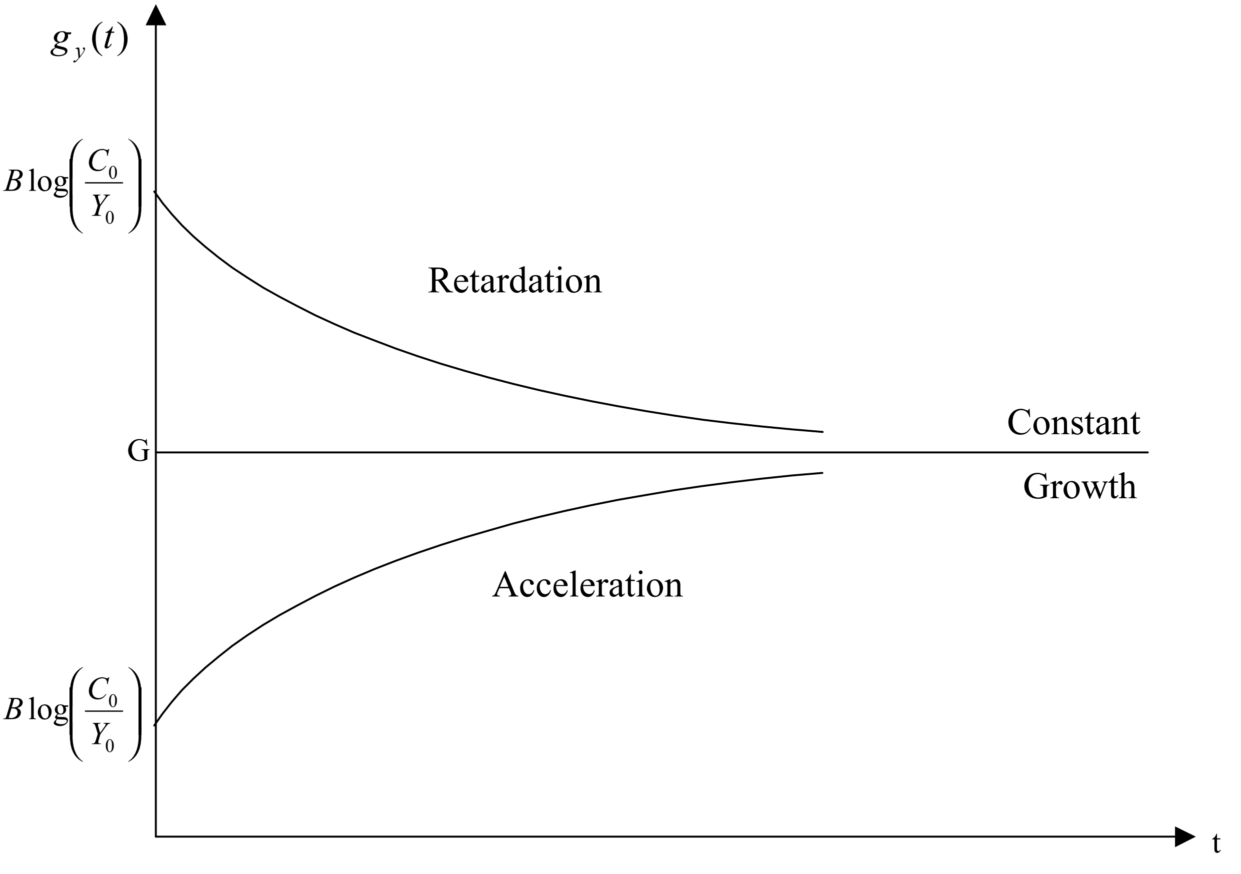


Figure 4



$g_y(t)$
$B\log\left(\frac{C_0}{Y_0}\right)$
Retardation
G
Constant
Growth
Acceleration
$B\log\left(\frac{C_0}{Y_0}\right)$
t