CREATIVE DESTRUCTION AND THE MEASUREMENT OF PRODUCTIVITY CHANGE*

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Recent advances in the measurement of productivity change have exposed a much clearer picture of the turbulent dynamics of restless capitalism. This essay has two objectives. First, to show that the population method drawn from evolutionary theory provides a coherent frame in which the various processes impinging on productivity change can be integrated. Secondly, to identify some of the puzzles and ambiguities that arise from decomposing any aggregate measure of productivity growth into innovation effects in firms and selection effects in markets. We shall also show that there is no unique way of making this decomposition. This is an important matter because the transmission process between innovation and changing resource allocation underpins the process of economic development in the broad sense.

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1. Introduction

Recent advances in the measurement of productivity change made possible by new micro data sets (Caves, 1998; Bartelsman and Doms, 2000; Tybout, 2000), have exposed a much clearer picture of the turbulent dynamics of restless capitalism and by implication the connections between innovations and aggregate economic performance. That growth and development proceed hand in hand with changing structures of economic activity has been understood since the early days of economics as a discipline. No economy ever grows with all activities increasing in exact step; some grow and some decline and within those that grow and decline there is great diversity of growth experience. The broad shifts between primary, secondary and tertiary sectors are well documented but what these new data sets expose is the extent of creative destruction at much lower levels of aggregation. Here we propose a brief assessment of the industrial dynamics literature linking innovation to productivity growth. The essay has two objectives. Firstly, and 'constructively', to show that the population method drawn from evolutionary theory provides a coherent frame in which the various processes impinging on productivity change can be integrated. We shall show how the growth of productivity in a population obeys one of the fundamental principles of evolutionary dynamics— the Fisher/Price theorem— which demonstrates how the rate and direction of change depends on variation and correlation of characteristics in a population. Secondly, and 'destructively', to identify some of the puzzles and ambiguities that arise from decomposing any aggregate measure of productivity growth into effects that arise from innovation processes and those that reflect selection processes and the changing relative importance of entities in a population. We shall also show that there is no unique way of making this decomposition. This is an important matter because the transmission process between innovation and changing resource allocation underpins the process by which standards of living are raised in the narrow sense, and the process of economic development in the broad sense. In this paper we shall also review some evidence on the magnitude of structural change in the American manufacturing economy. Our understanding of the connection between the growth of knowledge and the growth of the economy rests on a clarification of these and other relations in industrial dynamics.

The study of productivity growth in the economy as a whole has a distinguished history, but it is largely aided by resort to explicitly macroeconomic constructs such as the aggregate production function. Indeed the pioneering studies of Abramovitz, Schmookler, Kendrick, Denison, and others, were among the first empirical fruits of the macro turn in economic thinking that followed from the Keynesian revolution. That tradition has brought great gains in understanding even if the problem of identifying the contribution of new technology to economic growth remains fraught with conceptual and measurement issues (Metcalfe 2002). However, any macro economic method, of necessity hides the diversity of productivity growth experience within industries and economies, as scholars such as Nelson (1989) have carefully pointed out, and, therefore, acts as a barrier to a deeper understanding of the links between innovation and economic growth[1]. For example, the crucial concept of the aggregate production elasticity linking say 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 technology construct alone[2]. 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. Most fundamentally of all a macro approach hides the central point that in the process of development some activities have to decline in absolute and relative importance and others must disappear; not everything can grow in a process of development and certainly no economy ever develops with all activities expanding at the same proportional rate— Von Neumann style. In short development requires the reallocation of resources and a changing composition of output and demand, consequences of the market process. Yet more fundamentally it requires innovation, the application of knowledge to create the new productive opportunities to which the reallocation of resources is an adaptive response. The framework which brings together innovation and adaptation, we argue, is naturally evolutionary and takes as its frame the concept of a population of activities.

1.1. Population Analysis

Population analysis is a standard reference concept in evolutionary thought, a device to emphasise the fundamental evolutionary categories of variety and the dynamic consequences of selection acting on differences between entities to produce evolutionary change. As such it stands in contradistinction to the concept of essentialism that phenomena are to be understood in terms of a few key, defining attributes around which discrepancies are abnormal irregularities. Within population analysis, by contrast, the focus is precisely on the significance of the 'abnormalities' simply because uniform populations are devoid of evolutionary potential. An economy in which all agents behave identically is simply an economy that cannot develop.

The concept of a population implies two contributing ideas: a set of differentiated entities or 'individuals', and a causal selection process that serves to identify the inclusion criteria for membership of the population and

1. See the more recent discussion in Harberger (1998) on micro diversity and aggregate productivity growth, pointing to the very uneven cross sector incidence of productivity change in the US economy.

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 the 'production' elasticities did reflect the composition of output and thus the composition of demand.

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 subject to the same causal selection forces (Metcalfe, 2004; Andersen, 2004a,b). Thus the individual entities are defined in terms of sets of characteristics across which the common selection pressures discriminate. The particular characteristics can be unique to each entity or they may reflect differently distributed degrees of the same characteristic, either interpretation reflects the diversity and differentiation within the population. Since in general, it is bundles of selective characteristics that shape evolution it is possible to conceive of any one characteristic as having a negative, neutral or positive impact on the course of selection, while changes in characteristics may be linked by explicit constraints.

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 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.

Since evolutionary theory provides an explanation of change in a suitably defined population we can begin with a simple classification of the various kinds of change that can occur in an abstract population over some given time interval as illustrated in Figure 1.

If we consider the population at two dates the various possible changes can be resolved into the following three, exhaustive categories:

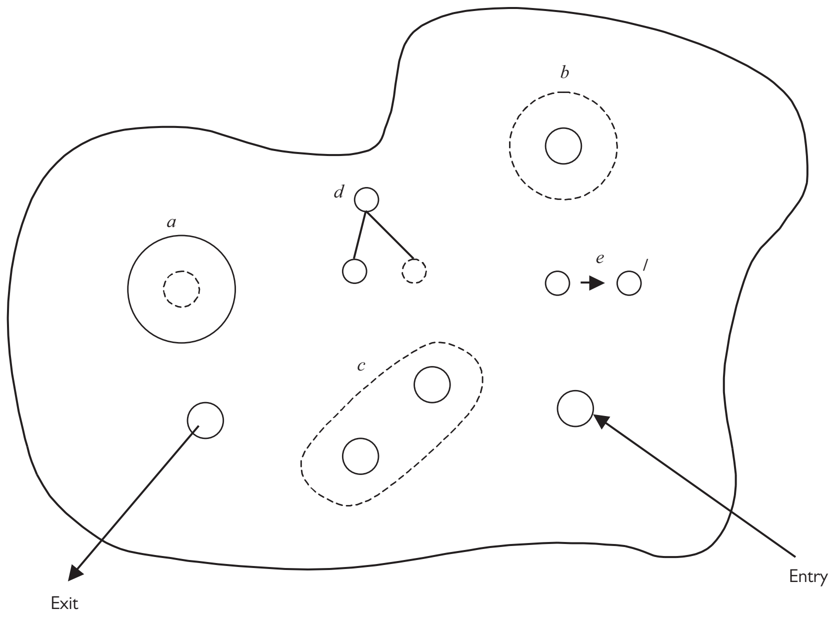
Changes in the number of distinct, individual entities in the population over the given interval. These changes are defined in turn by four sub processes: the entry of 'new' entities; the demise or exit of existing entities; the recombination of existing entities into new entities (including the possibility of recombination with entrants); and, the fission of existing entities (including parts of entities that exit the population).

Changes in the relevant selection characteristics of the existing entities, essentially innovation processes proper which may also be connected to the entry, recombination and fission process.

Changes in the relative importance (weight) of those different entities in the population, active throughout the interval. Changes in population weight reflect differences in the growth rates of the entities pointing to the fact that evolutionary theory is fundamentally a differential growth theory.

The notion of a population nests naturally in that the entities can also be populations so that the same phenomena repeat at multiple scales. In

1. Population Dynamics



a Relative decline
b Relative expansion
c Recombination
d Fissione Innovation

the economic terms relevant for this discussion, the population could be a set of national economies, a set of industries within a given economy or a set of competing firms within a given industry or indeed submarket of an industry. If we now think of our entities as 'firms' in 'industries' 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 population framework. From this evolutionary viewpoint the various possible changes can be subsumed under the general categories of 1) Selection processes (exit and differential growth of firms), and 2) Creative processes (innovation based changes in product and process characteristics in continuing firms, entry and recombination/fusion of firms). These are each markedly different in both their nature and their consequences for economic change. The conditions, for example, 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 economic theory would be sensitive to these differences.

Yet a third way of distinguishing the various change processes in Figure 1, and one that is extensively used in the literature on productivity change, is to distinguish those changes that are internal to a firm or industry from those that arise from reallocations of resources between firms and industries and from those that reflect the patterns of entry and exit, so called 'within' effects, 'between' effects and 'net entry' effects. Innovations proper and perhaps the effects of recombination or fusion fall in the first category, selection effects fall in the second category and the balance of entry and exit defines the third[3]. This is a valuable set of distinctions for it points to the importance of the firm process— market process dichotomy in the dynamics of progress under capitalism.

These categories provide the basis for an evolutionary accounting that tracks and decomposes population level change into its various components. As an accounting scheme 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.

1.2. Productivity Change in Populations

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 (or total factor productivity, the choice of indicator is immaterial) 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[4]. 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.

It turns out that is not such an easy question to answer as it might appear at first sight, indeed the literature covers radically different positions. In part the difficulties arise because of different measures of productivity, labour versus total factor productivity, for example, applied to different data sets covering different countries and industries over different time periods, and in part because different accounting schemes are used by different protagonists[5]. The conventional difficulties of measuring input and output

3. If we take long enough periods of time it is perfectly sensible to think of the entry and exit of entire industries, electric light and gas mantles or mobile phones and telegrams for example.

4. It could equally be a population of plants within a single firm or set of firms.

5. On the different accounting methods see Bartelsman and Doms (2000) and Balk (2003).

flows with sufficient accuracy add to the complications, but they are not our concern here. Rather, we shall explore how the empirical results look through the lens of population analysis.

The principal issue at stake is the relative contribution of the different elements outlined in figure 1, although no study to our knowledge has investigated the effects of recombination and fission on the productivity measures. If we consider a single industry the aim is to identify the relative contributions of within (innovation), between (selection) and net entry effects. Notice that the nested nature of population analysis allows the focus to be at higher or lower levels than the industry. Thus taking the population as a set of industries (an economy), we could apply the same accounting logic to assess the effects of productivity growth at industry level, a 'within' effect, and of structural change, the emergence of new industries and the disappearance of old industries, the 'between' effects. Of course, the 'within' effect for any one industry as a whole, is a mélange of the 'within' effects in firms and the 'between' firm and net entry effects in that industry. Similarly, we could take the multi plant firm as the population and measure within productivity effects at plant level together with the opening of new plants, closure of old plants and changing allocation of the firm's output across continuing plants as the between effects.

The creation of micro data sets has greatly facilitated assessment at these different levels so that the manufacturing sector in a whole economy could be treated as a population of productive establishments. How does the empirical evidence turn out? Consider first the study by Olley and Pakes (1996) on plant level data for the telecommunications industry in the USA post deregulation, which identified the importance of firms reallocating output to more efficient plants, the expansion in the capacity of those plants and the exit of less efficient plants for industry productivity growth. In their view it was reallocation of capital resources and not increases in plant productivity that account for the improvement in industry performance. An early study by Bailey *et al.* (1992) measuring total factor productivity growth in US manufacturing plants in twenty-three industries for 1972-1987, concluded that entry and exit played only a minor role in changing industry productivity growth and that the growth in the relative output of high productivity plants, the 'between' effect, was very important to the growth of manufacturing productivity. Similarly, a study of three high-tech industries by Bartelsman and Dhrymes (1998) found that the reallocation of resources to more productive plants accounted for about 25% of total factor productivity growth between 1972 and 1986. Other scholars, however, have taken a different view on the evidence, privileging the 'within' effects much more than the 'between' effects. The OECD (2001a,b), for example, in a number of studies has argued to the effect that a large fraction of aggregate labour productivity growth is due to firm level 'within' effects alone and that while exit processes boost aggregate productivity, changes in market shares play a modest role[6]. Similarly, a comprehensive study by Disney *et al*. (2003) for the UK over the period 1980-1992 also found that 'within' effects at firm level dominate the contribution to aggregate labour productivity change and that entry and exit both have positive effects on productivity growth. In particular they assign roughly 50% of the aggregate change to establishment level 'within' effects and, to the effects of net entry, almost all of the remainder. However, when total factor productivity measures are used, the contribution of the 'within' effects drops to less than 20% while net entry continues to account for 50% of the change, making resource allocation effects account for a very significant component of the total. More recently, Bartelsman *et al*. (2005) in a study of the industrial sectors of twenty-four countries over the last decade of the twentieth century reach a more nuanced conclusion that restructuring and entry and exit patterns play an important role in boosting aggregate labour productivity. Finally, consider the very detailed empirical work reported in Baldwin and Gu (2005). Their study is based on the analysis of 35,000 Canadian manufacturing plants grouped into 236 four-digit industries and 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 1999, leaving a dominant proportion to be explained by various 'between' and net entry effects. Contrary to the OECD view 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[7,8]. To show how different accounting conventions have major effects on the resulting decomposition, Baldwin and Gu 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 own method. We shall explore this contrary finding in more detail below, but for the moment, how can we sum up this literature?

6. Similar results are reported in Hazeldine (1985) and Foster ***et al.*** (2001).

7. 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).

8. 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. Carlin *et al*., 2001 discuss productivity growth decompositions for the transition economies of Eastern Europe. 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.

Clear cut conclusions cannot be drawn from the studies available but some lessons are clear. It matters greatly whether one is computing the effects on labour productivity growth or total factor productivity growth; within effects seem to arise more significantly with respect to the latter than the former. Secondly, the precise decomposition method also matters very greatly in assigning different effects as explanations of productivity change at the population level. Thirdly, and hardly surprisingly, measurement across different populations leads to different outcomes. Why does this matter?

Most fundamentally the resolution of the question is important for the light it throws on the dynamics of development under market capitalism and the role played by market forces in the process of creative destruction. For evolutionary scholars, recognition of the heterogeneity of establishment, firm or industry performance is a central tenet of their view and the reason why they reject theorizing in terms of representative entities. It is the interaction between developmental 'within' effects and market mediated 'between' effects that forms the core of their argument and the differential growth dynamic of resource reallocation has been a core feature of evolutionary models at least since Nelson and Winter (1982) if not before (Downie, 1958). Important matters are at stake here and they imply radically different interpretations of the development process and the associated policy implications. If it were true that productivity change is primarily a matter of 'within' effects at establishment or firm levels then the prime cause of productivity growth in the aggregate reduces to productivity growth within the constituent population members[9]. The basis for productivity growth reduces in this case to innovation, technical and organisational, and its implementation pure and simple. 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. A finding that 'within' effects dominate in explaining the aggregate rate of productivity growth also has major implications for the creative destruction perspective, in terms of the two way connection between innovation and market processes. Firstly, by discounting any incentive based connection between differential innovation performance and changes in market position, that is to say by discounting the idea that more competitive, innovative firms gain resources and customers at the expense of less competitive firms and consequently grow more rapidly and increase their weight in the population. Secondly, by discounting the idea of a reverse competitive effect, that is to say a combination of competitive pressure and or positive feedback from a strengthened market position that further stimulates innovation. In both respects the argument for creative destruction is weakened. Fundamentally, the controversy is about

9. This is scarcely a comforting conclusion, given our 'ignorance' about the determinants of plant and firm level productivity performance. Harberger (1998) captures the essence of the point with his reference to "real cost reductions stemming from 1001 different causes" (p. 5).

how wealth is created from knowledge, perhaps the most important question in growth dynamics.

To answer this question we need to spell out the deeper content of the population method and explore how different measurement schemes reflect different assumptions about the role of market forces in labour and product markets, for the differences highlighted in the empirical literature 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.

1.3. 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 a population of firms, labelled 'a'. We want to know how the population average value, labelled $\bar{a}$, changes over a given 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 $t + \Delta t$ produced by firms that enter in the interval. Let $c_i(t)$ be the share of a 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'

$$\bar{a}(t) = (1 - d)\bar{a}_c(t) + d\,\bar{a}_d(t)$$

where $\bar{a}_c(t) = \sum c_i(t) a_i(t)$ is average unit labour requirements in the continuing firms and $\bar{a}_d(t) = \sum d_i(t) a_i(t)$ is the average value of $a(t)$ for those firms that will exit during the interval Δt[10]. 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 $\bar{a}_c(t + \Delta t) = \sum c_i(t + \Delta t) a_i(t + \Delta t)$ and $\bar{a}_n = \sum n_i(t + \Delta t) a_i(t + \Delta t)$ is the average value of $a(t + \Delta t)$ for the entrants over the interval[11]. The change in $\bar{a}$ follows as

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

10. $c_i(t)$ is the share of each continuing firm in the total output of such firms at date t. Similarly, $d_i(t)$ is the share of each exiting firm in the total output of those firms at t. We are following the convention of indexing the period by the date at the end of the period.

11. $n_i(t)$ is the share of entrants in the output of all entrants at $t + \Delta t$ and $c_i(t + \Delta t)$ is the corresponding output share of the continuing firms at this date.

Expression (1) is a complete evolutionary accounting for the change in the average population value of unit labour requirements[12] and it is a close representation of most of the accountings used in the empirical literature. On the right hand side, the first term is the combined effect of competitive selection and innovation operating on the continuing firms. The second and third terms measure the effects of entry and exit expressed in terms of the deviations from the average productivity level of the continuing entities at the appropriate dates . Productivity growth in the population as a whole is accounted for 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.

The 'within' and 'between' effects are captured in the first term in equation (1) and it is one of the central accounting techniques in evolutionary population analysis to separate the different effects operating on the continuing firms with a method 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

$$\begin{aligned}\Delta\bar{a}_c &= \sum c_i(t+\Delta t)a_i(t+\Delta t) - \sum c_i(t)a_i(t)\\ &= \sum \Delta c_i a_i(t) + \sum c_i(t+\Delta t)\Delta a_i\\ &= \frac{1}{1+g_c}\{\sum c_i(t)(g_i - g_c)a_i(t) + \sum c_i(t)(1+g_i)\Delta a_i\}\end{aligned}$$

or $$(1+g_c)\Delta\bar{a}_c + C_c(g_i a_i) + E_c((1+g_i)\cdot\Delta a_i) \qquad (2)$$

Expression (2) is the Price equation; in which, $C_c(g_i a_i)$, the measure of the 'between' (selection) effect, is the (c_i weighted) covariance between fitness values (the output growth rates g_i) and the values of a_i at the initial census date[13]. This captures the idea that the change in the average value of the characteristic depends on how that characteristic co-varies with the output growth rates across the population; in short, that evolution is a matter of correlation as well as variation. The second term, $E_c((1+g)\cdot\Delta a_i)$, the measure of the 'within' (innovation) effect, is the expected value (again c_i weighted) of the product of the growth rates and the changes in the unit labour requirements values at the level of each firm. In relation to productivity decompositions it measures the 'within' effect over the

12. (1) is 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' = 'd', the displacement hypothesis. Then the only empirical issue is whether entrants on average have higher productivity than exits, which they do.

13. This formula makes use of the fact that $(1+g_c)\Delta c_i = c_i(g_i - g_c)$. The symbol '$g$' refers to the growth rate of output between the dates defining the interval.

interval weighted by the output shares at $t + \Delta t$. 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

$$(1 + g_i)\Delta\overline{a}_i + C_{cj}(g_{ij}, a_{ij}) + E_{ci}((1 + g_{ij})\,\Delta a_{ij})$$

and apply this to each of the i entities in the original population. As Anderson (2004b) has pointed out, 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 those 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. Of course, 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 the competitive process that fit within this framework (Andersen, 1994; Dosi, 2000; Marsilli, 2001; Mazzucato, 2000; Metcalfe, 1998; Nelson and Winter, 2002; Witt, 2003).

The force of this general evolutionary approach can be summarised as follows. 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 (including exit) 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).

2. Ambiguities and Puzzles

We can now address the second more 'destructive' section of this paper, namely the sources of the conflicting evidence over the relative importance of 'within' and 'between' effects which the population accounting perspective helps clarify. We shall argue that there are two possible decompositions of productivity change at the population level, each one correct in its own terms, and each one with its own pair of 'within' and 'between' effects. A unique decomposition does not exist. 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 and in different degrees. 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 labour inputs across firms or establishments. In particular, between effects would be suppressed in the denominator if the allocation of labour across firms did not change and they would be suppressed in the numerator if the distribution of output across the firms did not change. In general, changes in employment patterns and output patterns jointly contribute to productivity growth. More precisely, in these productivity decompositions two very different notions of productivity growth are involved and they should not be confused or treated as equivalent. Productivity growth proper is what happens within plants or firms and this is logically a quite different process from shifting output and resources between firms with given but different levels of productivity[14]. It is this within/between distinction that is at the centre of the empirical difficulty noted above, 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. To be even more exact assume that productivity is a technical attribute of a firm's production process changing only when the firm changes its method of production cum organisation. Define that firm's share in total employment as e_i and its corresponding share in total output as s_i. Clearly $a_i q_i = 1$ and making the appropriate aggregate measures for the population as a whole we have $a_s q_e = 1$, with the average quantities being defined by $a_s = \sum s_i a_i$, 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. It follows from these definitions that the shares and the productivity levels are related by

$$s_i a_i = e_i a_s \tag{3}$$

and

$$e_i q_i = s_i q_e \tag{4}$$

and that the corresponding rates of change must obey the following conservation condition[15]

$$\hat{e}_i + \hat{q}_i = \hat{s}_i + \hat{q}_e \text{, or equivalently that } \hat{s}_i + \hat{a}_i = \hat{e}_i + \hat{a}_s \tag{5}$$

From (5) we infer that the proportionate changes in output and employment weights for any firm are only equal when that firm's *rate of*

14. In principle, the between effects can also arise in multi plant firms when new plants are built or existing ones closed or the relative contribution of different plants to total firm output is changed. The firm turns out to be a slippery concept in productivity accounting and we shall short circuit this by assuming our firms are single plant, single process, and single product entities.

15. We use a caret over a variable to indicate proportional rates of change and a dot to indicate time differentiation. Continuous time differentials allow the suppression of interaction effects.

productivity growth equals the population average rate of productivity growth. From (4) we can infer that the proportional contribution that a firm makes to population labour productivity is equal to its share in the output of that population. 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. Notice immediately that if, say, we hold the employment share constant it follows in general that the output share cannot be constant, and conversely. Given the pattern of productivity growth differences the employment and output shares cannot evolve independently of one another. Notice also, that the wider the spread of productivity levels in the population the greater the difference between output shares and employment shares[16].

2.1. A Brief Empirical Excursus

Before proceeding, it will help to consider some evidence on how the structures of output and employment vary over time in a particular economy. Within industry data are not available to us, but the inter industry data generated in the NBER data base are and they cover the output, employment and productivity dynamics for 459 USA industries over the period 1958-1997. From this data base we can track movements in output and employment shares at the four digit level, still aggregated data, but sufficiently refined to identify detailed inter sectoral changes in output and resource allocation. We would expect these changes to be smaller than those occurring within sectors, but the matter of how large and variable they are is clearly of interest as it bears directly on the productivity accounting question.

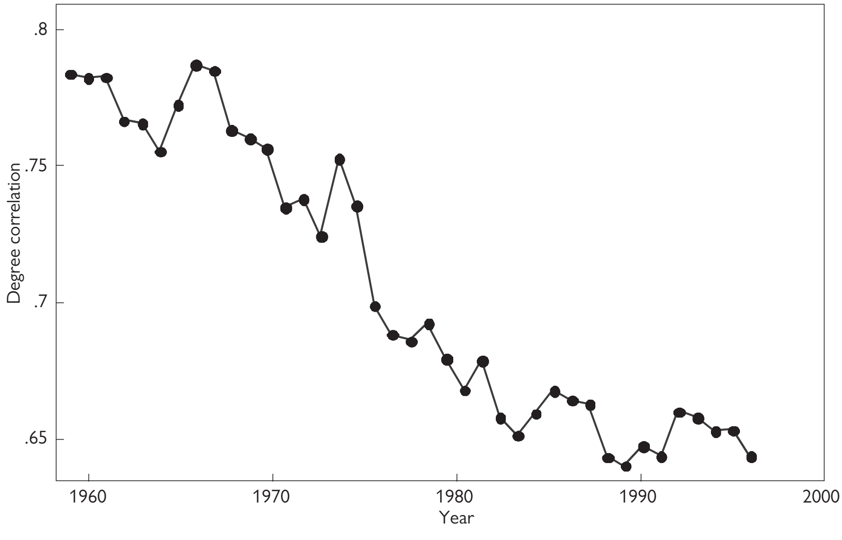
Consider first the relative movement in employment and output shares[17]. Figure 2 shows the annual correlation coefficients between employment shares and real output shares across the sectors.

They are positive but decline progressively over the period, indicating a weakening of a general tendency for above average output shares to be associated with above average employment shares. Further light on the relationship between the two dimensions of population structure is provided by the movement over time in the

16. Carlin *et al*. (2001) point out that the 90th decile of the UK manufacturing productivity ranking is almost five times more productive in labour productivity terms than the 10th decile.

17. In calculating the latter we have two alternatives: the first is to calculate the shares in nominal terms, the second is to infer the shares in terms of real output by using (4) and data on real productivity in each sector derived by deflating nominal shipments (output) by the sectoral price deflators. It turns out that nominal and real output shares covary very closely apart from the last two years when large changes in the deflators for the electronic computers (SIC 3571) and the semi conductor (SIC 3674) sub-sectors cause the two measures to diverge very sharply. Our doubts about the validity of their deflators lead us to exclude these two sectors in the following calculations. The correlation coefficient between real and nominal output shares for all 459 industries over the whole period is 0.954. Excluding the two sectors it is 0.970.

2. Annual correlation coefficient between employment and real output share 1958-1996 (excl. 3571, 3674)



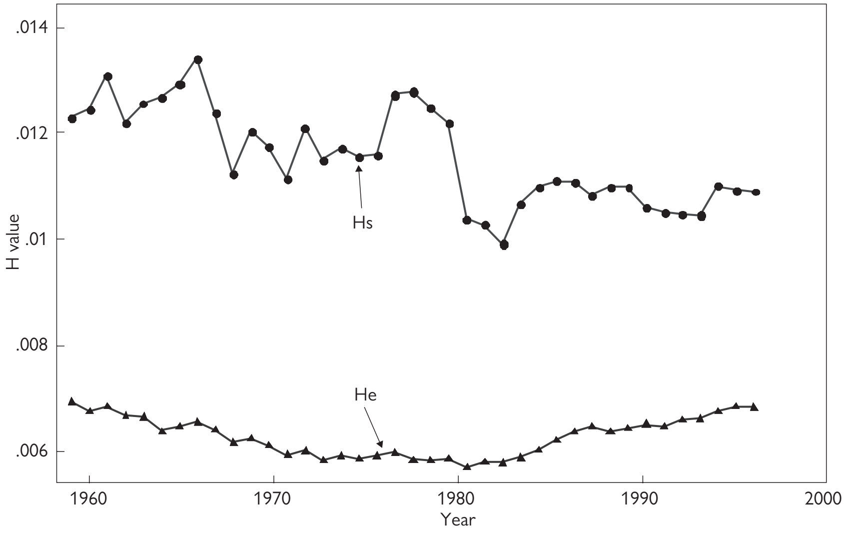
population averages of the sector shares, measured by the employment and output share Herfindahl indices.

If this index is declining, there is a general tendency for sectors with above average employment or output shares to have below average employment or output growth rates and conversely if the index is increasing. Figure 3 shows the respective movements of the real output and employment Herfindahl indices which exhibit quite different histories. Output structure is more concentrated than employment structure and shows greater variability. The employment Herfindahl declines steadily until 1980 and then returns to its 1958 value by the close of the period. The output Herfindahl is generally declining until 1980 but then appears to lose this trend. Movements of the Herfindahl indices of this degree can be a summary statement of a considerable degree of intersectoral turbulence, and one way to expose this further is to measure the 'instability' in employment and output shares by computing the sum of the absolute annual changes in market shares across the sectors[18]. Figure 4 shows the outcome for the employment and output patterns and indicates considerable and correlated instability between the two indices, with output shares more unstable than employment shares[19]. In a loose sense the employment structure is more 'sticky' than the output structure.

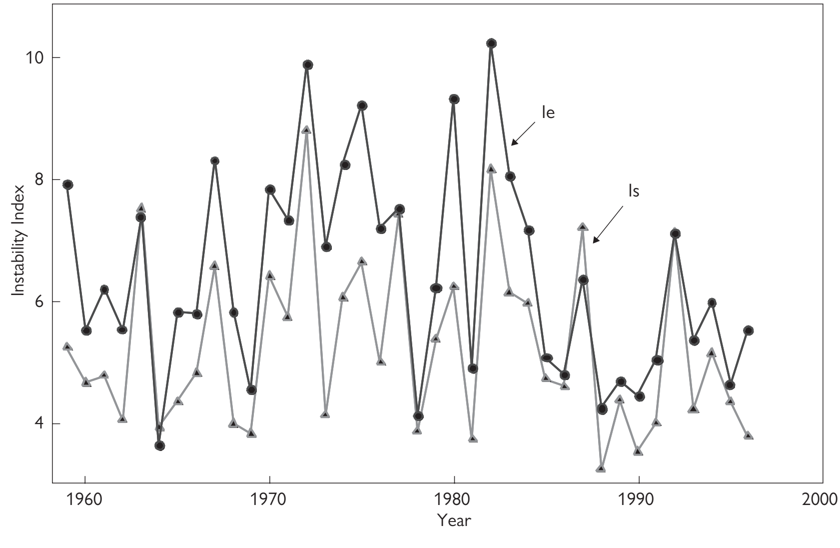
18. See Mazzucato (2000) for discussion of these measures.

19. Over the sample period the average of the output instability index is 6.26 and of the employment index 5.12.

3. Herfindahl (H) Indices Employment and Real Output 1958-1996



4. Instability Indices (I) for Employment and Real Output Shares 1958-1996



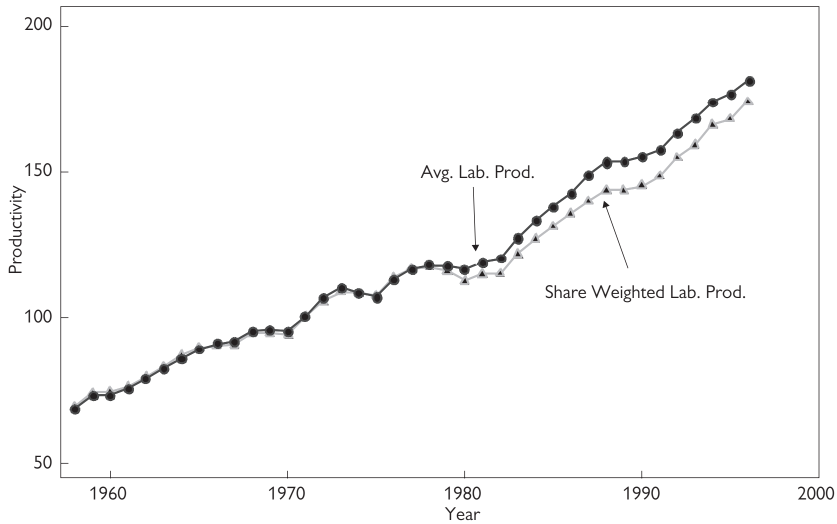
Notwithstanding that the industry data will have averaged away a great deal of intra industry evolution it remains the case that there is considerable turbulence even at this quite highly aggregated level.

One immediate consequence of these different patterns of evolution is that the respective changes in the employment structure and output structure will have different effects on the movement of aggregate labour productivity and unit labour requirements. There will be different 'within' and 'between' effects, according to whether the weights for constructing the population aggregate are derived from output or employment. To drive this home, consider the different evolutions of aggregate labour productivity and aggregate unit labour requirements in our NBER data set. In the aggregate the movement of one is exactly the inverse of the movement of the other so they should tell the same story when the decomposition is carried out. A simple test for this is to follow the procedure used by Olley and Pakes (1996) and compare the share weighted movements of the weighted average productivity measures (true productivity) with the corresponding averages constructed by assuming that each sector has the same share in the population total - the simple, arithmetic average. The simple average eliminates any effects of structural change on the computed aggregate. The difference between the two averages is a 'rough and ready' indicator of how much the actual structure contributes to aggregate productivity or labour efficiency.

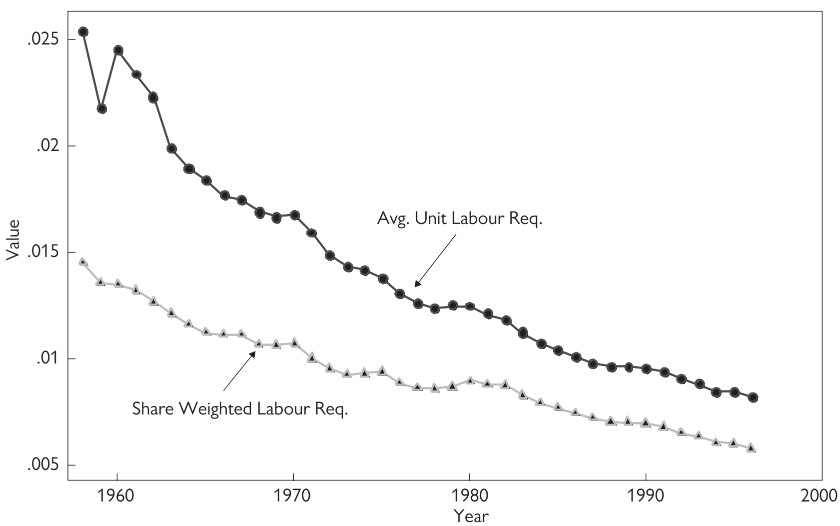
Figure 5 shows the results for labour productivity (5a) and unit labour requirements (5b). Again they tell very different stories. As far as labour productivity is concerned the structure of employment makes very little difference to the movement of aggregate labour productivity until 1978 after which the two measures diverge such that the effect of structure is to reduce true, aggregate productivity relative to the simple average. In respect of unit labour requirements the difference between the two measures is more marked with the effect of output structure adding considerably to the overall efficiency with which labour is used, between 25 and 40 percentage points depending on the year.

Figure 6 illustrates the same point by computing the percentage difference between the weighted and simple averages for the two productivity measures. Again the histories are quite different. For labour productivity the percentage difference between the averages are constant until 1978 but from then on the percentage difference begins to increase in such a way that changes in structure are reducing weighted average labour productivity growth. For unit labour requirements, the difference between the simple and share weighted averages indicates that structural change worked to reduce the growth rate of aggregate labour efficiency until 1982, after which the change in output structure begins to slowly increase average labour efficiency. That structural change makes different contributions to changes in population labour productivity and population unit labour requirements is not at all surprising given the divergent evolution of the

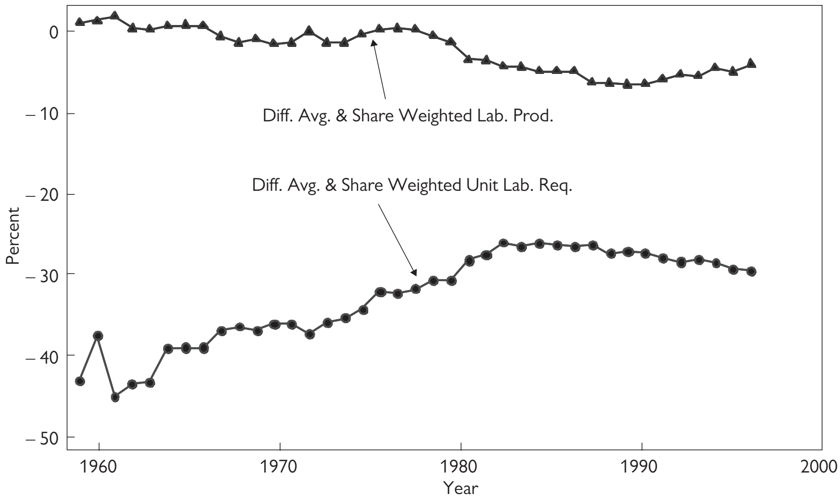
5a. Share weighted v Average Labour Productivity



5b. Share weighted v Average Unit Labour Requirement



6. Percentage Difference between Average and Share Weighted measures for Labour Productivity and Unit Labour Requirement 1958-1996



output and employment structures demonstrated above. However, the fact that the percentage rate of productivity growth is precisely the inverse of the percentage reduction in unit labour requirements points to an underlying puzzle, 'How is it possible for there to be different decompositions of productivity change in 'within' and 'between' effects when in aggregate they amount to the same rate of change?'

2.2. The Different Decompositions of Productivity Change in a Population

We return to the main argument and explore this question in more detail, again in the context of a single industry[20]. We begin by considering 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 $\hat{q}_e = \left(\sum \frac{e_i q_i}{q_e}\right)(\hat{q}_i + \hat{e}_i)$

or, making use of the relations between the population weights and productivity levels (4), as

$$q_e = \sum s_i (q_i + e_i) \qquad (6)$$

20. To avoid undue complication we also set entry and exit rates at zero, the generalisation does not change the substance of the argument.

In the bracket the first term corresponds to the 'within' effects and the second to the 'between' effects that follow from reallocating labour between the firms in the population. Notice that the 'between' effects are equivalently a statement of how the employment growth rates of the individual firms are distributed around the population average employment growth rate; reflecting the elementary fact that evolution in structure follows from growth rate differentiation.

Now, from the opposite direction we can perform the same calculation in terms of the change in unit labour requirements (using 3) to give,

$$\hat{a}_s = \sum e_i(\hat{a}_i + \hat{s}_i) \tag{7}$$

In this decomposition, the corresponding 'between' effects refer to the reallocation of output between the different firms. Clearly one could have a zero 'between' effect in terms of (6) and a non zero 'between' effect in (7), or conversely, depending on how the employment and output structures differently evolve.

However, (6) and (7) are by definition expressions that are numerically equivalent in magnitude but of opposite sign, since it is purely definitional to write $\hat{a}_s = -\hat{q}_e$ and $\hat{a}_i = -\hat{q}_i$. Indeed taking account of this identity we can rewrite (7) as

$$\hat{q}_e = \sum e_i(\hat{q}_i - \hat{s}_i) \tag{6'}$$

so making transparent the differences in the measurement procedure that arise in focusing alternately on labour reallocation (6) and output reallocation (6'). The two expressions necessarily add up to the same aggregate population effect but they do so in very different ways and with very different decompositions of 'within' and 'between' effects depending on how the labour and product markets interact.

The conclusion is rather stark. We have two different decompositions of the same growth rate in aggregate labour productivity or unit labour requirements. They use different weights for the 'within' and 'between' effects and measure the two effects differently, one in terms or reallocating labour the other in terms of reallocating output. As Baldwin and Gu (2005) put it, the first expression (6) measures what the 'within' effect would be if there was no reallocation of output within the population and the second expression (7) measures the 'within' effect on the assumption that there is no reallocation of labour within the population. However, changing the output shares generally means changing the employment shares so, in general, neither decomposition (6) nor (6') is a complete accounting since selection effects occur simultaneously in labour and product markets. 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.

The clear implication is that the contribution of selection and innovation to productivity change is legitimately measured in different ways and that any particular empirical outcome will depend on how adaptations to productivity change are distributed across product and factor markets. A simple example may help. Suppose an economy consists of two sectors and that sector one experiences labour productivity growth, a 'within', innovation effect. If the market response is for that sector to increase its output by exactly the productivity change, and thus to increase its output share at the expense of sector two, then the employment 'between' effect will be zero but the output 'between' effect will be positive or negative according to whether sector one has a higher or lower labour productivity level than sector two. If productivity levels are positively correlated with rates of productivity change then the selection effect reinforces the innovation effect, and conversely if they are negatively related. Similarly, if the market adaptation is such that all the productivity gain is matched by an employment reduction in sector one, it follows that the output 'between' effect is zero but the employment 'between' effect is positive or negative as sector one, whose relative employment share has decreased, has a lower or higher productivity than sector two. Intermediate market responses will obviously lead to results between these two extremes.

Under what conditions would the ambiguity disappear and the two measures give the same result? It clearly does not arise for any firm or sector that maintains the population average level of productivity, for then output and employment shares are the same so the within and between effects are the same. More generally, on equating the two expressions (6) and (6') and taking account of the fact that $a_i q_i = 1$ we can write

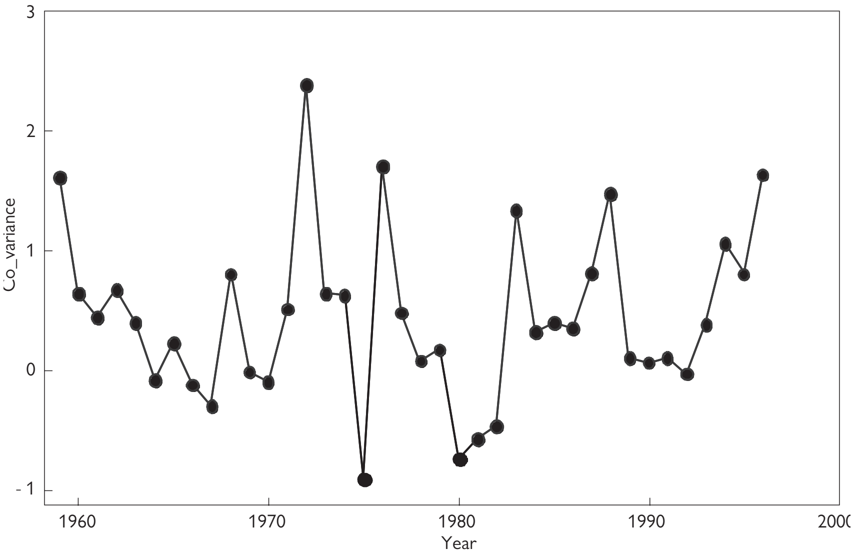
$$\sum(e_i - s_i)\hat{q}_i = \sum e_i \hat{s}_i + \sum s_i \hat{e}_i \tag{8}$$

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 (8) in the familiar evolutionary way in terms of measures of population diversity, thus

$$-\frac{C_e(q_i,\hat{q}_i)}{q_e} = -\frac{C_s(a_i,g_i)}{a_s} + \frac{C_e(q_i,g'_i)}{q_e} \tag{9}$$

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 rates of productivity growth. The right hand side measures the total flux in terms of sum of two covariances, the one between unit labour requirements and output growth rates (g), and the other between labour productivity and employment growth rates (g'). When does the ambiguity of decomposition disappear? First, only when there are no reallocations of resources and output but this is only possible in the trivial case when all the firms have the same rates of productivity growth.

7. Co-variance between Labour Productivity levels and Labour Productivity growth rates deflated by avg. Labour Productivity 1958-1996



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. Secondly, the two measures are equal whenever the covariance between productivity level and productivity change in the population is zero. This is the crucial test; when there is no correlation there is no evolution. The same NBER data set can be used to calculate this critical covariance across the set of industries referred to in 2.1 above and the result is shown in Figure 7. The general outcome is that the covariance between productivity growth rates and levels is positive but noisy. Flux is clearly present and flux is variable from year to year.

To sum up, it is perfectly possible for the same data to yield widely differing answers to the 'within' 'between' productivity decomposition exactly as empirical scholars have found. We have proposed a simple test of when this will be the case. Changes in the composition of output have different productivity implications from changes in the composition of employment and that is in the nature of productivity as a ratio. The different decompositions we have derived in (6) and (6') are each correct in their own terms because they are the answers to different counterfactual questions about the evolutionary population dynamics of productivity change.

3. Conclusion

The argument above is no more than an accounting exercise, albeit one sophisticated enough to incorporate the many influences that transform firms, industries and economies with remarkable persistence under the rules of the game of modern capitalism. However, accounting is only part of the story; more interesting still are the real and interconnected evolutionary processes that drive economic change in markets and productivity change in firms. Accounting relations cannot tell us how that flux in the composition of output and employment is distributed over the population or how it links to innovation. Only some specific theory of resource allocation in the presence of innovation can do that, and a market based one would do so in terms of a statement of how labour, capital and product markets adapt to the evolving pattern of productivity change. A yet more sophisticated account would develop the feedback links between market adaptation and induced innovation to embed the innovation process in the market process and its wider instituted frame. Thus we have in our hands a problem in general evolutionary economics or GEE. That the connection between innovation and development requires more thorough attention is obvious but that this is most likely to be achieved through the GEE lens should be obvious too.

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