

Paper to be presented at the DRUID Tenth Anniversary Summer Conference 2005 on

**DYNAMICS OF INDUSTRY AND INNOVATION:
ORGANIZATIONS, NETWORKS AND SYSTEMS**

Copenhagen, Denmark, June 27-29, 2005

THE EVOLUTION OF INDUSTRIAL DYNAMICS

Stanley Metcalfe
ESRC CENTRE FOR RESEARCH ON INNOVATION
AND COMPETITION
THE UNIVERSITY OF MANCHESTER

June 2005

Abstract

I begin with a general question, 'What kind of knowledge based economic system is modern capitalism?' In giving an answer I will focus on the claim that capitalism's principal organisational forms, firms and markets, provide jointly a unique instituted connection between the growth of knowledge and the transformation of economic relationships and activities over time. It is a self exciting system so designed as it were to encourage innovation and economic experimentation and so facilitate the adaptation to and the stimulation of new knowledge. Thus what distinguishes modern capitalism is the specific transmission process that is invoked to connect the evolution of knowledge to the development of the economy. Indeed, I shall argue that the relationship is two way, markets are social processes that facilitate and give incentives to the economic application of new knowledge and they also provide a context in which the development of new knowledge is embedded and contextualised. At the core of this argument lie the rules of the game which make capitalism a creative, experimental, restless system and which combine market and non-market processes to facilitate innovation and its diffusion.

Keywords:



THE EVOLUTION OF INDUSTRIAL DYNAMICS

**PROFESSOR J S METCALFE
ESRC CENTRE FOR RESEARCH ON INNOVATION
AND COMPETITION
THE UNIVERSITY OF MANCHESTER**

JUNE 2005

**PAPER PREPARED FOR “DYNAMICS OF INDUSTRY AND
INNOVATION: ORGANIZATIONS, NETWORKS AND
SYSTEMS”, DRUID TENTH ANNIVERSARY SUMMER
CONFERENCE, JUNE 27TH-29TH 2005**

FIRST DRAFT, PLEASE DO NOT QUOTE

Introduction

I begin with a general question, ‘What kind of knowledge based economic system is modern capitalism?’ In giving an answer I will focus on the claim that capitalism’s principal organisational forms, firms and markets, provide jointly a unique instituted connection between the growth of knowledge and the transformation of economic relationships and activities over time. It is a self exciting system so designed as it were to encourage innovation and economic experimentation and so facilitate the adaptation to and the stimulation of new knowledge. Thus what distinguishes modern capitalism is the specific transmission process that is invoked to connect the evolution of knowledge to the development of the economy. Indeed, I shall argue that the relationship is two way, markets are social processes that facilitate and give incentives to the economic application of new knowledge and they also provide a context in which the development of new knowledge is embedded and contextualised. At the core of this argument lie the rules of the game which make capitalism a creative, experimental, restless system and which combine market and non-market processes to facilitate innovation and its diffusion.

From a positive viewpoint our agenda engages with questions about the performance of firms and markets. From a normative viewpoint we confront the issue of the specific rules of the game that might be imposed to best connect economic development and the growth of knowledge. In particular three claims of an is/ought kind are often made for a competitive market process:

- That it is more effective in bringing firms with better technology and organization to a position of dominance in their industry and that it does this by facilitating the differential growth of firms and also by facilitating the entry of ‘better’ firms;
- That it rewards firms who innovate relative to their rivals in terms of products and business processes so that the consequent competitive advantages allow them to increase their relative share of the market; and
- That it eliminates the least efficient contributors to an industry and thereby releases resources to be absorbed by more productive firms.

In the following we shall review a small portion of the contributions that bear on this broad question by examining recent developments in the theory and empirics of 'industrial dynamics' from an explicitly evolutionary perspective and, in so doing, draw a number of conclusions in relation to the 'restless' nature of modern capitalism.

The literatures I survey provide a rich testimony to the self transforming attributes of modern capitalism but beg the question of a wider framework in which to fit rather precise conclusions about the inner dynamics of economic change. These wider questions matter not least because of the light they throw on the sources of material welfare, the connections between the growth of knowledge and the process of innovation, the uneven nature of economic development across time and space and the instituted frame of capitalism that predisposes it to business experimentation. The framework I propose is evolutionary in content, it builds on the variation, selection, development triad to characterise evolutionary processes and seeks to unify them within a population dynamics framework. This framework is distinguished by its emphasis on the ordered but necessarily non equilibrium nature of evolutionary economic processes and a complementary emphasis on the emergence of statistical macro phenomena from micro and meso foundations. In fact the feature of modern capitalism that is most dramatic in all but the shortest of perspectives is the continuity of the system as a whole in the presence of the instability, indeed transient presence of particular activities. Not only is capitalism self ordering, the lesson from Smith to Hayek, it is also self transforming; spontaneous order it seems coexists with, indeed fosters, spontaneous transformation, the lesson from Schumpeter.

I will suggest that it is not helpful to draw upon the equilibrium metaphor to deal with this internal capacity for change, for systems in equilibrium do not change except through the imposition of external forces, the explanation of which cannot, by construction, be part of the explanation of the equilibrium. The problem confronting us is development from within the system, the problem of self transformation in the context of self organisation. Two further points unify this discussion. The first, hinted at already is the natural instability of the market and institutional order of capitalism, instability that is essential to its development. Every position is open to challenge over time and what is to be explained is the different degrees of transience within the system as a whole, the different rates of evolution that we identify in structural change. The issue is not that the economy and its instituted framework changes but that it changes in such an uneven fashion and by a particular general category of process. Secondly, the explanation of aggregate growth performance is not to be found in macro

economic constructs such as an economy wide production function but in the order superimposed by market processes at different levels of co ordination on the countless growth events in individual firms and markets. We can measure macro economically but we cannot understand macro economically because aggregation hides the very diversity in individual performance upon which economic progress depends and it also hides the nature of the market process that resolve economic variation into economic transformation. In traditional evolutionary fashion, the alternative is to see macro outcomes as statistical constructs, as emergent but transient properties of an ordered system. The nature of statistical analysis is that it only makes sense in the presence of variety (an average of identical units is a redundant notion) and thus opens up a discussion of the importance of non representative behaviours in the development of system wide performance measures. In any evolutionary framework there is room for statistically representative behaviour but not uniform behaviour, moreover what is representative is an emergent property and not something that can be determined a priori (Horan, 1995; Andersen, 2004a, 2004b).

To summarise so far, if we are to seek any fundamental reason why the evolutionary approach is appropriate it is to be found in the experimental nature of capitalism and the central role of innovation in its performance. Innovation equates to variation, to non representative behaviour, to the significance of outliers, and to the importance of new business enterprise in capitalisms dynamic. Not surprisingly all the literatures I draw upon place great weight on innovation as the prime mover of economic transformation. However, innovation qua variation is only part of the story, the instituted processes that transform variation into broader adaptations in patterns of resource utilisation must also figure heavily. Prime among these instituted processes are markets and their modes of regulation; it is the interplay between innovation and markets that captures the uniqueness of capitalism, its incessantly restless nature. All markets are involved, for commodity outputs for labour and for free capital and business capabilities. To invoke a Polanyian notion, there is a continuous ‘double movement’ in which innovations invoke market and institutional responses which, in turn, feedback to stimulate further innovations. The higher institutional frames of capitalism that might be designed, as it were, to promote this dynamic I return to later in the conclusion.

The literatures that bear on these topics are vast and quite beyond the scope of this address to treat other than superficially. I have been very selective in the choice of material, settling on the contributions that speak to the idea of evolution as a matter of population dynamics. Really the essay is to be read as a first cut at a much bigger work of synthesis that will

include discussion of the strategic management and organisational ecology literatures as well as a more extended discussion of the economically oriented literature. Different organizing principles will obviously produce different themes but the current coverage must suffice. Some of the material I cover is from literatures that are certainly not evolutionary in outlook but that add to the sense of breadth in the evolutionary perspective. In particular we divide our treatment as follows:

- Productivity growth analysis. Growth accounting within and between industries.
- Industry life cycle dynamics of entry, exit and shakeouts.
- The differential growth of firms and market selection.
- Industry level growth theory and retardation effects and the connection to logistic population dynamics.

Before turning to these topics we must spend a little time on the population dynamic framework that serves to integrate the different empirical parts of this paper.

Population Dynamics

The framework I use to interrogate the literature is one based on population dynamics, and I argue that each of the empirical fields in view is appropriately interpreted as a case in population analysis. This organising device implies two contributing ideas: a set of differentiated entities or individuals, and a causal selection process that acts to identify the inclusion criteria for membership of the population and to alter its structure and composition over time. Thus a population is both a set concept and a causal concept (Knudsen and Hodgson, 2004). Although each entity is a different individual the basis for classifying them as members of a particular population is that each of them, however much they may differ in particular respects, is subjected to the same set of causal selection processes (Metcalfé, 2004b; Andersen, 2004a, 2004b). Thus the individual entities are defined in terms of sets of characteristics across which the selection pressures discriminate. Particular characteristics can be unique to each entity and so reflect the diversity and differentiation within the population. It is of course obvious that a population of identical individuals contains no evolutionary potential.

The unifying causal processes which are the key to identifying the evolutionary potential in a population are of two general kinds: processes that evaluate the different characteristics of the individual members so rendering them comparable in terms of a smaller subset of performance measures; and, processes that translate measured performance into survival and a changing relative importance of the entities in the population. This is the typical, dual structure of the variation selection dynamic of evolutionary theory in which measured fitness is a statement of differential growth causally connected to differential performance. This suggests immediately that the notion of the selection environment is multi dimensional and that it has a nested property such that populations can be aggregated into larger populations or broken down into smaller sub populations each subjected to its own variation selection dynamic.

In the literatures discussed below the variation selection dynamic appears in many forms and its precise form is often hidden from view. To make it more precise and concordant with the present discussion we identify the entities with firms, or sometimes production plants, and the population with an industry of differentiated firms subjected to the unifying effects of competition for custom and resources. The selection environment consists of the product and factor market processes between which each firm is positioned and the standard performance metric is the profitability of each firm which in turn reflects the market evaluation of products and production methods to generate a distribution of prices and unit production costs. In this literature, industries are usually synonymous with product markets although this overlooks the equally important aspect of factor market selection. Of course, there is nothing to prevent a firm being the member of different populations if it produces different kinds of products for different groups of customers or draws on different sets of factors of production to produce them. From an evolutionary perspective the firm is a rather slippery entity and we are on safer ground if we consider the fundamental entities to be distinct activities defined as producing relatively uniform sets of products using similar production methods. Nonetheless I will speak of the firm as the fundamental population entity, treat it as a single plant and leave the many caveats to another discussion¹.

¹ Disney *et al* point out that 84% of firms in their study of UK manufacturing are single establishment firms and that they account for 23% total employment. (3% of entrants and 87% of exits they identify are also single establishment firms.)

Since evolutionary theory is an explanation of change in the population we can begin with a simple classification of the various kinds of change that can occur in a population over some given time interval as illustrated in Figure 1. If we consider the population at two distinct dates the various possible changes can be resolved into the following exhaustive categories:

- Changes in the number of distinct, individual entities in the population over the given interval. These changes are defined in turn by four sub processes: the entry of ‘new’ firms; the demise or exit of existing firms; the recombination of existing firms into different firms (including the possibility of recombination with entrants); and, the fission of existing firms into distinctly different firms (including parts that exit the population).
- Changes in the economically relevant selection characteristics of the existing entities essentially innovation processes proper which may also be connected to the recombination and fission process.
- Changes in the relative importance (economic weight) of those different entities in the population, active throughout the interval. Changes in weight reflect differences in their growth rates pointing to the fact that evolutionary theory is fundamentally differential growth theory.

However, there is an alternative way to distinguish the various change processes acting on the population, a way that emphasises the variation and selection basis for the framework. From this evolutionary viewpoint the various possible changes can be subsumed under the general category of 1) Selection processes, (exit and differential growth), and 2) Creative processes, (innovation based changes in product and process characteristics in existing firms, entry and recombination/fusion). These are each markedly different. The conditions that drive an activity out of the industry population are not the same as those that generate differential growth and decline although both are related to profitability. Similarly, product innovation involves different issues from merger or divestiture and a full evolutionary theory would be sensitive to these differences.

Yet a third way of distinguishing the various change processes, and one that is extensively used in the literature on productivity change, is to distinguish those changes that are internal to a firm from those that arise from reallocations of resources between firms, so called ‘within’ effects and ‘between’ effects. Innovations proper and perhaps the effects of recombination or fusion fall in the first category and all the other processes fall into the second category.

These distinctions provide the basis for an evolutionary accounting that tracks and decomposes population level change into its various components. As an accounting it is compatible with many different kinds of causal explanation behind the selection and innovation processes. Whatever the theory its fundamental feature is that it must explain how variety in the population originates and how the extant variation connects to the changes in the population, and as we shall see many different theoretical frames are possible.

The Evolution of Productivity Aggregates

The study of productivity growth in the aggregate has a distinguished history but it is largely aided by resort to explicitly macroeconomic constructs such as the aggregate production function. These of necessity hide the diversity of productivity growth experience as scholars such as Nelson (1989) have carefully pointed out and act as a barrier to an understanding of the links between innovation and economic growth. For example, the crucial concept of the aggregate production elasticity linking labour input increase to output increase frays in our hands in a multi sector economy, for its magnitude will depend on how any increase in labour is allocated across the different industries. Thus it cannot be interpreted as a technical construct alone². More importantly it loses sight of the fact that the evolution of the economic structure is itself a function of the diversity of productivity performance across the constituent firms and industries within it and that this is in turn fueled by diversity in productivity growth performance.

A typical exercise in evolutionary population dynamics is to focus on some representative statistic of population performance and enquire how this changes over time under the forces of selection and creativity. The extensive literature on the evolution of labour productivity either within an industry or across sets of industries is exactly of this kind. The relevant population is either an aggregate economy, a population of well defined industries, or an industry, a population of well defined firms. Many of these studies are aimed at decomposing the change in some productivity aggregate into the various possible effects described in Figure 1 to uncover the relative importance of entry exit and differential growth compared to the effects of innovation in the individual firms or industries.

² Empirically minded scholars such as Massell (1960) clearly understood this point but the pursuit of macro fundamentalism soon buried the implications. Interestingly, careful theorists such as Hicks (1932) who did so much to promote a production function approach were at pains to point out that production elasticities did reflect the composition of output and thus the composition of demand.

Note first that the stylised facts on the scale and ubiquity of economic variation are becoming well established thanks to new data sets that have made it easier to answer this kind of question. The wide variations in productivity growth and productivity levels within and between industries (Bartlesmann and Doms, 2000) and the high rates of entry, exit and market share mobility (Audretsch, 1995; Geroski, 1995; Caves, 1998) are typical examples. More recently Baldwin and Gu (2005) in a detailed study of Canadian manufacturing find persuasive evidence for the restless nature of economic growth in terms of population dynamics. Among their findings we note:

- 70% of firms in operation in 1989 were not in operation in 1999, exits accounted for 46% of total output and 50% of total; employment. Most exits are closedowns, business failures that are not acquired by another firm.
- About 45% of firms active in 1999 entered between then and 1989. Exits on average have 74% of the productivity of incumbents and Greenfield entrants 68% but merger entrants are 19% more productive than incumbents.
- Turnover among incumbents was far important than turnover from entry and exit. Over the period 1979-1999 growing firms gained 7.5% points of market share per annum and declining firms lost 13.6% point pa. Entering firms captured 4.2% and exiting firms lost 4.1% per annum in market share.

The findings on entry and exit processes are also confirmed by a previous study on the Canadian by Baldwin and Rafiquezzaman (1995), which distinguishes entirely new entrants, 'green-field' entrants consisting of a new firm plus new plant, from entry by firms established in some other industry. They find that 6.7% of establishments operating in any one year are green-field entrants and that only 3.4% of them survive to age ten, although larger firms survive relatively more at this age. Green-field entrants start with a disadvantage in respect of wages paid, productivity and profitability and it takes 8/9 years for them to improve their performance to approximate to the industry average. However, for the entrants who survive they find that they are 32% of average industry size at birth, and by ten years they are 48% of this figure. By contrast, failed entrants, those not surviving to year ten, are only 20% of average size at birth.

The issue to be addressed now is how these processes are connected to productivity growth in suitably defined populations, taking account of the different processes contained in Figure 1.

It turns out that is not such an easy question to answer as it might appear at first sight, for the literature covers radically different positions. Thus many studies claim that the ‘within’ effects account for almost all productivity growth at the aggregate level leaving next to nothing to be explained by ‘between effects’ (Hazeldine, 1985; OECD, 2001; Foster, Haltiwanger and Krizan, 2001). Alternatively, between effects can be identified as empirically important but equated almost entirely with the effects of entry and exit leaving no role for the differential growth dynamic that is a core feature of evolutionary models at least since Nelson and Winter (1982) if not before (Downie, 1958). The study by Disney *et al* (2003) falls in this category. Important matters are at stake here and they imply radically different broad policy conclusions. If it were true that productivity change is primarily a matter of ‘within’ effects then the basis for stimulating productivity growth reduces to innovation pure and simple, including in this recombination and fission of firms. Market processes would have little weight and arguments about market flexibility and adaptability of the invisible hand at the system level would be rendered otiose. Similarly, entry and exit relate to very different aspects of the market dynamic than does differential growth of established firms. A finding that ‘within’ effects dominate in explaining the aggregate rate of productivity growth also has major implications for the connection between innovation and market processes. Firstly, by discounting any connection between differential innovation performance and changes in market position, that is to say by discounting the idea that more competitive firms gain resources and customers at the expense of less competitive firms. Secondly by discounting the idea of a reverse competitive effect that it is a combination of negative competitive pressure and or positive feedback from a strengthened market position that further stimulates innovation. In both respects the argument for creative destruction is undermined.

However, matters are not as simple as some of these studies imply. Indeed as Baldwin and Gu (2005) point out a different approach to the problem strongly supports the idea of significant ‘between’ effects including differential growth of incumbent firms. Their study based on the analysis of 35,000 Canadian manufacturing plants grouped into 236 four digit industries throws important light on these arguments. They find that the ‘within’ effects of innovation in the broad account for around 27% to 30% of Canadian productivity growth between 1979 and 1989 leaving a dominant proportion to be explained by various ‘between’ effects. Contrary to the OECD they find that output reallocation within the set of incumbents accounts for 48% in the first decade and 40% in the second decade of the total increase in productivity and that green-field entry and close down exit account for 5% each of the total

change, the balance largely being accounted for by entry and exit associated with merger and divestiture, recombination and fission in our terms. They also find that the within effect in incumbent firms is largely concentrated in those firms that are growing, since declining firms show greatly inferior productivity growth rates. A more recent study of productivity growth in Germany, pre and post unification, also finds good evidence for between effects and notes that they vary considerably across different industries (Cantner and Kruger, 2004, 2005).

All of this is grist to the evolutionary mill and suggests that differential growth, entry and exit processes may play different roles in productivity dynamics depending on the economy studied, the degree of aggregation of the data set, and the methodology employed to make the decomposition. How is it that such divergent conclusions are reached even with the same data set? Is it that there are certain ambiguities in the measurement and decomposition process leading to premature conclusions? Baldwin and Gu, for example, are able to replicate the dominance of ‘within’ effects on the same Canadian data using the methods of Foster *et al* (2001) and make ‘within’ effects in incumbents account for circa 70% of productivity growth, quite the reverse the conclusion they had reached by their method.

To answer this question we need to spell out the deeper content of the population method and see how different measurement schemes reflect different assumptions about the role of market forces in labour and product markets. For the differences in conclusion depend on whether one assumes that the ‘between’ effects relate to reallocations of the labour force or whether they relate to reallocations of output. In short it is a matter of the relative contribution of labour market and product market competition to the evolution of aggregate productivity in the relevant populations.

Accounting Formalities

To develop this point ignore the effects of recombination and fission in Figure 1 and let the population characteristic in focus be unit labour requirements (the inverse of labour productivity) in this population of firms, labeled ‘ a ’. We want to know how the population average value, labelled \bar{a} , changes over our time interval. Let d be the fraction of output at t produced by firms that exit in the following interval. Let n be the fraction of output at $t + Dt$ produced by firms that enter in the interval. Let $s_i(t)$ be the share of a continuing firm in the total output of the sub population of continuing firms.

It follows from the definitions above that in relation to the ‘selection processes’

$$\bar{a}(t) = (1 - d)\bar{a}_s(t) + d\bar{a}_e(t)$$

where $\bar{a}_s(t) = \sum s_i(t)a_i(t)$ is average unit labour requirements in the continuing firms and $\bar{a}_e(t)$ is the average value of $a(t)$ for those entities that will exit over the interval Δt . Similarly, in relation to the ‘innovation processes’

$$\bar{a}(t + \Delta t) = (1 - n)\bar{a}_c(t + \Delta t) + n\bar{a}_n(t + \Delta t)$$

where \bar{a}_n is the average value of $a(t + \Delta t)$ for the entrants over the interval. The change in \bar{a} follows as

$$\Delta \bar{a} = \bar{a}(t + \Delta t) - \bar{a}(t) = \Delta \bar{a}_s + n\Delta t(\bar{a}_n(t + \Delta t) - \bar{a}_s(t + \Delta t)) - d\Delta t(\bar{a}_e(t) - \bar{a}_s(t)) \quad (1)$$

Expression (1) is a complete evolutionary accounting for the change in average population value of unit labour requirements³ and it is a close representation of most of the accountings used in the empirical literature⁴. On the right hand side, the first term is the combined effect of competitive growth and innovation operating on the surviving firms. The second and third terms reflect the productivity levels in entrants and exits, expressed as deviations from the average productivity value for the continuing entities at the appropriate dates⁵. Productivity growth in the population is caused by 1) productivity growth in the individual firms, the ‘within’ effect 2) expansion of high productivity firms relative to low productivity firms, the ‘differential growth’ effect, and 3) entrants of above average productivity and exits of below average productivity.

³ Written in special forms in many different ways in the literature. Baldwin and Gu (2005) for example assume, because the Canadian evidence supports this view, that ‘ n ’=‘ e ’, the displacement hypothesis. Then the only empirical issue is whether entrants on average have higher productivity than exits.

⁴ See Bartelsmann and Doms (2000) for alternative formula.

⁵ In his survey of industry dynamics processes in LDCs, Tybout (2000) discusses some limited empirical evidence in favour of relatively high rates of turnover in plants and employment, the finding that efficiency, compared to survivors, is lower in exiting plants and in entrant plants, and that these categories rarely account for more than 5% of total output in any year. This suggests that some entrants fail to survive, and that those that do soon overcome the liability of newness and achieve at least average levels of productivity in the relevant populations. The same decomposition, or variants of it, has been used extensively in recent empirical work demonstrating the importance of selection for productivity growth (Carlin *et al.*, 2001; Bailey *et al.*, 1992; Bartelsman and Doms, 2000). This empirical literature provides striking empirical verification of the dynamic nature of competition and of the importance of distinguishing selection of activities in plants from selection of firms. Its conclusions are deeply dependent, of course, on access to finely disaggregated micro data, since aggregation always masks evolution.

The first two of these effects are captured in the first term in equation (1) and it is one of the central accounting devices in evolutionary population analysis to decompose this measure, a device known as the Fisher Price theorem (Price, 1970; Frank, 1998; Metcalfe, 1998; Andersen, 2004a; Gintis, 2002; Knudsen, 2004). This is a general method for decomposing the change in average value of some population characteristic into two independent, additive effects, one due to selection the other due to innovation. Thus, following a proper accounting for the continuing firms at the two dates, we find

$$\begin{aligned}\Delta \bar{a}_x &= \sum s_i(t + \Delta t) a_i(t + \Delta t) - \sum s_i(t) a_i(t) \\ &= \sum \Delta s_i a_i(t) + \sum s_i(t + \Delta t) \Delta a_i \\ &= \frac{1}{1 + g_s} \{ \sum s_i(t) (g_i - g_s) a_i(t) + \sum s_i(t) (1 + g_i) \Delta a_i \}\end{aligned}$$

or
$$(1 + g_s) \Delta \bar{a}_c = C_s(g_i, a_i) + E_s((1 + g_i) \cdot \Delta a_i) \quad (2)$$

Expression (2) is the Price equation; in which, $C_s(g_i, a_i)$, the measure of the selection effect, is the (s_i weighted) covariance between fitness values (the growth rates g_i) and the values of a_i at the initial census date. This captures the idea that the change in the average value of the characteristic depends on how that characteristic co-varies with growth rates across the population; in short, that evolution is a matter of correlation. The second term, $E_s((1 + g_i) \cdot \Delta a_i)$, the measure of the innovation effect, is the expected value (again s_i weighted) between the growth rates and the changes in the characteristic values at the level of each firm. In relation to productivity decompositions it measures the ‘within’ effect. Notice the recursive nature of this formulation; for if the entities are also defined as sub populations of further entities we can apply the Price equation successively to each sub population. For example, if entity i itself consists of a sub-population of j entities we can apply the Price method and write

$$(1 + g_i) \Delta \bar{a}_i = C_{sj}(g_{ij}, a_{ij}) + E_{sj}((1 + g_{ij}) \Delta a_{ij})$$

and apply this to each of the i entities in the original population. As Anderson (2005) suggests, the Price equation “eats its own tail”, an attribute of considerable significance in the analysis of multi-level evolutionary processes. It means that we can decompose population change into change between any number of sub-populations and change within sub-

populations in an identical fashion, so that at each level of aggregation we can reflect the forces of adaptation whether through selection or innovation. Since these relations are accounting relations they are compatible with any theory of evolutionary change that combines together the principles of variation, selection and innovation. Indeed, evolutionary economists have developed a rich set of explanations of competition that fit within this framework (Nelson and Winter 2002; Andersen, 1994; Dosi, 2000; Metcalfe, 1998; Witt, 2003).

The force of this general approach can be summarised simply. Though selection is only one level of explanation for population change it cannot be separated from innovation. Innovation creates the variety (including entry) on which selection depends and the ensuing process reshapes the conditions for further innovation. It is an ensemble rather than an individual type of explanation but one that is based on the specifics of individual variation (Matthen and Ariew, 2002).

Ambiguities and Puzzles

The conflicting evidence over the relative importance of ‘within’ and ‘between’ effects creates a series of puzzles which the population accounting perspective helps clarify. The starting point is to note that any productivity measure is a ratio of output to input so that ‘within’ and ‘between’ effects might in principle apply to both numerator and denominator of the ratio. Thus to enquire into the contribution of changes in patterns of output on aggregate productivity growth is a quite separate question from enquiring into the corresponding effects of changes in the patterns of inputs across firms or establishments. Two very different notions of productivity growth are thus involved. Productivity growth proper is what happens within plants or firms and this is logically quite a different process from shifting output and resources between firms, including entry and exit, with given but different levels of productivity. It is this later effect that has created the difficulty and we now show that there are two different reallocation effects in principle and thus two different measures of the corresponding ‘within’ effects. There is no single unambiguous decomposition of the sources of productivity growth across a population and it is worth a little detour to enquire why.

Define labour productivity in a given firm as q_i and its inverse unit labour requirements as a_i . Clearly $a_i q_i = 1$ and making the appropriate aggregate measures for the population as a whole we have $a_s q_e = 1$, the aggregate average quantities being defined as $a_s = \sum s_i a_i$, and $q_e = \sum e_i q_i$ respectively. Note carefully the different weights used to perform each aggregation for it is changes in these different weights that will contribute to the different ‘between’ effects. It simplifies the exposition if we consider the changes that take place in a time interval sufficiently short that we can ignore interaction between the ‘within’ and ‘between’ effects and it follows that

$$\hat{e}_i + \hat{q}_i = \hat{s}_i + \hat{q}_e \text{ or equivalently that } \hat{s}_i + \hat{a}_i = \hat{e}_i + \hat{a}_s$$

from which we infer that the proportionate changes in output and employment weights for any firm are only equal when that firm’s *rate of productivity growth* equals the population average rate of productivity growth. This is the counterpart to the proposition that the employment and output share weights for a firm are equal only when it has a *level of productivity* equal to the population average. Similar statements apply to the unit labour requirement statistics.

Now consider the conventional decomposition of the aggregate change in productivity at the population level

$$\dot{q}_e = \frac{d}{dt} \sum e_i q_i = \sum e_i \dot{q}_i + \sum \dot{e}_i q_i$$

which we can rewrite as $\hat{q}_e = \sum \left(\frac{e_i q_i}{q_e} \right) (\hat{q}_i + \hat{e}_i)$

or, making use of the relations between the population weights and productivity levels, as

$$\hat{q}_e = \sum s_i (\hat{q}_i + \hat{e}_i) \tag{3}$$

Now, from the opposite direction we can perform the same calculation for the change in unit labour requirements to give,

$$\hat{a}_s = \sum e_i (\hat{a}_i + \hat{s}_i) \quad (4)$$

However, (3) and (4) are by definition numerically equivalent in magnitude and of opposite sign and by definition $a = -q$. Hence we have two different decompositions of the same growth in aggregate labour productivity. Each decomposition uses different weights for the ‘within’ and ‘between’ effects and measures the two effects differently. As Baldwin and Gu (2005) put it, the first expression (3) measures what the ‘within’ effect would be if there was no reallocation of labour within the population and the second expression (4) measures the ‘within’ effect on the assumption that there is no reallocation of output within the population. In general neither is complete since selection effects occur simultaneously in labour and product markets; hence there are two ‘between’ effects and thus two ‘within’ effects. The difficulty is obvious if we reflect that a constant set of employment shares mean that output shares must be changing unless rates of productivity growth are equal across firms. In general, and in the presence of a diversity of productivity growth rates, the absence of a ‘between’ effect on one measure means the presence of a ‘between’ effect on the second measure.

Under what conditions would the ambiguity disappear? On equating the two expressions and taking account of the fact that $a_i q_i = 1$ we can write

$$\sum (e_i - s_i) \hat{q}_i = \sum e_i \hat{s}_i + \sum s_i \hat{e}_i \quad (5)$$

The left hand side measures the difference in the ‘within’ effects and the right hand side measures the total selective flux in the population, the difference in the ‘between’ effects. Further elaboration allows us to write this in the familiar evolutionary way in terms of measures of population diversity

$$-\frac{C_e(q_i, \hat{q}_i)}{q_e} = -\frac{C_s(a_i, g_i)}{a_s} + \frac{C_e(q_i, g'_i)}{q_e}$$

The difference in within effects is measured by the employment weighted covariance between productivity levels and rates of change of productivity, and would be positive if more productive firms on average enjoyed higher productivity growth. The right hand side measures the total flux in terms of sum of the covariance between unit labour requirements

and output growth rates and the covariance between labour productivity and employment growth rates. When does the ambiguity disappear? Only when the population is evolving in neither labour markets nor product markets, and one case of this is when all the firms have the same productivity levels or the same rates of productivity growth. In short the assumptions that make macro aggregates meaningful also equate the two measures. In general this is not the case and we have two measures because there are two selective forces at work one in product markets and one in labour markets.

The covariances in the above account capture exactly the Fisher/ Price dynamics of evolutionary processes. When there is no correlation there is no evolution. It is therefore perfectly possible for the same data to yield widely differing answers to the ‘within’ ‘between’ productivity decomposition exactly as Baldwin and Gu (2005) demonstrate. Both answers are right because they are the answers to different questions about population dynamics. What may be the case is that output shares are far more mobile than employment shares but why this should be so I cannot speculate on here.

Entry Exit and the ‘Shakeout’ Hypothesis

The importance of entry and exit phenomena to the market dynamic both in their own right and in relation to productivity growth is incontrovertible, and so a deeper explanation of the two processes and their interconnection is an important aspect of population dynamics perspective. This is an old theme, traceable back to Marshall and the ‘trees in the forest’ metaphor and the idea that economic events can follow patterned sequences. Recent work, particularly by Klepper and his co workers has thrown a great deal of light on these phenomena under the guise of the ‘shakeout’ hypothesis⁶. The general observation is that entry and exit patterns follow an ordered sequence over the life of the industry as it gradually evolves towards an oligopoly. The industry becomes as it were an organic whole subject to growth and development as it interacts with its environment to establish a supporting niche. However at some point in this lifecycle a drastic reduction occurs in the number of viable firms, the ‘shakeout’, which forms the break between a pre history and a post history of the industry. Thus, studies of the auto, television, tyre and penicillin industries all conform to an

⁶ I draw upon the following references in the following account. References to earlier work by Klepper are contained within them. Klepper (2000), Klepper and Simons (1997, 2000, 2005), Buenstorf and Klepper (2005). The recent work by Buenstorf and Klepper (2005) puts more emphasis on fission processes in the tyre industry and finds that leading firms disproportionately generate spin-offs. This leads them to an explanation of regional concentration in the industry based on inherited organisational capabilities and their reproduction in other firms. They suggest that this account explains the industry history more accurately than do explanations based on agglomeration economies.

entry, exit pattern with several common features. Figure 2 (Buenstorf and Klepper, 2005) shows the general pattern for the tyre industry, the sequences of entry and exit and the change in the total number of firms in operation. Within these general patterns a number of important generalisations can be made:

- All four industries converged to stable oligopolies over a period lasting thirty years or more, with the number of firms dropping by between 77% to 97% from the peak;
- Entry is concentrated predominantly before the shakeout but exit is distributed across the life of the industry as the forces of selection impose concentration;
- The survival probabilities vary systematically with the age of firm and with the place of a firm in the entry sequence. Early entrants tend to have lower hazard rates than later entrants and it is the timing of entry that most affects the age to exit relation;
- Prior experience of an entrant in another industry (compare Baldwin and Gu's findings on diversified entrants relative to green-field entrants, also) significantly improves the probability of survival although this effect decays as ages increase;
- Entrants who draw on core knowledge from other activities also have enhanced prospects of survival (Mitchell, 1989, Helfat and Lieberman, 2002, Thompson, 2002).

Other studies confirm these general findings. For example, Horvath *et al* (2001), apply similar methods to the US brewing industry and the shakeout that occurred in the late 19th century when the number of firms dropped by 40% in a decade. In addition the pioneering work by organisational ecologists provides important support to these general findings in terms of the connection of firm birth and death rates with the evolving density of the population. These are more ecologically grounded models focusing on the changing carrying capacity of an environment and the age dependence of firm/organisational performance (Singh, 1990)⁷.

While the empirical findings are clear and relatively uniform the possible explanations for the shakeout are far more diverse and indeed different industries may support different explanations. Thus, Horvath *et al* (2001) rely upon information cascade arguments to motivate the idea that misinformed entry in haste stimulates exit at leisure in the cold light of experience. However, many of the studies referred to above place technological innovation at the core of the explanation. Klepper's model (2002) is one on which the costs of R&D

⁷ See also the special issue of *Industrial and Corporate Change*, Vol. 13 No. 1, 2004, for a stocktaking of the literature.

drive a process of increasing returns as systematic shifts in the industry environment deliver less profitability to support R&D. This gradually reduces the probability of entry and leaves late entrants with insufficient resource to lower their costs to a level consistent with survival. Random shocks to costs also take their toll of survivors but the additional systematic force is that more profitable, lower cost firms can expand more rapidly thus reducing the average cost of R&D and increasing its marginal payoff. In the process, average price falls and plays the role of grim reaper for firms that are no longer able to compete in terms of innovation. In sum, this is a Mathew principle model in which once a firm is ahead that greatly increases the probability of its staying ahead, the advantages are for it to lose. In relation to the shakeout hypothesis this suggests that key technological events may trigger the cascade of exits and while this is appealing Klepper (2002) holds to a different view, that it is the ability to associate the firm with a trajectory of major and minor innovations that distinguishes the firms which survive the shakeout. In effect, older and larger firms that are better managed in general are able to keep closer to the best practice frontier. This is not dissimilar to the dominant design approaches (Utterback and Suarez, 1993; Utterback, 1995) which attribute survival and the shakeout to a coalescence of the industry around a ‘winning’ process and product innovation trajectory. Mention may also be made here of the Jovanovic and MacDonald paper (1994) which also takes the US tyre industry as its empirical referent and explains the shakeout in terms of a major innovation that leaves ‘old’ firms with minimum average costs at a lower scale of output and at a higher level than those associated with the ‘new’ firms. What matters about these different approaches is not their reliance on different models of firm behaviour, optimizing or adaptive, but rather the recognition of variation as the driving force in industry evolution⁸. Effectively they each define their industry dynamics across populations of firms that are heterogeneous and derive their evolutionary consequences from this fact.

This field of research has proved remarkably fruitful and is capable of much further extension to other industries and to comparisons of the same industry across different countries. Yet much more can be said conceptually in relation to entry and exit processes. Exit is not a flow profitability decision but a balance sheet decision and many factors can stand between negative profits and exit, accumulated reserves, public subsidy or support from a different

⁸ The Jovanovic and MacDonald model is really a Viner model of a perfectly competitive industry in which the radical innovation opens up the entry possibility which in turn drives the consequences for exit. Hence the rather angular pattern of prices that this model predicts. Klepper’s model is also based on explicit optimising arguments in which firms equate the marginal costs and benefits of R&D and the marginal costs and benefits of capacity expansion. In both cases optimisation, first order conditions, are not the determining issue which is instead the introduction of variation in behaviour across cohorts of firms.

branch of the firm's activities, the prospects for selling on the capital value of the business into new ownership or a different line of production. Optimistic expectations may foster injudicious entry they may also encourage a firm to hang on irrationally in the hope of better times. Over the longer term these factors may wash out and leave profit performance as the relevant discriminator between survival and exit on average if not for explaining the demise of individual firms. Systematic changes in the environment also extend beyond technology. The typical phenomenon that the rate of growth of the market declines as the industry matures will put pressure on margins even though the industry is still expanding. Competition from foreign producers too is often significant and so we can generalize the population of firms to those located in different countries. As we pursue these developments we see the broad contours of economic evolution and the different routes through which selection acts to determine fitness and survival. From a system viewpoint it is important that the rules of the game facilitate efficient entry and exit. It matters that when a firm 'dies' the capabilities within it are readily available for other uses including the capabilities of the founders if they are still active. Hence the importance of the market for corporate control in facilitating the takeover of business units that are ailing in their current performance but which can be deployed more effectively in different markets under different management. More generally the role of selection in relation to exit and indeed entry cannot be reduced to the sole role of product markets. Markets for labour and for capital more generally should be part of the explanation of a wider industry dynamics.

Differential Growth and the Fisher/Price Dynamics.

It remains to discuss the last of the population processes, the differential growth of the continuing members of the population, the theme that has been the formal centre piece of the literature stimulated by Nelson and Winter (1982). This literature reminds us that evolutionary theory is a theory of differential growth and thus of structural change and that it is behaviour that is far from the norm that causes the most significant changes in the population structure. Three propositions capture the core of the argument:

- That the pattern of changes in relative population importance obeys a distance from mean dynamic, otherwise known as a replicator principle, in which the share of an entity in the population varies according to the difference between the growth rate of the entity and the average growth rate across the population as a whole.

- That the growth rates are interdependent and mutually determining, the mark of a ‘selection’ theory as distinct from a ‘sorting’ theory in which the growth rates are independently given constants.
- That the average growth rate evolves over time according to the Fisher/Price dynamics outlined above (2), in particular the selection component implies that the average growth rate changes at a rate exactly proportional to the variance of growth rates in a population. In fact selection causes all the population moments to evolve according to the statistical variety in the system in a clearly determined way⁹.

This framework provides a rich basis for confronting the empirical evidence that increases in quality as we gain access to more finely disaggregated data sets¹⁰. The Canadian data interrogated by Baldwin and Sabourian (2004) for example show that there is considerable flux in market shares defined at enterprise level. Over a period as short as a decade some 46% of market share is transferred from firms in relative decline to those in relative growth, and a large number of very small changes can and do cumulate to significant shifts over time. Using a transition matrix to track mobility across market share quartiles they find that the majority stay in quartile but that the movements are significant. For example 83% in the top quartile remain there and 82% in bottom quartile also do so but 23% of firms in the second quartile drop to the first quartile. Of firms in the third quartile 16% make it to the top quartile but 2% fall to the first quartile and so on. This degree of flux implies considerable intra distributional shifts in rates of growth and raises many interesting issues in relation to the causal mechanisms. One might conjecture that finer partitions of the cumulative distribution would reinforce the evidence for mobility and that the higher the level of aggregation the less evidence we will find for mobility in relative positions¹¹, and some evidence points in this direction (Geroski and Toker, 1996). The stability of growth rates over time is a central question, ‘Is all this merely ‘higgledy piggedly’ growth or do systematic and sustained changes in market positions occur?’¹² The answer is probably both, with much growth rate instability for smaller firms and those close to the population mean but with some significant persistent growth rates for a much smaller number of firms who are much better and much worse than average, precisely the conclusion that follows from the work by Klepper and colleagues referred to above. What the distance from mean dynamics predicts is the

⁹ In fact their evolution follows the so called cumulant principle (Metcalf 1998).

¹⁰ See Caves (1998) for a detailed survey of the market share mobility literature.

¹¹ See Geroski and Toker (1996) for some evidence on the stability of large firm positions in the UK

¹² There is a vast literature on the topic of growth rate distributions, scaling laws and stochastic growth dynamics. See Dosi (2004) for an introduction.

importance of non-representative behaviour exactly the behaviour we associate with significant innovation.

More relevant to the current discussion is the theoretical foundations for the population dynamic perspective on which there is now a large literature. (Nelson and Winter, 1982; Dosi, 2000; Mazzucato, 2000; Marsilli, 2001; Metcalfe, 1998; Saviotti, 1996; Andersen, 1994, 2004a). The central theme is that the variety in 'firm' characteristics is evaluated by a market environment to cause a distribution of growth rates across the population of firms. Three different groups of firm characteristics underpin this claim. Differences in product and process characteristics are evaluated by the environment to establish patterns of prices and costs, the resulting profits are the basis for firms to expand capacity and develop their market differentially and over longer horizons for them to innovate to further enhance product and process characteristics. The relative position of any firm thus depends on its comparative performance in three broad dimensions, current technology and organisation, ability and willingness to invest in capacity and market, and ability to innovate. There is nothing in the argument at all that claims that a low cost firm will rise to market dominance or that a very innovative firm will out compete its rivals. It is the joint distribution of behaviours that matters and the corresponding correlations of performance in the three dimensions. Correspondingly a firm that is more profitable than average may find this superiority in either product and process technology and there is no guarantee that it will also expand more rapidly than average or innovate more successfully than average. Replicator dynamic outcomes depend on the correlations over time across all three of the performance dimensions. Particularly intriguing is the question of whether it is the firms with superior technical performance today who will be in the same position tomorrow or whether their basis for market dominance is undermined by the innovative efforts of rivals. The answer may point to one of the most powerful effects of market competition to the effect that the selection mechanism with its tendencies to concentration is offset by the innovation mechanism as a powerful countervailing force so that the evolution of the market is a succession of leapfrogging positions (Downie, 1958). What stands in the way of this is the prospect of increasing returns in the innovation process, in which firms that get ahead stay ahead because they have the resources to underpin the required rate of innovation relative to rivals. This is the Schumpeter Mark II model, partially supported by some of the evidence we have from the work on entry/exit patterns, shakeouts and consolidations. The Baldwin and Sabourian (2002) work indeed suggests that there is more mobility in terms of changes in productivity performance than there is in terms of market shares but that the firms most

successful at increasing market shares are also the firms with the largest increases in productivity performance but which firms these are cannot be predicted at the beginning of the period. More generally the jury is out. Innovative success is not only a matter of resources, it reflects managerial and strategic capabilities to conduct innovation and on the perception of innovation opportunities which may reflect changes of knowledge from outside the traditional epistemic base of an industry¹³. In fact there may be no general rules simply a large number of different cases given meaning by their consistency with the principles of economic evolution. How evolution takes place then depends on the degrees of correlation between efficiency, growth and innovation, and the varying degrees of transience of these correlations. It is the task of evolutionary economics to link these different dimensions of variation in the most illuminating way possible.

While the evolutionary account seems to focus on the primacy of variation across the population of firms it only does this in the context of market valuation processes and if these change so will the distribution of profits, abilities to expand and incentives to innovate. Moreover, it is too easy to slip into the view that market selection is only about product markets but this cannot be the case. Any firm is suspended, as it were, between product markets and factor markets, and imperfections in all these markets will influence the distribution of growth rates. The firm that has to pay disproportionately higher wages to attract the particular skilled labour required for expansion, or which pays an excessive premium for access to risk capital or working capital will be put at an evolutionary disadvantage¹⁴. How markets work in this regard as open systems for transferring resources (as well as customers) between firms and industries in a non discriminatory way is one of the core questions in appraising modern capitalism. Similar issues influence the distribution of innovation performance and the idea that markets provide an architecture for parallel innovative efforts. Taken together they perhaps imply that the regulation of markets is more important than the regulation of firms through anti trust policy, and that innovation policy is a natural complement to competition policy. Moreover, they suggest a richer agenda for evolutionary work, for example tracing the links between the capital market, share valuation processes and the allocation of capital to investment and innovation¹⁵.

¹³ This is a frequent theme in the strategic management literature. Utterback (1994), Christensen (1997).

¹⁴ Metcalfe (1997) is as far as I can ascertain the only attempt to write the Fisher dynamics in terms of labour market constraints on firm expansion.

¹⁵ See Jovanovic and MacDonald (1994) for an early attempt to link above average stock market performance to innovation based variation across firms. Marianna Mazzucato is one of the few evolutionary scholars to have treated this question seriously (Mazzucato, 2000; Mazzucato and Semmler, 1999).

One particular way to make these connections is provided by the emerging body of work on history friendly modeling of economic evolution. Through this approach the multiple dimensions of firm performance can be integrated into different models of selection environments, to judge, for example, the effects of market regulation, and to understand what has happened by asking the question, ‘Why might events have turned out differently?’ Recent work by Malerba and colleagues (Malerba *et al.*, 2001, 2002) is extremely promising in its ability to connect market change to variety in a population dynamic approach and to calibrate the complicated interactions against data from the computer and pharmaceutical industries. In their study of the pharmaceutical industry, for example, Malerba and Orsenigo (2002) investigate the effect of major shifts in drug discovery technology and its interaction with patent regulation, and agreements between incumbents and new biology based entrants on the evolving structure of the industry. In these studies, computable population models are devices for constructing counterfactuals in which systematic causes and probabilistic events can be fine tuned to allow the long term exploration of alternative histories (Saviotti and Pyka, 2004).

Retardation Theory and Logistic Industrial Growth

Discussion of history friendly modeling takes me to the final topic, the characteristic growth patterns of different industries. No survey of industrial dynamics should be concluded without drawing attention to its extended past and the implicit connections with a population approach. The work of American empirical scholars in the 1930s and subsequently is particularly important here in terms of the empirical evidence gathered on the diversity of growth experience and the search for a theoretical framework that was strongly evolutionary. The focus here is on the dynamics of industry output and employment as a whole rather than the number of firms or exit and entry patterns. In particular, Simon Kuznets (1929,1954), Arthur Burns (1934) and Soloman Fabricant (1940, 1942) made major contributions to growth dynamics before the consequences of the Keynesian revolution, or more strictly, a particular interpretation of it, turned growth theory and empirics in a macroeconomic, counter evolutionary direction. The details of their accounts need not concern us other than to say that the principle cause of the dynamic patterns they discovered was judged to be technological innovation and, more precisely, the declining prospect for innovation in any one industry after its foundation. In terms familiar from the modern shakeout literature they gave an industry a ‘life cycle’ closely connected with the life cycle of its technological base. Instead I want to draw attention to two related aspects of these theories, the notion of

retardation that an industry's output growth rate declines systematically from foundation to maturity, and its empirical counterpart that the increase of output over time follows a sigmoid curve, a logistic or Gompertz curve are typical examples, with a profile such as that in Figure 3.

It transpires that the logistic process is a deep signature of an evolutionary process within populations that are governed by a variation and selection dynamic. Moreover, it is the connection with the distance from mean dynamics of population change which helps explain the empirical ubiquity of the logistic curve because all processes of structural change are population phenomena. However, a logistic process need not generate the familiar 'S' shaped logistic curve expressed as a function of time, indeed it may be associated with non monotonic time profiles, quite non logistic profiles, for the changing relative importance of many of the entities in a population. The logistic process has, therefore, a degree of generality that the logistic curve does not possess. For example, Marchetti and Nakicenovic (1979) in a study of the evolution of populations of rival energy technologies recognised that in the substitution process the logistic phase of growth and saturation is normally followed by a phase of decline such that a logistic time trend only captures part of the evolutionary process¹⁶. That growth may be followed by decline is unexceptional but that both aspects of evolution are captured in the same general logistic process is perhaps worthy of further investigation. Moreover, this logistic process depends on the distance from mean dynamic and its close relatives that we have alluded to already.

This is not the place to explore these two ideas in depth but rather to demonstrate briefly how the ubiquitous 'S' curve of growth, and its corollary, output retardation, is deeply connected to evolutionary population dynamics. Indeed that this earlier industrial dynamics literature is a relative of the Fisher/Price principles of evolutionary dynamics. To illustrate this point consider the movement of an average growth rate g_s of an ensemble of a fixed number of industries, $\sum s_i g_i$, where the shares are measured in terms of each industry's contribution to total output. Following the Fisher/Price principle this growth rate will change according to the selection effect and the innovation effect as follows

$$\frac{dg_s}{dt} = \sum \frac{ds_i}{dt} g_i + \sum s_i \frac{dg_i}{dt} = V_s(g_i) + \sum s_i \frac{dg_i}{dt}$$

¹⁶ For useful references to the technology substitution literature see, Fisher and Pry (1971), Kwasnicki and Kwasnicki (1996) and Mahajan and Petersen (1985). On the use of the logistic in relation to economic development see, in particular, Nelson (1968) and Nelson and Pack (1999).

Empirically, the trend growth rates for an economy as a whole are close to constant exponential rates so let the population average also be constant whence it follows that

$$\sum s_i \frac{dg_i}{dt} = -V_s(g_i) \quad (6)$$

The average rate at which the individual growth rates change is negative and equal in magnitude to the variance of the growth rates across that population. This is the retardation principle, and it applies whenever the variance of growth rates in the population exceeds the rate of change of the average growth rate. Not all the individual growth rates need decline at any particular time but the acceleration of some growth rates would necessarily be accompanied by the more rapid retardation of others. Now the retardation of an industry's growth rate leads directly to the 'S' shaped curve of the increase of output over time. One familiar curve that is used empirically to capture this widespread phenomenon is the logistic, a curve that is also widely used in modern technology substitution and diffusion of innovation analysis.

It is a consequence of the distance from mean population dynamic for any member of the population the time trend of its share in the population will follow a logistic process given by¹⁷

$$s_i(t) = \frac{1}{1 + A_i \exp - D_i(t)}$$

Where A is a constant of integration and D is the integral time path of the distance from mean function for that population member.

$$D_i(t) = \int_0^t [g_i(t) - g'_{si}(t)] dt$$

Only in special cases, for example a population with only two members, will this translate into a logistic time trend in the familiar way favoured by ecological approaches to technological substitution and diffusion. More generally the time trend for the share of the population will not be logistic and will encompass a phase of decline after a point of maturity has been passed but both phases obey the logistic principle. Thus the typical life cycle of an

¹⁷ The details are in Metcalfe 2004a and 2004b.

industry in a population: it starts small, expands its share in the output of the population by growing more quickly than the population average and then enters a phase of relative decline when its growth rate drops below that average. In absolute terms the output will be the product of two effects the logistic principle working on the share and the other forces working on the growth of the total output of the population of industries. This dynamic was captured very well by Fabricant (1940)

‘When we turn from the averages and concentrate upon the movements of manufacturing production in individual industries, we find sharp differences in the secular rates of change in the physical outputs of these industries. In every period, some decline, some forge ahead, and only a few industries follow the general trend of manufacturing output. These disparate rates of growth affect and are affected by changes in the structure of industry, in technical processes, in the kind of goods produced and in the distribution of employment’ (p. 9).

To summarise this branch of industrial dynamics too conforms to population principles. Just as entry, exit and differential growth play key roles within an industry so the same applies in terms of industries in relation to the economy as a whole. Over time new industries appear stimulating economic variety while old ones suffer demise and remain only in the industrial museums of society, while differential growth of the rest shapes the evolving structure of the economy. The system is restless at all levels and the ultimate source of this restlessness is the way capitalism has institutionalized the relation between economic activity and the growth of knowledge.

A Summing Up

Rather than conclude I prefer to return to the question of the instituted rules of capitalism that generate the phenomena discussed above, for the dynamic properties of the system are a reflection of the underlying rules of the game. The systems we have described are clearly creative, enterprise and entrepreneurs surely figure largely in their operation. Yet the conjecturing of different economic worlds is not enough, nor is the leadership to turn conjectures to reality, the system itself must be instituted in such a way as to accommodate to change, to foster instability within a continuing system. Here three aspects are important which view the institutions of capitalism in terms of fostering experimentation not in terms of

economic efficiency¹⁸. The first is the weak nature of property rights that are defined in terms of use and disposal not in terms of economic values. Values are not frozen by instituted edict but instead are entirely open to the contingencies of the market situation. The second is the significance of distinguishing contractual incomes from residual incomes for without this distinction no room could be found for the extraordinary but unanticipated rewards that innovation can bring to its promoters. The third is the open nature of markets, the fact that within them every position is in principle open to challenge by innovative entrants. Taken as a whole these three attributes could not be better designed to foster the experimental nature of the system. When combined with the human propensity to generate new knowledge they provide the framework for restless capitalism and its immense self transforming record.

Much of the literature discussed above points to the very uneven nature of this development. If there is progress overall it is certainly accompanied by a great deal of pain. Standard welfare economics in the past made much of the idea of compensation principles for assessing the desirability of economic change. However, a standard rule of capitalism is that ‘gainers’ do not compensate ‘losers’ in the competitive process unless illegal action is involved. Had the rules been to the contrary capitalism would not have got very far. In institutional terms an interesting issue arises centered around the capacity of the system to generate rules that offset the uneven consequences of knowledge driven evolution. Lacking compensation governments play a role through the invention of social insurance and private pressure groups play a role often bringing the social consequences of industrial dynamics into the picture.

I thus suggest that the interaction between industrial dynamic process of the kind discussed above and the co-evolution of compensating institutional rules would be a useful way to extend our understanding of restless capitalism.

¹⁸ On this topic see in particular, Nelson, 1981, 1990.

Bibliography

Andersen, E.S., 1994, Evolutionary Economics: Post Schumpeterian Contributions, Francis Pinter, London.

Andersen, E.S., 2004a, 'Knowledges, Specialization and Economic Evolution: Modelling the Evolving Division of Human Time', in S. Metcalfe and J. Foster (eds.), Evolution and Economic Complexity, Edward Elgar, Cheltenham.

Andersen, E.S., 2004b, 'Population Thinking, Price's Equation and the Analysis of Economic Evolution', Evolutionary and Institutional Economics Review, Vol. 1, pp. 127-148.

Audretsch, D.B., 1995, 'Innovation, Growth and Survival', International Journal of Industrial Organisation, Vol. 13, pp. 441-457.

Bailey, M.N., Hulten, C., and Campbell, D., 1992, 'Productivity Dynamics in Manufacturing Plants', Brookings Papers on Economic Activity: Microeconomics, Vol. 2.

Baldwin, J.R. and Gu, W., 2005, 'Competition, Firm Turnover and Productivity Growth', mimeo, Micro Economic Analysis Division, Statistics Canada, Ottawa.

Baldwin, J.R. and Rafiquzzaman, M., 1995, 'Selection vs. Evolutionary Adaptation: Learning and Post-Entry Performance', International Journal of Industrial Organisation, Vol. 13, pp. 501-522.

Baldwin, J.R. and Sabourian, D., 2002, 'The Effect of Changing Technology Use on Plant Performance in the Canadian Manufacturing Sector', Economic Analysis Research Paper, No. 20, Ottawa, Statistics Canada.

Bartlesmann, E. and Doms, M., 2000, 'Understanding Productivity: Lessons from Longitudinal Data', Journal of Economic Literature, Vol. 38, pp. 569-594.

Buenstorf, G. and Klepper, S., 2005, 'Heritage and Agglomeration: The Akron Tire Cluster Revisited', mimeo, Evolutionary Economics Group, MPI, Jena.

Burns, A.F., 1934, Production Trends in the United States Since 1870, NBER, Boston.

Cantner, U. and Kruger, J., 2004, 'Technological and Economic Mobility in Large German Manufacturing Firms' in J.S. Metcalfe and J. Foster (eds.), Evolution and Economic Complexity, Edward Elgar, Cheltenham.

Cantner, U. and Kruger, J., 2005, 'Micro Heterogeneity and Aggregate Productivity Development in the German Manufacturing Sector', mimeo, Friedrich-Schiller University, Jena.

Carlin, W., Haskel, J. and Seabright, P., 2001, 'Understanding 'The Essential Fact About Capitalism': Markets, Competition and Creative Destruction', National Institute Economic Review, No. 175, pp. 67-84.

Caves, R., 1998, 'Industrial Organisation and New Findings on the Turnover and Mobility of Firms', Journal of Economic Literature, Vol. 36, pp. 1947-1982.

Christensen, C.M., 1997, The Innovator's Dilemma: When Technologies Cause Great Firms to Fail, Harvard University Press.

Disney, R., Haskel, J. and Heden, Y., 2003, 'Restructuring and Productivity Growth in UK Manufacturing', Economic Journal, Vol. 113, pp. 666-694.

Dosi, G., 2000, Innovation, Organisation and Economic Dynamics, Cheltenham, Edward Elgar.

Dosi, G., 2004, 'On Some Statistical Regularities in the Evolution of Industries: Evidence, Interpretation and Questions', mimeo, Sant'Anna School of Advanced Studies, Pisa.

Downie, J., 1958, The Competitive Process, London, Duckworth.

Foster, L., Haltiwanger, J. and Krizan, C.J., 2001, 'Aggregate Productivity Growth: Lessons from Microeconomic Evidence', in C.R. Hulten, E.R. Dean, and M.J. Harper (eds), New Developments in Productivity Analysis, University of Chicago Press.

Fabricant, S., 1940, The Output of Manufacturing Industries: 1899-1937, NBER, New York.

Fabricant, S., 1942, Employment in Manufacturing: 1899-1937, NBER, New York.

Fisher, J. and Pry, R., 1971, 'A Simple Substitution Model of Technological Change', Technological Forecasting and Social Change, Vol. 3, pp. 75-88.

Frank, S.A., 1998, Foundations of Social Evolution, Princeton University Press.

Geroski, P., 1995, 'What do we Know about Entry?', International Journal of Industrial Organisation, Vol.13, pp.421-440.

Geroski, P. and Toker, S., 1996, 'The Turnover of Market Leaders in UK Manufacturing Industry, 1979-86', International Journal of Industrial Organisation, Vol. 14, pp. 141-158.

Gintis, H., 2002, Game Theory Evolving, Princeton University Press.

Hazeldine, T., 1985, 'The Anatomy of Productivity Growth Slowdown and Recovery in Canadian Manufacturing, 1970-79' Vol.3, pp.307-325.

Helfat, C.E. and Lieberman, M.B., 2002, 'The Birth of Capabilities: Market Entry and the importance of Pre History', Industrial and Corporate Change, Vol. 11, pp. 725-760.

Hicks, J., 1932, The Theory of Wages, Macmillan, London.

Horan, B.L. 1995, 'The Statistical Character of Evolutionary Theory', Philosophy of Science, Vol. 61, pp. 76-95.

Horvath, M., Schivardi, F. and Woywode, M., 2001, 'On Industry Life Cycles: Entry and Shakeout in Beer Brewing', International Journal of Industrial Organisation, Vol. 19, pp. 1023-1042.

Jovanovic, B. and MacDonald, G.M., 1994, 'The Life Cycle of a Competitive Industry', Journal of Political Economy, Vol. 102, pp. 322-347.
Klepper 2000

- Klepper, S., 2002, 'Firm Survival and the Evolution of Oligopoly', RAND Journal of Economics, Vol.33, pp.37-61.
- Klepper, S. and Simons, K.L., 1997, 'Technological Extinctions of Industrial Firms: an Enquiry into their Nature and Causes', Industrial and Corporate Change, Vol. 6. pp. 379-460.
- Klepper, S. and Simons, K.L., 2000, 'The Making of an Oligopoly: Firm Survival and Technological Change in the Evolution of the US Tire Industry', Journal of Political Economy, Vol. 108, pp. 728-760.
- Klepper, S. and Simons, K.L., 2005, 'Industry Shakeouts and Technological Change', International Journal of Industrial Organisation, Vol. 23, pp. 23-43.
- Knudsen, T. 2004, 'General Selection Theory and Economic Evolution: The Price Equation and the Replicator/Interactor Distinction', Journal of Economic Methodology, Vol. 11, pp. 147-173.
- Knudsen, T. and Hodgson, G., 2004, 'The Nature and units of Social Selection', paper presented at the 'Evolutionary concepts in Economics and Biology' Workshop. MPI, Jena, December 2004.
- Kuznets, S., 1929, Secular Movements of Production and Prices, Boston, Houghton Mifflin.
- Kuznets, S., 1954, Economic Change, London, Heinemann.
- Kwasnicki, W. and Kwasnicki, H., 1996, 'Long Term Diffusion Factors of Technological Development: An Evolutionary Model and Case Study', Technological Forecasting and Social Change, Vol. 52, pp. 31-57.
- Mahajan, V. and Peterson, R., 1985, Models for Innovation Diffusion, London: Sage.
- Malerba, F. and Cohen, W.M., 2001, 'Is the Tendency to Variation a Chief Source of Progress?', Industrial and Corporate Change, Vol. 10, pp. 587-608.
- Malerba, F. and Orsenigo, L., 2002, 'Innovation and Market Structure in the Dynamics of Pharmaceutical Industry and Biotechnology: towards a History Friendly Model', Industrial and Corporate Change, Vol. 11, pp. 667-704.
- Malerba, F., Nelson, R., Orsenigo, L. and Winter, S., 2001, 'Competition and Industrial Policies in a 'History Friendly' Model of the Evolution of the Computer Industry', International Journal of Industrial Organisation, Vol. 19, pp. 635-644.
- Marchetti, C. and Nakicenovic, N., 1979, The Dynamics of Energy Systems and the Logistic Substitution Model, Mimeo, IIASA, Laxenburg.
- Marsilli, O., 2001, The Anatomy and Evolution of Industries: Technological Change and Industrial Dynamics, Edward Elgar, Cheltenham.
- Massell, B., 1960, 'Capital Formation and Technological Change in US Manufacturing', Review of Economics and Statistics, Vol. 42, pp. 182-188.
- Matthen, M. and Ariew, A., 2002, 'Two Ways of Thinking about Fitness and Natural Selection', Journal of Philosophy, Vol. 99(2), pp. 55-83.

- Mazzucato, M., 2000, Firm Size, Innovation and Market Structure, Edward Elgar, Cheltenham.
- Mazzucato, M. and Semmler, W., 1999, 'Stock Market Volatility and Market Share Instability during the USA Automobile Industry Life Cycle', Journal of Evolutionary Economics, Vol. 9, pp. 67-96.
- Metcalf, J.S., 1997, 'Labour Markets and Competition as an Evolutionary Process, in P. Arestis, G. Palma and M. Sawyer (eds.), Markets, Unemployment and Economic Policy, Routledge, London.
- Metcalf, J.S., 1998, Evolutionary Economics and Creative Destruction, London, Routledge.
- Metcalf, J.S., 2004a, 'Ed Mansfield and the Diffusion of Innovation: An Evolutionary Connection', Journal of Technology Transfer, Vol. 30, pp. 171-181.
- Metcalf, J.S., 2004b, 'Accounting for Evolution: An Assessment of the Population Method', Papers on Economics and Evolution, MPI for Research into Economic Systems, Jena.
- Mitchell, W., 1989, 'Whither and When? Probability and Timing of Incumbent's Entry into Emerging Industrial Subfields', Administrative Science Quarterly, Vol. 34, pp. 208-230.
- Nelson, R.R., 1968, 'A "Diffusion" Model of International Productivity Differences in Manufacturing', American Economic Review, Vol. 58, pp. 1219-1248.
- Nelson, R.R., 1981, 'Assessing Private Enterprise: An Exegesis of Tangled Doctrine', The Bell Journal of Economics, Vol. 12, pp. 93-111.
- Nelson, R.R., 1989, 'Industry Growth Accounts and Production Functions when Techniques are Idiosyncratic', Journal of Economic Behaviour and Organisation, Vol. 11, pp. 323-341.
- Nelson, R.R., 1990, 'Capitalism as an Engine of Progress', Research Policy, Vol. 19, pp. 193-204.
- Nelson, R.R. and Pack, H., 1999, 'The Asian Miracle and Modern Growth Theory', Economic Journal, Vol. 109, pp. 416-436.
- Nelson, R., and Winter, S., 1982, An Evolutionary Theory of Economic Change, Belknap press, Harvard.
- Nelson R.R. and Winter, S., 2002, 'Evolutionary Theorizing in Economics', Journal of Economic Perspectives, Vol. 16(2), pp. 23-46.
- OECD, 2001, 'Productivity and Firm Dynamics: Evidence from Micro Data', OECD Economic Outlook, No.69, Chapter 7.
- Price, G.R., 1970, 'Selection and Covariance', Nature, Vol. 227, pp. 520-521.
- Saviotti, P., 1996. Technological Evolution, Variety and the Economy, Edward Elgar, Cheltenham.
- Saviotti, P. and Pyka, A., 2004, 'Economic Development by the Creation of New Sectors' Journal of Evolutionary Economics, Vol. 14, pp. 1-36.

Singh, J.V. 1990, Organisational Evolution: New Directions, Sage, London.

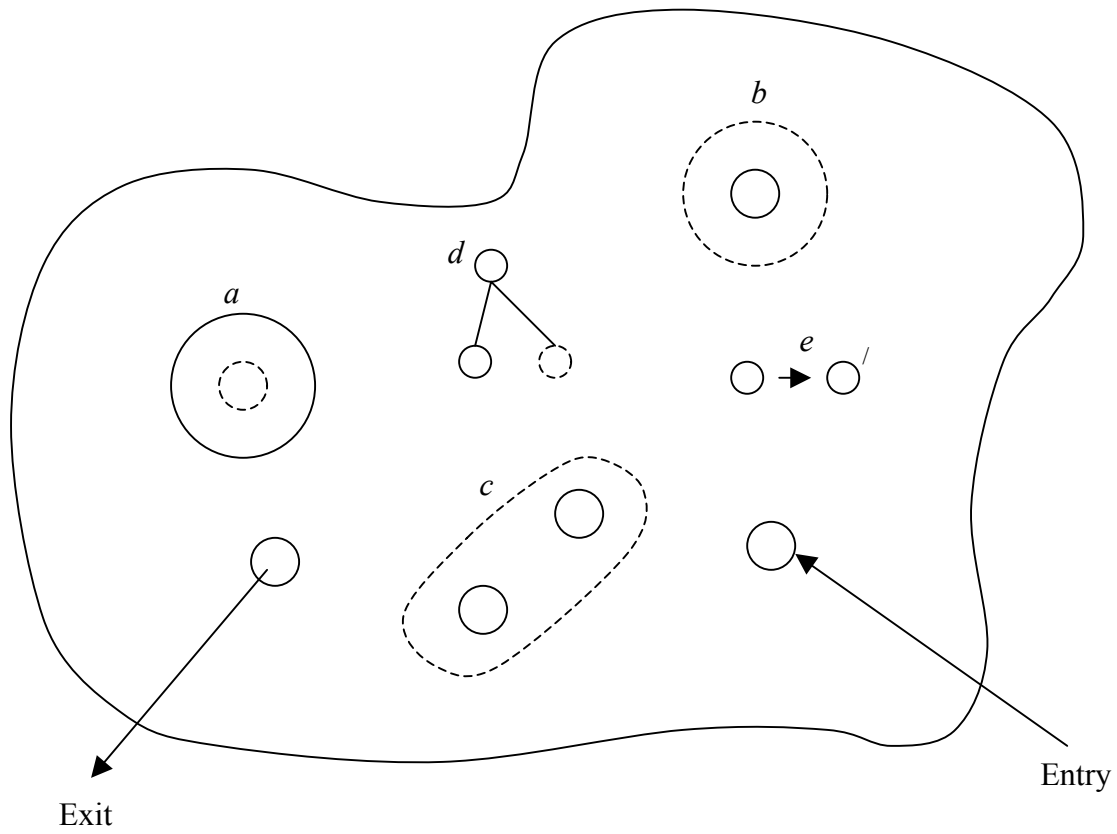
Thompson, P., 2002, 'Surviving in Ships: Firm Capabilities and Survival in the Us Iron and Steel Shipbuilding Industry, 1825-1914, mimeo, Carnegie Mellon University.

Tybout, J.R., 2000, 'Manufacturing Firms in Developing Countries: How Well Do They Do, and Why?', Journal of Economic Literature, Vol. 38(1), pp. 11-44.

Utterback, J.M. and Suarez, F.F., 1993, 'Innovation, Competition and Industry Structure' Research Policy, Vol. 22, pp. 1-21.

Utterback, J., 1995, Mastering the Dynamics of Innovation, Harvard University Press.

Witt, U., 2003, The Evolving Economy, Cheltenham Edward Elgar.



- Relative decline
- Relative expansion
- Recombination
- Fission
- Innovation

Figure 1: Population Dynamics

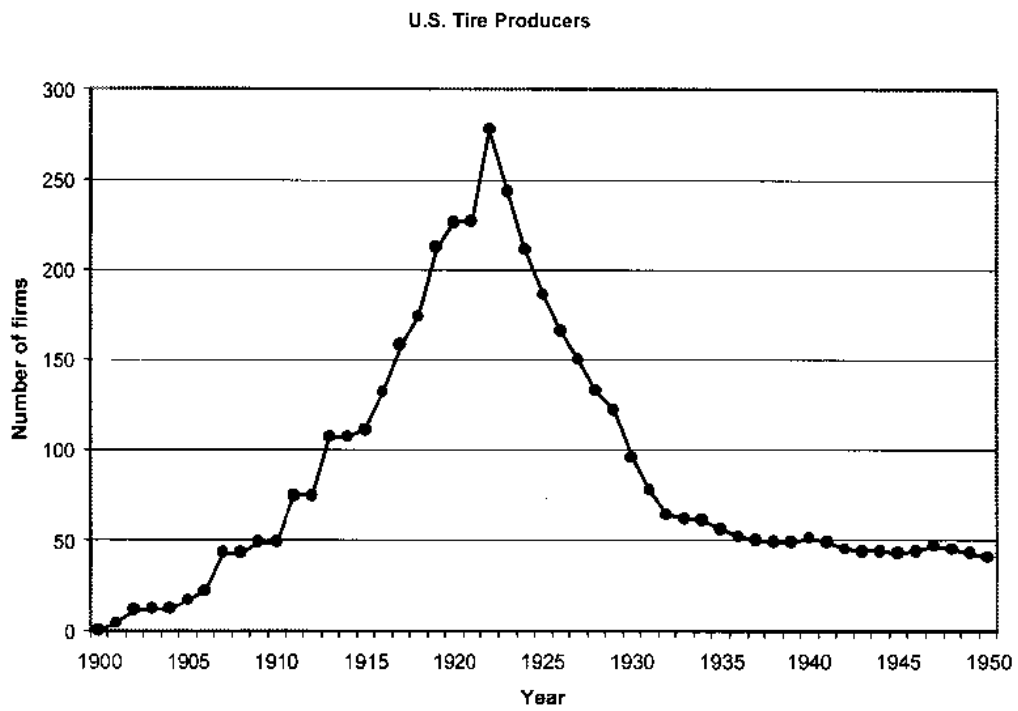
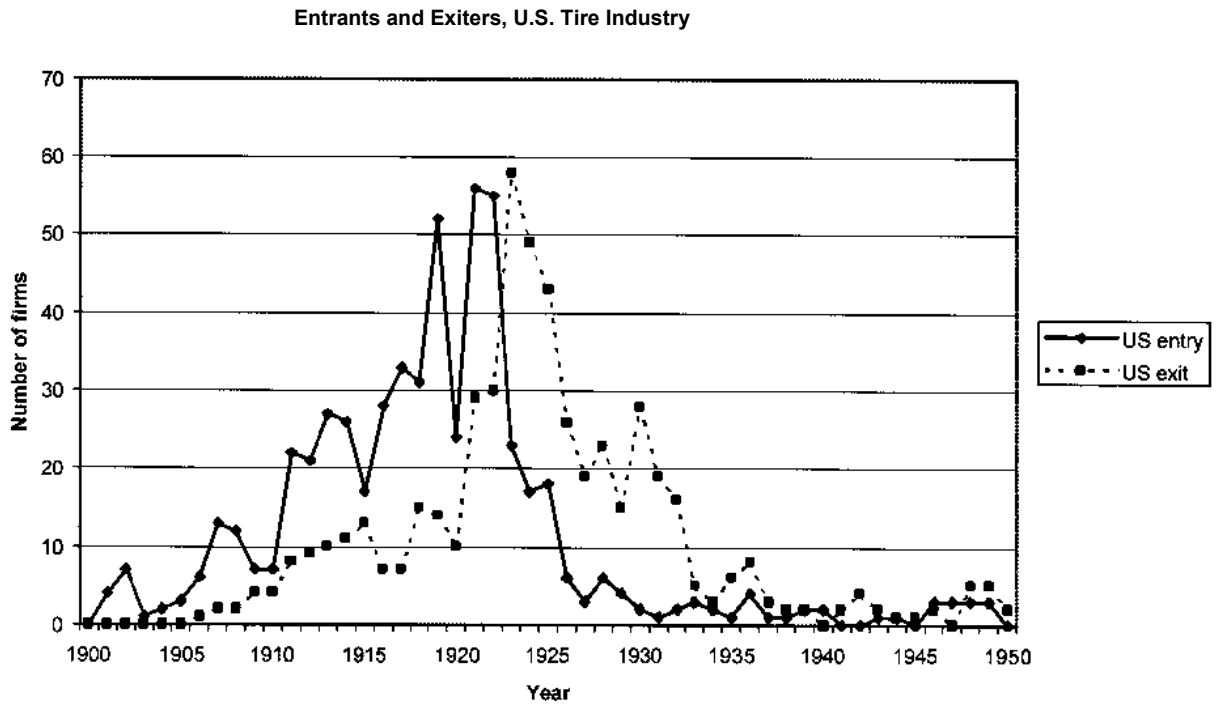


Figure 2: Entry, Exit and Number of Producers in the U.S. Tire Industry, 1900-1950
 (source: Buernstorf and Klepper, 2005)

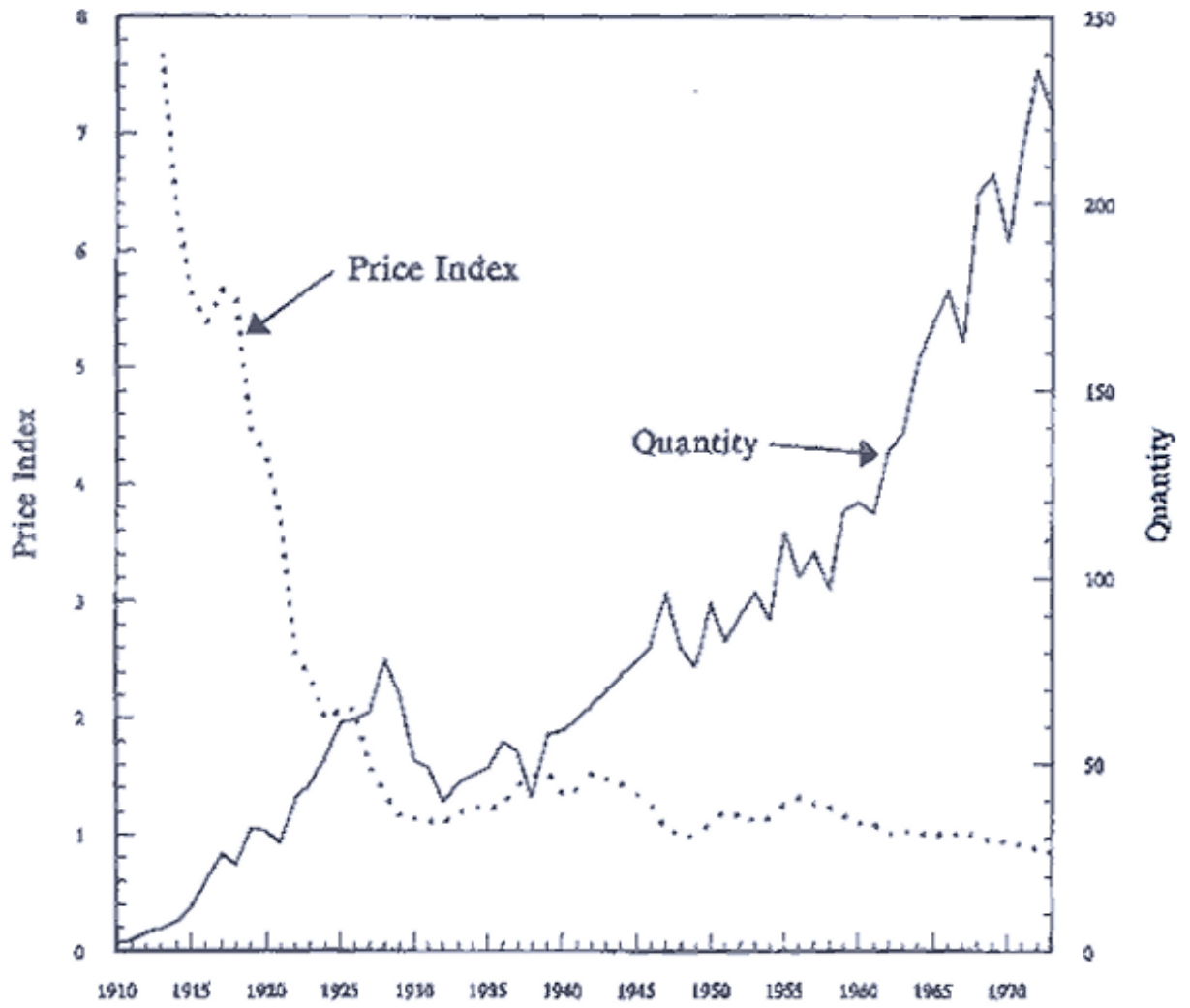


Figure 3: Price and quantity in the U.S. automobile tire industry (source: Jovanovic and Macdonald, 1994)