Centre for Research in Applied Economics (CRAE)

Working Paper Series
200903
April

"Evolutionary Growth Theory"

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ISSN 1834-9536

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EVOLUTIONARY GROWTH THEORY

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To appear in Mark Setterfield(ed)

Handbook of Alternative Theories of Economic Growth

Edward Elgar, Cheltenham.

Final version, 28th March, 2009

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"Our general conclusion must be that in the field of economic progress the notion of tendency towards equilibrium is definitely inapplicable to particular elements of growth and with reference to progress as a unitary process or system of interconnected changes is of such limited and partial application as to be misleading rather than useful." (Knight, F.H., 1935(1997), p.176)

I. Introduction

An evolutionary theory of economic growth is naturally designed to answer the all important question "How is wealth created from knowledge?" No serious economist doubts that the growth of per capita income and welfare is a consequence of the growth of understanding about the human built and natural worlds but how useful knowledge is created and translated into economic development is a matter of great complexity. At the heart of this problem is the need for a disaggregated framework of understanding that explains much more than the rate of growth of aggregate economic activity and the evolution of broad macroeconomic ratios. Of course, many different theoretical frames can be consistent with the same broad aggregate facts but they must also be consistent with many more disaggregated facts about the way a capitalist economy develops, particularly those facts that are ultimately traceable to the role of enterprise and creative thought in economic growth.[1] Inventive creativity is part of this process, as is its relationship to the development of formal, general scientific and technological knowledge. But invention alone is insufficient; it must be translated into innovation, which depends greatly on specific knowledge of time and place and conjectures of market opportunity, quite different dimensions of knowing. Moreover, if innovations are to have significant growth effects, the allocation of resources and patterns of demand must adapt to the possibilities opened up by new methods and new goods and services. Market processes loom large in this scheme but so do other instituted systems, such as the science and technology system or the education system[2]. The interplay between these different forms of organisation leads to a two way interaction between economic growth and the growth of knowledge that fully deserves to be labelled an

[1] See for example Nelson and Winter (1974) where an evolutionary model of innovation is used to replicate the aggregate behaviour of a Solow-type, neoclassical growth model. The two theoretical worlds are poles apart, yet they are consistent with the same aggregate facts.

[2] For a powerful exposition of knowledge related factors in economic growth, together with the importance of distinguishing different kinds of knowledge, and an understanding of the instituted context in which useful knowledge is developed and applied, see Mokyr (2002)

endogenous growth theory. It is the nature of the two way interaction that is the primary focus of this paper. It is certainly not a comprehensive treatment of evolutionary growth theory but rather an exposition of some of the links between technical progress and structural change in an evolving economy. The foundations are Schumpeterian, and there are strong elements of Marshall too. We build on these foundations in a way which renders compatible the diverse circumstances of innovation and investment with aggregate patterns of economic change[3]. How innovations in firms and markets "add up" to constitute industry and whole economy level adaptations is the evolutionary problem that we are addressing.

There are three themes to this essay that follow from its evolutionary perspective. The first is that capitalist economies grow as they develop, so that growth cannot be treated meaningfully by a concept of uniform expansion in which all the components of an economy expand at the same proportionate rate. Balanced growth is a chimera, it is the heterogeneity of growth rates within the economy that needs to be explained, and differential rates of growth lead us directly to structural change and development. It follows that an aggregate rate of growth or an aggregate ratio has no more substance than the individual components from which it is constructed by the observer. Indeed, even in a multi sector economy, there may be no activity which grows at the aggregate, average rate. Consequently, the evolutionary modes of explanation used below are essentially statistical in nature and relate to changes in population ensembles. Secondly, as the epigraph to this essay indicates, growth is not an equilibrium process and cannot be if it is knowledge based, for what sense is there in the idea that the growth of knowledge is an equilibrium process?[4]. Yet the possibility of evolution depends on order and on the organising processes that generate coherent structures of economic activity, whether in firms, in markets or in other organisational forms that sit within the wider set of evolved and instituted rules of the game (Abramovitz, 1989, Nelson, 2005). Thus there is a paradox at the centre of capitalism: the presence of order depends on stabilizing forces that give coherence and durability to patterns of organisation but the development of the system requires that the prevailing order is open to invasion by economic novelty, and to this degree it is marked by instability[5]. It is the inherent openness of the market system to the challenge contained in novel economic conjectures, its

[3] Schumpeter (1912 and (1928) are the key texts here, and Marshall (1919) is at least as significant as Marshall (1920).

[4] For alternative, complementary approaches to out of equilibrium growth theory, see Amendola and Gaffard, (1988, 1998), and Silverberg and Verspagen, (1998).

[5] A stationary state is in this sense a closed economic system, a system without history as Schumpeter pointed out.

capacity to stimulate and resolve disagreement about better ways to allocate resources and meet changing needs, which gives innovation and the entrepreneur such a powerful role to play in evolutionary growth theory. This is Schumpeter's argument but it was surely also Marshall's point when he identified knowledge and organisation as "our most powerful engine of production" (1920, p.138). Thirdly, like Nelson and Winter (1982), we believe that aggregate explanations of economic growth should be compatible with the vast diversity of micro level, historical evidence concerning the events and processes that equate to the notions of 'innovation' and 'enterprise'. Technical progress has measurable aggregate effects but it is not generated by any aggregate process. Thus, any respectable evolutionary explanation of growth should connect to the rich literatures which study innovation and its management, the history of technology and business organisation, and the developing capabilities of firms and other institutions that jointly influence the growth and application of knowledge. These literatures are natural complements to an evolutionary theory of economic growth; they frame our understanding of the processes generating and limiting innovation, and they provide countless empirical examples to shape our thinking on the knowledge-growth connection.

Several formal consequences follow that differentiate an evolutionary account from modern equilibrium growth theory, endogenous or otherwise. First, we make no appeal to the representative agent, or more accurately described "the uniform agent". What is statistically representative cannot be chosen on a priori grounds. Rather, representative action is an emergent, developing consequence of the economic process, and no evolutionary theory can operate by eliminating diversity in economic behaviour. Indeed, our whole scheme generates growth because of non representative behaviour. Secondly, while our economy is competitive, we do not mean by this a state of perfect competition but rather a process of competition within and between industries, the grand themes of Marshallian flux and Schumpeterian enterprise. The importance of competition is not to be understood narrowly, in terms of optimal resource allocation but, broadly, in terms of the connection between technical progress and the widespread diffusion of gains in real income through reductions in the prices of goods and services. Finally, we make no sharp separation between factor substitution within a given technique and changes in technique, for the two phenomena are inseparable. All change in methods requires some new understanding that is only obtained by investing resources in problem solving activities. In part this is because we do not accept the neoclassical production function as a frame of analysis (Bliss 1975, Harcourt, 1972), but more fundamentally it is because we do not reason in terms of aggregate stocks of knowledge. There is no metric to reduce knowledge and its changes to a meaningful real aggregate, and the attempt to construct such an aggregate serves only to disguise the role of new knowledge in the process of development. What matters is the uneven development and ever changing heterogeneity of what is known and understood (Kurz, 2008, Steedman, 2003; Metcalfe, 2001). This does not mean that capital accumulation is reduced to a relatively minor, passive role in the growth process, far from it. The accumulation of capabilities through the embodiment of new understanding in the labour force and in the stock of capital structures is a central channel of economic growth, and we place great emphasis on investment processes as the vehicle of change (Nelson, Peck and Kalachek, 1967). It is important to recognise that these problems are treated here at a price. It is that we enter the argument at the level of the industry, suppressing all the lower level evolution that is occurring between and within firms, the evolution that is the epitomy of enterprise and innovation. The origins of economic development and growth are not to be found at the aggregate level, even though there are high level constraints on the evolution o f firms and industries. At most we have half an argument but none the less an interesting half that allows us to draw together previously unrelated strands of thought in classical and evolutionary reasoning.

The remainder of this essay is structured as follows. We begin by outlining competing stylised facts about economic growth and then set out the relations between structural change and aggregate productivity growth contingent on the evolution of the pattern of demand. We then introduce the concept of an industry level technical progress function, and show how rates of technical progress are mutually determined as a consequence of increasing returns and the changing distribution of demand. We next sketch a macroeconomic closure of the evolutionary process, expressed in terms of the mutual determination of rates of capital accumulation and rates of productivity growth. This takes us to the final section where we elaborate upon the restless nature of innovation based economic growth and the conditions under which Kaldor's stylised facts are compatible with the Clark-Kuznets stylised facts.

We may summarise our perspective quite sharply. What distinguishes modern capitalism is not only its order imposing properties that lead to the self organisation of the economy, but also the self transforming properties that create wealth from knowledge and in so doing induce the further development of useful knowledge. It is the manner in which self organisation and self transformation interact that is at the core of this essay[6].

II. The Competing Stylised Facts of Growth and Development

We have alluded above to the fact that economic evolution arises at multiple levels throughout an economy of which the aggregate, whole economy level is only one element in the total picture. Indeed, prior to the Keynesian revolution n and Harrod's formulation of aggregate growth theory in the late 1930s, a rich empirical and theoretical literature had developed on the problem of secular economic change, a literature that posed the problem of economic growth in terms of a set of meso level stylised facts relating to growth rate diversity, structural change, innovation and the development of demand in different industries. When growth theory turned "macro," economists largely forgot about the between and within industry detail and replaced one set of stylised facts with a quite different set, expressed in terms of aggregate growth rates and ratios. The two very different, and on the surface incompatible, sets of facts are those most usually associated with Colin Clark and Simon Kuznets on the one hand and Nicholas Kaldor on the other. The Clark-Kuznets facts relate to patterns of growth in different industries and point to the large scale changes in economic structure that accompany economic growth[7]. This is transparent in terms of the movements in the relative importance of the "high aggregates" such as agriculture, industry and services[8] but it becomes even more manifest when we consider the economy at more disaggregated levels where, for example, there are greater differences in rates of growth of individual industries relative to the manufacturing average, and even greater differences in the growth rates of individual firm relative to an industry average. Consequently there are large inter and intra sectoral shifts in shares in output, employment, and capital stocks over time that reflect a wide dispersion of growth rates around the economy wide averages[9]. These shifts are also associated with the entry of new industries and the elimination of old industries along the lines that leading economic historians rightly emphasise (Sayers, 1950,

[6] That an economic order is self transforming is not to be taken for granted but depends on wider instituted and encultured factors that overcome the conserving tendencies which reinforce the prevailing order. See Mokyr (2002) Chapter 6 for an extended discussion, and Nelson, (2005) Chapters 5&8.

[7] See Colin Clark, (1944) and Kuznets (1971) for original statements of the relation between aggregate growth and large scale structural change. Saviotti and Pyka (2004) simulate industry entry and exit effects in an evolutionary growth model.

[8] For some interesting commentary see Baumol *et al.* (1989, chapter 3). The idea that development is a process of reducing the relative importance of agriculture is a common theme among development economists.

[9] See Kuznets (1971) Chapter 7 for the details, particularly table 4.

Landes, 1969, Mokyr, 1990, 2002). On this the historical record is absolutely clear; measured economic growth flows from a process of structural change driven by long sequences of innovations in technique and organisation that may usefully be summarised as distinct technical epochs (Freeman and Louca, 2001).

However, this uneven pattern of the growth record is only part of the picture. Simon Kuznets (1929) and Arthur Burns (1934) also identified a further regularity in the process of restless growth, namely retardation, the persistent tendency of industry growth rates to decline over time from the inception of the industry. Soloman Fabricant (1940, 1942) found compelling evidence on the retardation of growth in American manufacturing output and employment over the period 1899 to 1939. Further studies, by Hoffman (1949), Stigler (1947) and Gaston (1961) also investigated the empirical basis of the retardation thesis in different bodies of industrial data but without any further development of the underlying theory. Taken together these authors might be described as espousing "a moving frontier" view of economic growth and structural change, in which, in Kuznet's words,

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

By contrast, Kaldor's (1961) stylised facts refer to the rough constancy of the growth rates of aggregate output and capital stocks together with the constancy of several key aggregate ratios, particularly, the capital output ratio, the shares of profits and contractual incomes in GDP, and the overall rate of profits (Maddison, 1991). To understand the relation between these very different facts is a major challenge to our thinking about economic growth, not least because the familiar devices of semi-stationary growth (Bliss, 1975), or proportional dynamics (Pasinetti, 1993) are no more than ways to hide from view the Clark-Kuznets facts, as if the relative proportions of different activities are frozen in time[10]. There is neither structural change nor retardation in these contrived macro worlds only uniform expansion or, just as readily, uniform contraction. In approaching the analysis of economic growth in this way, we effectively rule out any meaningful connection between the growth of knowledge and the growth of the economy. Several recent contributions have addressed this problem of reconciliation by developing frameworks in which rates of growth of demand and/or rates of technical progress differ sector by sector. In many of these frameworks the rates of technical progress are treated exogenously, and that is to us an unhelpful restriction which is certain to misrepresent the relation between the growth of knowledge and the development of the economy[11]

The important insight here is not that structural change and the growth of aggregate measures occur together, for that would be quite compatible with the idea of structural change as a passive, inessential by-product of growth. If that were all that were at stake, a macro, single sector approach would be a plausible first step. Unfortunately, this is not so; for structural change is not only a consequence of differential growth it is a cause of that differential growth. This process is autocatalytic, progress generates progress, structural change generates structural change, which is what we take Schumpeter to have meant when he wrote of “development from within”, or what Frank Knight meant when he described growth in capitalism as a “self-exciting” process. Precisely what one might expect to occur in an economy whose long run evolution is driven by new knowledge, by entrepreneurial conjecture and by the reallocation of resources to take advantage of the opportunities immanent in innovation.

To term this an evolutionary process is entirely appropriate. Structural change is a product of differential growth, and the mutual determination of growth rate differences within a population is a leading characteristic of evolutionary theory. Moreover, the more we disaggregate any given population into its component sub populations the more we find evidence for differential growth

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[10] This is not to deny that proportional dynamics has its uses as, for example, in the Von Neumann growth model. However, this method seems entirely incapable of addressing the two-way relation between the growth of knowledge and the growth of economic activity. Does any economic historian ever find proportional dynamics a useful device with which to order the record of the past? We think not.

[11] See for example, Kongsamut *et al* (2001), Ngai and Pissarides (2004), Echevarria (1997), and Acemoglu and Guerrieri (2008). For a very good synopsis of the developing literature, and of the different kinds of stylised facts, the reader is referred to the paper by Bonatti and Felice (2008). This latter paper is more closely connected to our approach than any of the other papers refereed to above, since the authors incorporate endogenous technical progress into their two sector model by effectively assuming a Kaldor style technical progress function (as do we). They also assume non homothetic preferences, equivalent to our reliance on Engel’s Law, and differentiated income elasticities of demand, sector by sector. Nonetheless our approaches to the broad problem are very different.

over any given period, and the longer that period the greater the diversity of growth experience. Thus there is a simple evolutionist's maxim that must always be born in mind, namely, "the more we aggregate the more we hide the evidence for and causes of economic evolution". The evolutionary question is "Why do rates of growth differ across activities and over time?" not the question "Why are they uniform and stable?"

It is because a macro perspective hides the very processes that explain the differential growth of productivity and output that we cannot confront many of the most important stylised facts of modern economic growth (Kuznets, 1954, 1971, 1977; Harberger, 1998). Nor can we incorporate the role of demand in shaping growth patterns between industries; indeed it is remarkable how the modern growth story is a predominately supply side account of the expansion of productivity and inputs. Changes in the composition of demand are ignored and the coordinating role of markets in the growth process is lost from view. Our approach therefore places two processes at the heart of evolutionary growth, the endogenous generation of industry specific rates of technical progress, and the endogenous evolution of demand as growing per capita income is reallocated across different lines of expenditure. Let us consider each one in turn.

At the core of any theory of endogenous growth we find some hypothesis about the origination of innovation and its impact on methods of production. Our approach develops the notion of an industry specific technical progress function that follows from Adam Smith's central idea linking technical progress to the changing division of labour within and between activities, and its subsequent elaboration by Allyn Young (1928). Developing from roots in Smith and Marshall, Young articulated the view that the extension of the market causes and is caused by the exploitation of new technological opportunities. We shall suggest below that this is precisely the insight needed to capture the link between structural change and aggregate growth. Of course, the scope of Young's argument was much broader than the linking of growth of market and technical progress *within* a single industry. What mattered was the reciprocal dependence between different industries in which 'inventions' in one sphere initiate 'responses elsewhere in the industrial structure which in turn have further unsettling effect' (*op. cit.*, p. 532). For Young, for Schumpeter and for Marshall, progress is systemic and the idea of capitalism as a system in equilibrium did not hold much appeal[12].

As soon as we abandon the equi-proportional method there is immediate scope for giving demand side forces a key role in the explanation of structural change, and for giving far more attention to the role of demand in the connection between growth and technical change. As Pasinetti has expressed it "... any investigation into technical progress must necessarily imply some hypotheses ... on the evolution of consumer preferences as income increases", while "increases in productivity and increases in income are two facets of the same phenomenon, since the first implies the second, and the *composition* of the second determines the relevance of the first, the one cannot be considered if the other is ignored" (our emphasis, 1981, p. 69). This is the territory marked out by Engel's law, not only in terms of the broad aggregates in relation to agriculture, industry and services but also in terms of income elasticities for the more narrowly defined outputs of specific industries (Kindleberger, 1989).

The mutual interdependence between the differential growth of demand and the differential incidence of technical progress is at the centre of our evolutionary account of growth and development. But we are not free to propose any pattern of economic evolution independently of the constraints implicit in the requirement that aggregate saving equals aggregate investment. This leads to the central importance of Harrod's insight that the aggregate rate of growth also depends on the interaction between capital productivity and thrift. This is what our frame is meant to capture in terms of the simultaneous evolution of the macro and the sectoral such that the one cannot be explained independently of the other. It is a frame that because it is both "bottom up" and "top down" allows us to render compatible the competing stylised facts.

III. The Population Method: Accounting for Structural Change and Economic Growth

An economy with many industries in which each industry engages in many different activities is of a level of complexity that places a great challenge to any growth theory. Yet, if we understand an economy to be a population of different activities, a method of analysis

[12] For a excellent account of Young's approach and its relation to the wider literature on economic development and cumulative causation see Toner (1999). The problem of cumulative causation is precisely the problem addressed here in terms of the disaggregated connections between increasing returns and the aggregate growth of per capita income.

immediately becomes apparent, one that is central to all evolutionary theories of a variation-cum-selective retention kind. This is the method that we call population analysis. In it an evolutionary population is represented by a set of differentiated entities that are acted upon by common causal forces to transform the population, either by changing the constituent entities or by changing their relative importance. In our case the entities are distinct industries. The common causal forces are the reallocation of demand across the industries as per capita income increases, the different rates of technical progress in each industry and the constraint imposed by the equality of saving and investment in the aggregate. One of the immediate advantages of the population method is that it can be conducted at multiple, interconnected levels so that change at one level correlates with change at other levels. Thus we could also treat each industry as a population of different branches of "similar but not identical" activities, and each such branch as a further population of closely competing firms. In this way an economy becomes a population of populations of populations. Even the firm could be analysed as a population of different activities under unified managerial control if we wanted to conduct the argument at its most refined level. For expositional reasons we must suppress the below industry level of aggregation, recognising that a full account of technical progress at the level of the industry necessarily requires an analysis of the differential innovation performance of firms and their differential rates of growth. All we need say here is that our knowledge-based economy is co-ordinated in the sense that that the average price within an industry is a long run normal price, set to maintain full capacity utilisation over time. Short period deviations from full capacity working are ignored, as seems appropriate in a treatment of sustainable growth. What we loose is any account of the within-industry determinants of prices and profitability and thus of the within-industry role of dynamic coordination through competition. However, intra industry analysis is already well developed in evolutionary economic theory, whereas the aspects treated here are not (Andersen 2004, ,Witt, 2003, Dosi, 2000, Metcalfe 1998, Nelson and Winter 1982).

One of the principal attributes of the population method is its connection with the statistical method of analysis that is common ground in modern evolutionary theory. This is reflected in the fact that the rate and direction of evolution in a population depends on statistical measures of the variety that are defined over that population. In the presence of pervasive heterogeneity we use the population moments of various industry characteristics, (means, variances, covariances and so on), to understand the rate and direction of evolutionary change in that population. Here the three principle characteristics in which the industries vary are, their prevailing levels of productivity, their income elasticities of demand, and their technical progress functions. Additional dimensions of differentiation are not ruled out; indeed the greater the number of dimensions of variation the richer is the evolutionary analysis in prospect. The population moments that play a central role in the evolutionary approach are always weighted moments, where the weights are the appropriate measures of the relative importance of each industry in the population. The weights capture the immediate structure of the population and change in response to the divergent rates of growth within that population. Moreover, because the weights are changing so are the moments that they are used to construct. The system is restless and we do not need to assume that its motion is governed by a stable attractor to which it is converging: which is fortunate, for the very process of movement necessarily revises the terms and conditions for future movement.

Within the total population of industries that defines our economy we identify three classes of structural change: there is the differential growth of the industries that continue in operation over some time interval; there is the entry of new industries; and, there is the exit of existing industries. Over a short interval of time the aggregate growth of the whole population is accounted for by $g = g_c + n - e$, where g is the growth rate of the ensemble of total activity, g_c is the growth rate of the aggregate of the continuing industries, n is the proportionate increase in output associated with newly created industries (the industry birth rate), and e is the proportionate loss of output associated with industries that disappear (the industry death rate)[13]. For short intervals of time these birth and death rates may be of negligible importance but over longer intervals they may make up the bulk of the explanation of population level change. Indeed, for sufficiently long intervals the output of continuing industries may be of negligible importance: that is to say, the sets of industries that define the economy at any two census dates may have few elements in common. However, any newly born industries can only increase their relative importance if they grow more quickly than the average population, just as the industries which have disappeared will have grown less rapidly than the economy as a whole. Entry and exit matter qualitatively but they only matter quantitatively in terms of the subsequent and

[13] See Metcalfe (2008) for a more detailed examination of the statistical nature of evolutionary population analysis.

antecedent rates of differential expansion. Hence we shall focus exclusively on this factor of differential expansion and contraction, considering rates of growth defined over short intervals and setting the net industry entry rate equal to zero

We must now be precise about the characteristics of each vertically integrated industry. Each one consists of a group of firms supplying final output ready to be consumed or invested, together with a group of firms supplying the produced means of production to produce the final goods. When we speak of employment, or investment we refer to the total quantities in the supply chain that support the current output of the final good, including investments to expand capacity to produce the requisite intermediate goods. The technology of each vertically integrated industry is reflected in a pattern of division of labour and specialisation which in turn reflects the different technological and organisational knowledge bases of each component activity. In relation to technology and organisation, the capital coefficient, 'b_j' (the ratio of capital stock in the whole integrate industry to the capacity output for the final good) is assumed to be different for each industry. Moreover, all innovations are assumed to be Harrod neutral process improvements; progress is purely labour augmenting within the entire supply chain. Let a_j be defined as unit labour requirements within the supply chain required to produce full capacity output, then labour productivity for the industry, again measured in terms of capacity output, is $q_j = 1/a_j$. Notice carefully that at levels of aggregation above the industry, the ensemble input proportions will change in response to the different final output growth rates of the various integrated industries. However, this is not factor substitution in the traditional sense, for there is no smooth industry production function, it is instead factor reallocation or between-industry adaptation and it is the reallocation or adaptation effects that play a central role in this evolutionary growth theory

III a Measures of Population Structure

We need just two measures of population structure to capture the relative importance of each vertically integrated industry- one in terms of its share of aggregate employment, e_j, the other in terms of its share in aggregate capacity output, z_j.[14] Once we know the population structure we can immediately translate industry labour efficiency (and its inverse labour productivity) into their population equivalents: reflecting the fact that each industry contributes to aggregate productivity in proportion to its share in total employment, and to aggregate unit labour requirements (efficiency) in proportion to its share in capacity output. It follows that average unit labour requirements are $a_z = \sum z_i a_i$ and average labour productivity is $q_e = \sum e_j q_j$, from which it follows that, $a_z q_e = 1$.

Some elementary but important aspects of population accounting now follow from these definitions. First there is a structural consistency condition

$$e_j q_j = z_j q_e \text{ and } z_j a_j = e_j a_z . \quad (1a)$$

From (1a) it follows immediately that the employment structure will differ from the output structure as individual productivity or efficiency levels deviate from their population averages. It also follows that the proportional rates of change in these measures are related by the conservation conditions[15]

$$\hat{q}_e = -\hat{a}_z \quad (1b)$$

$$\hat{e}_j + \hat{q}_j = \hat{z}_j + \hat{q}_e \text{ and } \hat{z}_j + \hat{a}_j = \hat{e}_j + \hat{a}_z \quad (1c)$$

This is the dynamic counterpart to the proposition that the employment and output share weights for any industry are equal only when it has a *level of productivity* equal to the population average. We can see immediately that proportional growth necessarily implies the absence of

[14] The measure of output shares is contingent on the particular set of price weights used to construct the aggregate measure of capacity output, just as the employment shares are contingent on the prices of different kinds of labour within the employment aggregate. The shares in final output are different from the shares in value added industry by industry. The two differ by the product of the economy wide ratio of intermediate to final output and the fraction of the value of total intermediate output used by an industry.

[15] We use a carat over a variable to indicate its logarithmic rate of change, and a dot above a variable to indicate its differential rate of change.

structural change, structure is frozen, and from this it follows that each industry must have the same rate of productivity and efficiency increase, a requirement that is not conformable to the facts. One immediate corollary is that if, say, we hold the employment share constant in some industry then, in general, the corresponding output share cannot be constant. The converse is also true. Notice also, that the wider the spread of productivity levels in the population the greater the difference between output shares and employment shares.[16]

These accounting relations are no more than bookkeeping devices but they provide the necessary connections between investment, technical progress and the changing pattern of demand as we can now establish. Investment is important in three complementary ways: as the means to expand productive capacity; as a generator of aggregate demand; and as the carrier of new knowledge and stimulant to productivity growth. This is the sense in which we have a long run growth theory; it is a theory dependent on the determinants and consequences of investment activity. However, by the long run we do not mean some date far into the hypothetical future when the economy has converged to a steady expansion path but rather the immediate present when long run forces of investment and technical progress are active. As in Marshall's analysis, different causal forces are working at every moment but with different velocities, and the different velocities are the generators of structural change and evolution.

III b. Demand and Aggregate Productivity Growth

Just as the production side of the economy can be analysed as a population of industries, so the demand side can be analysed as a population of final consumers, such that the final demand for the output of any one industry depends on the number of consumers it has and the rate at which they consume. We assume that the driving causal processes behind changes in the pattern of demand are employment growth in relation to the number of consumers, and the growth of per capita income (the consequence of the growth of aggregate productivity) in relation to their rates of consumption. In this scheme, productivity growth reduces prices relative to money incomes and the consequent increase in real income generates a redistribution of expenditure over the

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

different industries, the Engel law effects that we referred to above. That the rates of growth of demand differ across industries, differences that would become more marked the lower the level at which we construct our industry aggregates, is not only one of the most important empirical regularities in economics, it is the reason why proportional growth models cannot capture the process of economic growth in a substantial way[17].

Let the per capita income elasticities for each industry, ψ_j, be defined as the ratio of the growth in per capita demand for the output of each industry to the growth rate of aggregate per capita income, thus

$$\psi_j = \frac{g_j - n}{g_z - n} \tag{2}$$

Where, n is the rate of growth of total employment, and $g_z = \sum z_j g_j$ is the rate of growth of aggregate output[18]. These elasticities provide us with the basis for a selection process across the set of industries since they give rise to different growth rates of demand and output. The simplification, that employment growth is neutral in its demand composition effects, is precisely that, a convenient simplification. What matters is that per capita income growth and population growth have differential demand effects and this is what we have captured in (2) and in its consequences below. Of course, in emphasising the role of income elasticities in the inter-

[17] That we ignore pure substitution effects but not the income effects of price changes is simply a consequence of not delving below the level of the industry where prices are determined. See below, footnote37, for further comment on the role of pure substitution effects.

[18] If we distinguish two final uses for each good, in consumption and in investment, we can further decompose these total elasticities as follows

$$z_j \psi_j = (1-s) c_j \psi_{cj} + s i_i \psi_{Ij}$$

where s is the aggregate saving ratio, c_j is the fraction of the industry's output absorbed in consumption, and i_j is the corresponding fraction absorbed in investment ($c_j + i_j = 1$). Thus ψ_{cj} is the per capita consumption elasticity, and ψ_{Ij} is the per capita investment elasticity for industry *j*. Summing across the industries yields the relation

$$\psi_z = \sum z_j \psi_j = 1 = (1-s)\psi_c + s\psi_I$$

A constant saving ratio, as assumed below, implies a unitary income elasticity of demand for wealth. See Laitner (2000) for an analysis of non-unitary income elasticities for assets and the growth process.

industry selection process, we should not be deluded into thinking that we have said anything terribly profound. The elasticities are averages taken across the population of consumers, contingent on the distribution of tastes, on the distribution of income (both personal and functional) and on the particular prevailing pattern of expenditure across very different commodities. What we need is some empirical and conceptual understanding of the determinants of income elasticities in general, their relation to the distribution of income, and how they change in relation to innovation and the entry of new industries. This we do not yet have, nor do we need it for immediate purposes[19].

From (2) we can write the rate of output growth of each industry as

$$g_j = n + \psi_j \hat{q}_e \tag{3}$$

where $\hat{q}_e = \frac{d}{dt}\log q_e$ is the, yet to be constructed, aggregate rate of productivity increase. The immediate consequence of this formulation is that the rate of growth of each industry cannot be determined before we have determined the rates of growth of employment and productivity across the entire population ensemble. Thus, the pattern of industry growth rates that emerges is simultaneously determined with the aggregate rate of growth of employment and of productivity.

The pattern of structural change in terms of output follows immediately from (3) since

$$\dot{z}_j = z_j\left(g_j - g_z\right) = z_j\left(\psi_j - \psi_z\right)\hat{q}_e \tag{4a}$$

An industry gains or loses relative importance in the ensemble of total (capacity) output as its income elasticity is greater or less than the population average income elasticity, which, of course, necessarily takes the numerical value of one. However, the proximate driver of the changes in structure is the growth of average per capita income; without technical progress the output structure of the population and its employment structure are frozen in time.

[19] See Bianchi (1998) and Saviotti (2001) for a very useful discussion of innovation and consumer behaviour relevant to these questions.

Relation (4a) is our first example of the use of the replicator dynamic principle, in which the changing economic weight of an industry depends on how its characteristics compare to the population average of those characteristics.[20] The importance of the replicator dynamic is that provides a way of analysing economic change that is independent of any assumption of the existence of a long run attractor towards which the economy is converging. In an open, knowledge driven economy there cannot reasonably be expected to be any such stable attractor, for the very movement towards it would create new knowledge, new entrepreneurial conjectures and thus change the foundations of that attractor. Replicator dynamics sidesteps these inherent difficulties by making the relevant rates of change dependent on the distributions of industry characteristics around their current population averages, while simultaneously providing an explanation of how those averages are changing. We have already pointed out that evolutionary analysis is inherently statistical in the sense that it relates different statistical moments within a causal structure, and an immediate illustration of this principle can be found in the relation between the variance of the industry growth rates and the variance in the income elasticities of demand, which, making use of (4a) is given by

$$\sum z_i\left(g_i - g_z\right)^2 = V_z\left(g\right) = \hat{q}_e^2 V_z\left(\psi\right) \tag{4b}$$

where $V_z\left(\psi_j\right)$ is the capacity weighted variance in the income elasticities of demand. The greater the rate of productivity growth the greater is the variance in the industry growth rates for a given variance in the income elasticities, and the greater is the resultant turbulence in the capacity shares.

There is an implication of the replicator principle which is worth drawing out at this point. It is that the income elasticities of demand cannot all be constant in a progressive economy, unless, trivially, they are all equal to one, the necessary condition for proportional growth. This is a deduction that is already implicit in Engel's law in which the elasticities decline with increases in

[20] See Montobbio, 2002 for an exposition of the replicator principle in the context of industry dynamics.

per capita income. It follows because the population average elasticity ψ_z =1 is a constant even though the structure of demand is evolving according to (3). Consequently,

$$\sum \dot{z}_j \psi_j + \sum z_j \dot{\psi}_j = 0$$

and from (4b) this becomes

$$\sum z_j \dot{\psi}_j = -\hat{q}_e \sum z_j (\psi_j - \psi_z)\psi_j = -\hat{q}_e V_z(\psi_j)$$

It follows that $\sum z_j \dot{\psi}_j = 0$ if, and only if, productivity growth is zero or if all income elasticities are the same (unity in value). The former assumption rules out technical progress, the latter rules out structural change. Hence we are left with the requirement that in a progressive economy $\sum z_j \dot{\psi}_j < 0$. On average the income elasticities must decline as productivity grows, although this constraint is quite consistent with some of them increasing. This result is an example of what evolutionists call Fisher's Principle, after the eminent biologist who first formulated some of the statistical rules of population dynamics.[21] It will recur in many different guises below.

III c. Aggregate Productivity Growth

We can now explore the implications for the relation between productivity growth in the individual industries and productivity growth for the entire economy. This is not as straightforward as it might seem, because the movement in the ensemble averages for productivity or efficiency is composed of two components, technical progress in each industry and structural change. Thus, for example, since $q_e = \sum e_j q_j$, it follows from (1a) that the aggregate rate of productivity growth is given by

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[21] See Andersen, (2004), Foster, (2000) , Knudsen, (2004) and Metcalfe (2008) for further analysis and critical discussion of Fisher's Principle. Aldrich, *et al.*, (2008) provide a detailed, general discussion of evolutionary variation-cum-selection dynamics.

$$\hat{q}_e = \sum z_j \hat{q}_j + \sum z_j \hat{e}_j \quad (5a)$$

With a similar expression applying to the change in average efficiency, thus

$$\hat{a}_z = \sum e_j \hat{a}_j + \sum e_j \hat{z}_j \quad (5b)$$

In relations (5a) and (5b) the aggregate rate of change is the sum of the average technical progress effect and the average structural change effect; two terms that are often called the "within industry effect" and the "between industry effect" in modern productivity accounting exercises[22]. However, our hypothesis on demand dynamics allows us to elaborate further the structural change effect and to write $\hat{q}_e$ as proportional to the weighted sum of the industry productivity growth rates.[23] Since n_j is the rate of growth of employment in industry j and $g_j = n_j + \hat{q}_j$, it follows that $n_j - n = \psi_j \hat{q}_e - \hat{q}_j$. If we weight this last expression by the employment shares e_j and sum across the population of industries we find that

$$\sum e_j (n_j - n) = \left(\sum e_j \psi_j\right)\hat{q}_e - \sum e_j \hat{q}_j = 0$$

since $\sum e_j n_j = n$ by definition. Thus, our weighting scheme is provided by

$$\hat{q}_e = \frac{1}{\sum e_j \psi_j} \sum e_j \hat{q}_j \quad (6a)$$

Unless, $\sum e_j \psi_j = 1$, these weights do not sum to unity. Indeed, it follows immediately that the employment weighted income elasticity is given by

$$\sum e_j \psi_j = \psi_e = 1 - \frac{C_e(\psi_j, q_j)}{q_e} \quad (6b)$$

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[22] There is an extensive literature on this topic. See Bartlesman and Doms, (2000), Disney *et al*, (2003), Baldwin and Gu, (2005), and for an evolutionary perspective, Nelson, (1989) and Metcalfe and Ramlogan (2006)

[23] See Cornwall and Cornwall (2002) for a closely related derivation.

Where, $C_e(\psi_j, q_j)$ is the 'e' weighted covariance between productivity levels and income elasticities across the population of industries. Thus, the employment-weighted average of the income elasticities coincides with the output weighted average only if this covariance is zero.

By an analogous argument, the rate of decline in unit labour requirements is given by

$$\hat{a}_z = \frac{\sum e_j \hat{a}_j}{\psi_e} \tag{7a}$$

And here we can express the employment weighted income elasticity as

$$\sum e_j \psi_j = 1 + \frac{C_z(\psi_j, a_j)}{a_z} \tag{7b}$$

where $C_z(\psi_j, a_j)$ is the corresponding 'z'-weighted covariance between industry income elasticities and average unit labour requirements in each industry[24]. The employment weighted average income elasticity plays an important role in our analysis of aggregate growth and structural change, a result which could not be readily anticipated.

To explore this point further, we can establish how much of the overall growth of productivity or efficiency is due to structural change and how much is due to technical progress proper. Consider first the decomposition of changes in $\hat{a}_z$. Let σ_a be defined as the proportion of the rate of change in aggregate efficiency that is due to output structural change. Then we find from (5b) and (7b) that $\sigma_a = 1 - \psi_e$. It follows that the corresponding proportion of aggregate labour efficiency change that is due to technical progress, $1 - \sigma_a$ is equal to ψ_e. Consequently if $C_z(\psi_j, a_j) = 0$, i.e., the income elasticities and efficiency levels are uncorrelated when weighted by output shares ($\psi_e = 1$), then the contribution of structural change to average efficiency growth will be zero even though the output structure is changing. Moreover, if this covariance is

[24] To derive this result, write, $\sum e_j \psi_j = \sum z_j \psi_j + \sum (e_j - z_j)\psi_j$ and recall that $e_j a_z = z_j a_j$, with $a_z = \sum z_j a_j$. The analogous result in (6b) is proved similarly.

positive, then changes in the structure of output are offsetting the effect of technical progress in the generation of average efficiency change, because demand is shifting relatively in favour of industries that have above average unit labour requirements.

How much structural change in total is generated for this population of industries? One measure of this is obtained by adding together the weighted changes in the employment and output shares so that[25]

$$\sum z_j \hat{e}_j + \sum e_j \hat{z}_j = -\frac{C_e(q_j, \hat{q}_j)}{q_e} = -\frac{C_z(a_j, \hat{a}_j)}{a_z} \qquad (8)$$

In (8) the statistic $C_e(q_j, \hat{q}_j)$ is the employment weighted covariance between levels of productivity and rates of productivity change across the population of industries, while $C_z(a_j, \hat{a}_j)$ is the corresponding output weighted covariance between levels and rates of change in efficiency. When these covariances are zero, it follows that the average amount of structural change is zero. These covariances play an important role in constraining the patterns of change in the population. As one might expect, how the pattern of productivity change correlates with the pattern of productivity levels is an important determinant of the overall pattern of evolution[26].

It is less straightforward to establish how much of the change in aggregate labour productivity is due to structural change in the pattern of employment, because this depends on the co-movements of output and productivity. However, if we define σ_q as the proportional contribution of structural change in employment to total productivity growth then it follows from (8) that

[25] Using the fact that $\hat{q}_e = -\hat{a}_z$, we can rearrange equations (1a) and (1b) to derive (8).

[26] Another way to express (8) is to note that $\sum z_j \hat{e}_j = \frac{C_e(n_j, q_j)}{q_e}$ and that $\sum e_j \hat{z}_j = \frac{C_z(g_j, a_j)}{a_z}$ results that make use of the relations between output shares and employment shares noted above in (1).

$$\left(\sigma_q - \sigma_a\right)\hat{q}_e = -\frac{C_e\left(q_j, \hat{q}_j\right)}{q_e} \tag{9}$$

From (9) we see that σ_q and σ_a are different whenever levels and rates of change of productivity are correlated, and that $\sigma_q < \sigma_a$ whenever this correlation is positive. This is an important result in evolutionary productivity accounting. Since the output structure and the employment structure evolve differently one would expect that their changes make different structural contributions to aggregate productivity and efficiency change (Metcalfe and Ramlogan, 2006). Thus, for example, to discover empirically that changes in employment structure make a negligible contribution to aggregate productivity growth, $\sigma_q = 0$, would be consistent with the simultaneous finding that changes in the output structure made a large contribution to aggregate efficiency growth and by implication productivity growth

From (8) we can also decompose the aggregate rate of productivity growth in a different but illuminating way in terms of the average rate of technical progress and the average amount of structural change in the population. Let, the average rate of technical progress be defined as $T_z = \sum z_j \hat{q}_j = -\sum z_j \hat{a}_j$ from which it follows that

$$\hat{q}_e = \frac{1}{\psi_e}\left[T_z - \frac{C_e\left(q_j, \hat{q}_j\right)}{q_e}\right] \tag{10}$$

When $C_e\left(q_j, \hat{q}_j\right) = 0$ then $T_z = \psi_e \hat{q}_e$ and the employment weighted average income elasticity exactly measures the proportion of aggregate productivity growth that is contributed by technical progress alone.

Having spelt out the population accounting relations between structural change and productivity change, we turn next to the determinants of productivity growth at the industry level for this is the fundamental driving force in this evolutionary frame. Structural change in demand, operating through the differentiated income elasticities, matters but it only operates in response to these more fundamental forces that create wealth from knowledge. Since we reject any reference to a neoclassical production function and to changes in aggregate knowledge, how can we build an account of the self-transformation of industries and economies? Such an account should generate the transformation process "from within", it should connect with the sector-specific growth of knowledge and it should emphasise the fundamental features of enterprise in relation to investment and innovation. If we are to choose any principle that draws together these desiderata it is that the division of labour is limited by, and in turn limits, the extent of the market. Changes in the division of labour require changes in technology in the broad, and extension of the market requires the growth of per capita income. No other principle would seem to have the ability to unify the transformation of production methods and the extension of demand to create an endogenous theory of enterprise and economic transformation.

IV <u>Investment and a Technical Progress Function</u>

In a remarkable empirical investigation into the growth of manufacturing in the USA over the period 1899-1939, Solomon Fabricant (1942) drew attention to the fact that rapidly growing output in an industry is usually associated with rising employment and increasing labour productivity and that when output is in decline so is productivity. Across industries, there are wide variations both in levels of productivity and in growth rates of productivity, so Fabricant saw that the way was open to explain these differences in terms of the differential growth of the markets for different groups of products. Moreover, growth of output is usually associated with net investment, and conversely, such that output growth usually implies the growth of measured capital per worker. The significance of this argument was not only that investment creates the capacity to serve a growing market but that it is a major channel through which technical advances "cut into unit labour requirements" (p. 96)

By investment, we shall mean any use of resources that improves the capacity of productive assets of any kind, assets being defined in the conventional way, by their ability to yield future income streams. From this perspective, investment is the activity that enhances productive economic capabilities and, it is much broader than the laying down of new plant and physical infrastructure. Investments in human capital, in research and development, in improvements in the organisation of firms are all of importance alongside the development of new plants and structures. Investment can then be interpreted as the cost of making the arrangements to improve capabilities and thus the cost of generating improvements in productivity (Scott, 1989). Of course, any change in such capabilities will require the growth of knowledge somewhere in the economy but the kinds of knowledge required tend to vary enormously and cannot be reduced to any simple metric or common denominator. Following Harrod (1948) we can distinguish two broad classes of investment that realise productivity improvements. One is the investment that adds capacity at the margin of production, and the other is rather more diffuse and includes any investment that serves to raise efficiency in existing plants without changing their capacity output. We call the second the "improvement effect" (operating on existing capacity), and the first the "best practice" effect (operating at the margin of new capacity), following Salter (1960).

We now introduce the concept of a technical progress function, to connect the rate of productivity growth to the rate of gross investment industry by industry. This function is the realisation of the prevailing scope and scale of innovation and enterprise in a vertically integrated industry, and is thus the realisation of the opportunities opened up by the growth of knowledge throughout the entire vertically integrated supply chain. It combines the two classes of investment such that an industry's overall rate of productivity growth is necessarily a weighted average of their different effects. In general, the relative incidence of the two types of investment will vary industry by industry, reflecting the particular composition of its vertically integrated supply chain and the rates of progress in the component parts of that supply chain. However, in all cases, the faster the growth rate of capacity the faster is the rate of productivity growth and the greater is the relative importance of investment in "best practice" compared to the investment in improving the existing population of plants.

Let α_j denote the proportionate improvement effect on existing plants inclusive of the retirement of marginal capacity, and let β_j denote the proportionate rate of improvement in best practice design as embodied in new plants. Both these coefficients are averages struck across each vertically integrated industry to reflect technical change at plant level, and the wider effects of reorganisation and differentiation of the supply chain as a market grows Then we can write each vertically integrated technical progress function as.[27]

$$\hat{q}_j = \alpha_j + \beta_j g_j \quad (11a)$$

which is equivalent to

$$\hat{q}_j = \alpha_j + \omega_j \left(\frac{I}{Q_c} \right)_j \quad (11b)$$

where I / Q_c is the vertically integrated ratio of investment in new plant to physical capacity , and $\omega_j = \beta_j / b_j$ is the coefficient that translates that investment into productivity growth[28]. This specification informs us immediately that structural change has feedback effects on the industry rates of productivity growth, because each industry growth rate is arithmetically equal to the sum of the population average output growth rate and the proportionate rate of change in the output share of that industry. Hence the core evolutionary principle that productivity growth induces structural change which induces further productivity growth without limit provided that knowledge continues to develop.

Relations (11) are fundamental to understanding everything that follows; they are the basic building blocks of our investment led evolutionary theory of growth and development. Indeed the key point about any endogenous growth theory is that it requires some specification of the economic determinants of technical progress, some link between new knowledge and its economic application. We should note immediately that the same relation has been introduced

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[27] It is easily shown that the weight applied to the improvement effect, α_j, is $(1+g_j)^{-1}$ and the weight applied to the best practice effect, β_j, is $g_j \cdot (1+g_j)^{-1}$. When the growth rate, g_j, is small, and the time interval short, we can approximate the technical progress function by (11a) of the text.

[28] See Eltis (1973) Chapter 6 for an extended discussion of analogous technical progress functions. If we express the rate of productivity growth in terms of actual output ($\hat{q}'_j$) rather than capacity output ($\hat{q}_j$), then $\hat{q}'_j = \hat{q}_j + \hat{x}_j$, where $\hat{x}_j$ is the rate of change of the average degree of capacity utilisation in the industry. For reasons that we have already made clear it is appropriate in a long run analysis to hold capacity utilisation constant.

by Kaldor (1972), in his exposition of the Verdoorn law, although Verdoorn's original account has very different foundations from those articulated by Kaldor or Fabricant[29].

V. Increasing Returns and the Interdependence of Rates of Productivity Growth

The immediate consequence of combining the technical progress functions with the population analysis of productivity growth is to find that the industry rates of productivity growth are interdependent. Here we are following the line of enquiry that is traced from Adam Smith, through Alfred Marshall to Allyn Young (1928), to the effect that increasing returns and the extension of the market generate reciprocal interdependences of productivity growth between the different industries. As Young put it, "[e]very important advance in the organisation of production alters the conditions of industrial activity and initiates responses elsewhere in the industrial structure which in turn have a further unsettling effect" (p. 533). The precise forms those changes in organization and technique take within each supply chain are not the issue in question, rather it is their reciprocal effects on productivity growth that matter. There is an organic unity to the pattern of technical progress, a unity that is conditioned by the structure of the economy and which changes as that structure changes.

The interdependence of productivity growth rates follows directly from the technical progress functions (11), the relations between the growth of each industry and the overall rate of productivity growth (3), and the relation between the aggregate and the industry productivity growth rates (6a). Thus we can translate each technical progress function into the corresponding increasing returns function to integrate the evolution of technology with the evolution of demand,

$$\hat{q}_j = \alpha_j + \beta_j \left[n + \psi_j \left(\frac{\sum e_j \hat{q}_j}{\sum e_j \psi_j} \right) \right] \qquad (12)$$

This expresses the central point of the Smith/Marshall/Young approach, which is that productivity growth in any one sector increases with productivity growth in all other sectors provided that its output is a normal good. The productivity growth rates are mutually determined

[29] For outstanding reviews of this literature see Scott (1989), Toner (1999), Bairam (1987) and McCombie (1986).

through the coordination of demand and capacity in the market process, industry by industry. Equation (12) generates an ensemble of simultaneous productivity growth equations, and the solution in the two-industry case is sketched in Figure 1. The schedules Q_1 and Q_2 are the reciprocal increasing returns functions for each industry, and they intersect at 'a' to determine the market co-ordinated rates of technical progress, in each industry, $\hat{q}_1^*$ and $\hat{q}_2^*$.

The position and slope of each increasing returns function depends on the structure of the aggregate population and this structure is captured by the weights $u_j = e_j\psi_j / \psi_e$ which measure the contribution which each industry makes to the employment weighted average income elasticity of demand[30]. The coordinated rates of technical progress thus depend on the structure of the economy but in the subtle way embodied in the weights, u_j. Any change in employment structure, as mediated by the distribution of income elasticities, implies a different pattern of technical progress across the population of industries, and it also implies a different aggregate rate of technical progress. Thus structure shapes the pattern of progress and the pattern of progress reshapes the structure.

Now draw through point 'a' in Figure 1 the straight line $Z - Z$ with slope, $-z_1 / z_2$ (the relative capacity output shares) to intersect the 45^o line at 'b'. This point measures the rate of aggregate technical progress, $T_z = \sum z_j \hat{q}_j^*$ and, as drawn, $\hat{q}_1^* > T_z > \hat{q}_2^*$. This differs from the aggregate rate of productivity growth by the contribution made by employment structural change, as given in equation (10) above. Hence, if we also draw the line $E - E$ through point 'a' with slope $-e_1 / e_2$, it intersects the 45^o degree line at 'c' to measure $\psi_e \hat{q}_e$. One can see immediately how the average rate of structural change in employment and output combined is determined jointly with the pattern of productivity growth, because the distance between points 'b' and 'c' measures the covariance statistic $C_e\left(q_j, \hat{q}_j\right)/ q_e$. As drawn in Figure 1, $T_z > \psi_e \hat{q}_e$, so this

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[30] These weights change according to the rule $\hat{u}_i = \hat{e}_i - \hat{\psi}_e$. Since $\sum \dot{u}_i = 0$, it follows that $\hat{\psi}_e = \sum u_i \hat{e}_i$.
If we consider the increasing returns function for industry one we find that its slope is equal to $u_2 \beta_1 (\psi_1/\psi_2)[1 - u_1\beta_1]^{-1}$ and that the intercept is equal to $(\alpha_1 + \beta_1 n)[1 - u_1 \beta_1]^{-1}$, with corresponding expressions for industry two.

covariance is positive[31], and the overall pattern of structural change is acting to reduce aggregate productivity growth below the average rate of technical progress. The converse case means that this covariance statistic is negative. When the industry levels of productivity and rates of productivity growth are uncorrelated then points 'b' and 'c' coincide and the covariance is zero. Here there are two relevant possibilities. Either the levels of labour productivity are the same in each industry so that the schedules $Z-Z$ and $E-E$ coincide, or the two increasing returns functions happen to intersect on the 45° line, to equate the industry rates of productivity growth. Now consider point 'd'. This depicts the pattern of productivity growth when the best practice rates of design improvement β_j are equal to zero, so eliminating the possibility of increasing returns and the mutual interdependence of rates of technical progress. The difference between points '*d*' and '*a*' reflects the importance of increasing returns in this population and of reciprocal interdependence in the growth process: it measures what we shall term the "Young effect"; the stimulus to growth generated by the autocatalytic nature of technical progress and the growth of per capita income. The point about positive feedback, as Young emphasised, is that it augments growth within and between sectors, amplifying the wellspring of progress, provided by the enterprise-based relations between processes of innovation and investment.[32]. In this way, we can comprehend his insistence that changes in one industry induce changes in other industries mutually reinforcing the growth of productivity within the entire population of industries.[33].

Having dwelt extensively on the relation between industry rates of technical progress and aggregate productivity growth we should also draw attention to the other lessons contained in Figure 1. The first is that the industry pattern of technical progress depends on the rate of growth of total employment, and the faster is total employment growth the faster are the rates of technical progress industry by industry. The second relates to the fact that the technical progress functions are defined in terms of sets of supply chain relationships with the likelihood that different industries have elements of their respective supply chains in common. Thus, for example, an improvement in steel or plastics technology will influence the increasing returns

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[31] That is to say, $\hat{q}_1^* > \hat{q}_2^*$, implies that $q_1 > q_2$, which implies that $e_1/z_1 < e_2/z_2$.

[32] Of course, it is trivially obvious that without innovation there would be no technical progress functions, no positive feedback and no productivity growth. We haven't yet escaped from Usher's (1980) warning, that no progress means no growth.

[33] The reader can visualise this in terms of shifts in each increasing returns function in figure 1.

functions of all the vertically integrated industries that utilise steel and plastics in their supply chains. Such a technological breakthrough of a "general purpose" kind will shift outwards both the increasing returns functions in Figure 1, and induce further technical progress, according to the pattern of weights u_j`

Notice carefully, that Figure 1 represents a process of growth co-ordination at a point in time. It does not represent growth equilibrium interpreted in some more general sense, as a fixed attractor on which productivity patterns converge and stabilise. Indeed, it is a fundamental assumption of our evolutionary perspective that growth is open-ended, that there is not any state of dynamic rest in the presence of innovation-driven growth. Thus, points 'a' and 'b', 'c' and 'd' are continually "on the move" as the relative employment shares vary over time.

We can now derive the appropriate expressions for the aggregate rate of productivity growth and the aggregate rate of technical progress. For the former, we weight each increasing returns function (12) by the corresponding employment share weights and sum to yield the following relation between aggregate productivity growth and the rate of growth of total employment

$$\hat{q}_e = \frac{\alpha_e + \beta_e \cdot n}{\psi_e (1 - \beta_u)} \qquad (13a)$$

In (13a), $\alpha_e = \sum e_j \alpha_j$ is the average rate improvement to existing plant , $\beta_e = \sum e_j \beta_j$ is the average progress elasticity constructed with the employment shares, while $\beta_u = \sum u_j \beta_j$, is the average progress elasticity, derived from the weights u_j [34] The conditions for Fabricant's Law to hold in the aggregate are $\beta_e < 1$, and $\beta_u < 1$, which are certainly satisfied if the individual

[34] Neither of the aggregate progress elasticities β_e and β_u are constants; they vary with each change in the structure of employment. Exactly as one should expect, the dynamic properties of the economy change as its structure changes. A little manipulation establishes, for example, that $d\beta_u / dt = C_u(\beta, g)$ and that $d\beta_e / dt = C_e(\beta, g)$, and that these secondary covariances can be expressed in primary terms as in the case of (17) below.

rates of best practice design improvement are less than unity. Then we are assured that growth is autocatalytic, with demand, output and productivity growth mutually reinforcing one another.

To derive the average rate of technical progress, T_z, we net out the contribution of structural change to productivity growth by multiplying each increasing returns function by the capacity output weights z_j, to obtain the relation[35]

$$T_z = \left[\alpha_z + \frac{\alpha_e \beta_w}{\psi_e (1-\beta_u)}\right] + \left[\beta_z + \frac{\beta_e \beta_w}{\psi_e (1-\beta_n)}\right] n \tag{13b}$$

Where $\beta_z = \sum z_j \beta_j$ and $\beta_w = \sum w_j \beta_j$ are appropriately weighted best practice effect elasticities[36].

The formulations in equations (13) map directly into Figure 1 because they take as given the rate of employment growth. However, from our viewpoint the rate of growth of employment is not an arbitrary given but is rather a derived consequence of the difference between aggregate output growth and aggregate productivity growth. Rearranging (13a) we can thus express Young's Law across the ensemble of industries, as the aggregate relation between productivity growth and output growth, thus[37]

$$\hat{q}_e = \frac{\alpha_e + \beta_e g_z}{\psi_e (1-\beta_u) + \beta_e} \tag{14}$$

[35] Summing each technical progress function by the output shares gives $T_z^* = \alpha_z + \beta_z n + \beta_w \hat{q}_e$. The rate of growth of productivity is eliminated using (13a)

[36] The weights $w_j = z_j \psi_j$ measure the contribution that each industry makes to the output weighted income elasticity of demand, remembering that $\psi_z = 1$. We can always reduce a difference between the differently weighted means of a variable to an appropriate covariance Thus, for example, $q_e(\alpha_z - \alpha_e) = C_e(q_j, \alpha_j)$ expresses the difference between the different weighted averages for the industry rates of improvement. Similarly, $q_e(\beta_z - \beta_e) = C_e(q_j, \beta_j)$ and $\beta_w - \beta_z = C_z(\psi_j, \beta_j)$. If desired, the reader can, for example, rewrite (13b) in terms of various covariances to eliminate all the averages except those constructed using the employment weights.

[37] An analogous expression in terms of the aggregate growth rate of output can be derived for (13b)

Equation (14) is the aggregate increasing returns function for this population of industries. It reflects the implicit growth of knowledge and its rate of application industry by industry, and it captures the fundamental point that average productivity growth cannot be independent of the structure of the ensemble of industries and how that structure is changing. The economy is simultaneously co-ordinated and restless, as all knowledge-based economies must be. We shall take up the restless theme in our final section but we must turn first to the interdependence between aggregate output growth and aggregate productivity growth[38].

VI. Closing the System: Accumulation and Increasing Returns.

We have shown how productivity growth differences at the industry level and the aggregate rate of productivity growth are simultaneously determined. However, we have yet to determine what the aggregate rate of output and productivity growth will be, for the individual industry growth rates are ultimately constrained by the requirement that aggregate investment is equal to aggregate saving. That is to say, there are limits to the exploitation of increasing returns and these are naturally set by limits to the aggregate growth of the market. As Kaldor (1982), pointed out there is a missing element in the Young approach that can only be dealt with by an explanation of the relation between capital accumulation and effective demand in the aggregate.

[38] Technical progress has such a powerful effect on some relative prices, that the reader may rightly wonder how the results are changed if we give pure substitution affects a more explicit role. Briefly, we can state that the full analysis of relative price effects requires that (3) be replaced by $g_j = n + \psi_j \hat{q}_e - \sum_k \chi_{jk} (\hat{p}_k - \hat{p}_z)$, where the χ_{jk} are the own and cross (pure) price substitution elasticities of demand for industry j with respect to each industry price, the $\hat{p}_k$ are the proportional rates of change in the industry prices, and $\hat{p}_z = \sum_k z_k \hat{p}_k$ is the rate of change in the average price level- the standard of value. The aggregate income equals expenditure constraint and homogeneity ensure that the elasticities "add up" to give $g_z = n + \hat{q}_e$ so that the relative price effects net out to zero in the aggregate. That is to say, $\sum_k z_k \chi_{ki} = 0$ for the effect of changes in the price of industry i across all industries, and $\sum_k \chi_{ik} = 0$ for the effect of changes in all prices on the demand for industry i. To go further requires a theory of price formation and change at the industry level and this is why we do not take the discussion any further here. However, if one assumes that the dominant factor in changing prices is technical progress then one could, for example, approximate and set $\hat{p}_k = -\hat{q}_k$ and find that the analysis of figure 1 is reproduced but with the slopes and positions of the Q schedules depending on the own and cross price substitution elasticities as well as on the income elasticities.

To express this more formally, relation (14) provides only one relation to determine two unknowns. A relation is missing and here there are at least two possibilities. The first is to claim that the rate of growth of employment, n, is given by virtue of arguments in relation to the growth of population, labour migration, changing gender composition of the population, and changes in institutional rules in relation to the market for labour. Whatever the rationale, the full employment value of 'n' determines $\hat{q}_e$ through (13a) and correspondingly determines the growth rate of output, g_z. This is the route explicitly followed by Arrow (1962) and Jones (1995a and b) in their very different accounts of endogenous growth, for they both end up with the claim that steady state productivity growth is proportional to the growth in population. Consequently, a stationary population implies an end to progress which seems an unduly tough restriction on the growth of knowledge and its transfer into the growth of productivity. Instead we follow a different approach; one grounded in Harrod's pioneering treatment of endogenous growth in terms of aggregate saving and investment. In this view, the requirements for macroeconomic co-ordination set the aggregate constraints on the relations between growth rates at industry level. In following this approach, some hypothesis has to be adopted on the nature of capital markets, investment and saving behaviour.[39]

We start by assuming that all profits are distributed, all investment is funded via the capital market, and that the aggregate saving ratio of households is a constant, s[40].The ratio of saving to capacity output is then equal to sx_z where $x_z = \sum z_j x_j$ is the average degree of capacity utilisation and x_j is the degree of capacity utilisation (the ratio of actual to capacity output) in each industry. Long run normal prices are set to keep each industry operating at full capacity, $x_j = x_z = 1$, and thus ensure that the rate of growth of capacity is equal to the rate of growth of demand, given each industry's propensity to invest. Coordination of the capital market requires that aggregate saving ratio must equal the aggregate investment ratio for the economy but here

[39] The Harrod model is a more sophisticated version of the so-called AK model of endogenous growth, by virtue of requiring an independent investment function. The crucial change introduced by Solow's growth model was not the assumption of a variable capital output ratio but rather the disappearance of an independent investment function. It is Say's law model in which savings and investment are automatically equal in all economic circumstances. See Kurz and Salvadori (1998) for an elaboration and critique. Other, post-Keynesian, approaches differentiating savings by type of income are equally applicable but would take us too far afield in this preliminary exposition.

[40] As noted above, this is tantamount to assuming a unitary income elasticity of demand for per capita wealth.

we must introduce the two kinds of investment that we alluded to in constructing each technical progress function. First there is investment that expands capacity. Since capacity is fully employed in each industry, the ratio of this kind of investment to the industry's output is $(I/Q)_j = b_j g_j$. It follows that the aggregate ratio of capacity expanding investment to capacity is given by

$$\frac{I}{Q} = \sum z_j b_j g_j = b_z g_v$$

where $g_v = \sum v_j g_j$ is the rate of growth of the aggregate capital stock, defined using the weights $v_j b_z = z_j b_j$. The weights v_j measure the share of each industry in the total capital stock which is equal to the proportionate contribution that each industry makes to the aggregate capital output ratio. Secondly there is improvement investment that enhances the efficiency with which current capacity is operated, and we let μ denote the aggregate ratio of this kind of investment to capacity expanding investment.[41] From this, we immediately obtain a version of the familiar Harrod condition

$$g_v = \frac{s}{(1+\mu)b_z} \qquad (15a)$$

Given our assumptions about capacity utilization rates, this is the familiar Harrod formula, taking account of the distinction between the two kinds of investment. Clearly, the greater the fraction of investment that is devoted to improvement rather than capacity expansion, the smaller will be the rate of growth of the aggregate capital stock.

However, g_v in this formula is not the growth rate of aggregate capacity output as normally defined, which is, $g_z = \sum z_j g_j$, the output share weighted average of the industry growth rates. The two growth rates would only be equivalent in conditions of proportional growth, *that is, when growth is not associated with development,* but here they are logically different and are related by the condition

[41] The distinction was first made in relation to growth theory by Harrod, (1946, p.79).

$$g_z = g_v - \frac{C_z\left(g_j, b_j\right)}{\bar{b}_z}$$

In this expression $C_z\left(g_j, b_j\right)$ is a secondary covariance since the growth rates are endogenously determined. However, because of the relationship between the distribution of demand growth and aggregate productivity growth it follows that this secondary covariance is equal to, $C_z\left(\psi_j, b_j\right) \cdot \hat{q}_e$, where $C_z\left(\psi_j, b_j\right)$ is the capacity output weighted primary covariance between the industry capital output ratios and the industry income elasticities of demand. Thus, the aggregate rate of output growth becomes

$$g_z = g_v - \frac{C_z\left(\psi_j, b_j\right)}{b_z} \hat{q}_e$$

and it follows that the aggregate growth rate of output is related to the aggregate growth rate of productivity by

$$g_z = \frac{s}{(1+\mu) b_z} - \left[\frac{C_e\left(\psi_j, b_j\right)}{b_z}\right] \hat{q}_e \qquad (15b)$$

That is to say, the aggregate growth rate of output is not independent of the forces making for uneven rates of growth in the individual sectors.

Now, if we combine together the accumulation relation (15b) with Young's Law (14), we can simultaneously determine the mutually consistent values for the growth of aggregate output and the growth of aggregate productivity. This solution is sketched in Figure 2. The accumulation schedule labelled H shows the rates of growth of output associated with different rates of productivity growth when aggregate saving equals aggregate investment. It is a schedule of regular advance as Harrod put it. We have assumed for purposes of illustration that $C_z\left(\psi_j, b_j\right)$ is positive. The resulting negative association between the rates of growth of output and productivity reflects the "least favourable case", in that the industries with above average income elasticities of demand are also the industries with below average capital productivity. Productivity growth consequently has a retarding effect on output growth since it concentrates the latter in industries with a relatively lower productivity of invested capital[42]. The increasing returns schedule, labelled Y, imposes a positive association between the two rates of growth, and so the mutually dependent aggregate solutions for g_z and $\hat{q}_e$ follow, and are shown in Figure 2 by point y. The solution at y is the "Young", solution with mutual interdependence of productivity and output growth. By contrast, the point labelled h is the traditional "Harrod" solution, with output growth equal to capital stock growth and productivity growth independent of output growth. The diagram also depicts the aggregate rate of employment growth. The 45 degree line in Figure 2 shows all combinations of output and productivity growth that generate a zero rate of growth of aggregate employment. The distance $ya = 0n$ measures the positive rate of employment growth consistent with the solution at point y. Notice also that point e denotes the minimum rate of productivity growth consistent with non negative employment growth. That the joint distributions of income elasticities of demand, productivity levels, and capital output ratios matter for this outcome, is entirely a product of our evolutionary framework. Structure and variety matter in an essential way for the performance of the system and our solutions in Figure 2 show how.

Some rather obvious comparative static exercises now fall into place with the help of Figure 2. Thus comparing two economies that are identical except for their savings ratios, we find that the high saving economy has faster growth rates of output, productivity and employment. Similarly comparing two economies, one of which is technically more progressive, this later will have a higher rate of productivity growth, a lower rate of output growth and a lower rate of employment growth. A more difficult exercise is to consider the effects of an increase in μ, the ratio of improvement to capacity expanding investment. This notional change shifts the H schedule downwards and reduces the growth rate and the rate of productivity growth for a given aggregate increasing returns function.. However, the expectation is that an increase in the resources

[42] The converse case of a negative value for the covariance between capital output ratios and income elasticities we leave to the reader to explore. .The comparative static exercises below are contingent on the assumed positive value of this covariance.

devoted to improvement investment, for example, through more R&D or training, will also shift this schedule to the right, increasing the rate of productivity growth but further reducing the rate of output growth. How this works out in full will depend on how the investments pay off in terms of improved productivity growth and this is a question that can only be addressed industry by industry and firm by firm. This is beyond our remit but at least we know where to look to see how investments in knowledge generation are translated into additional wealth, and it is not at the macroeconomic level.

The pattern of co ordination in Figure 2 represents a perfectly plausible "model" of evolutionary growth without making any assumptions that the point of coordination is a stable long run attractor for the economy. Quite the contrary, what makes this approach evolutionary is that the determinants of the point of coordination are restless; they evolve in response to the structural changes that are induced by the processes of economic coordination at aggregate and industry levels. It is not a system in equilibrium; indeed, capitalism in equilibrium seems from this point of view a contradiction in terms. There are always reasons and incentives to change prevailing arrangements, and every change opens up new opportunities for further change, *ad infinitum.* This is the powerful message first stated by Smith, refined by Marshall and Young, and given empirical content by Fabricant, Schumpeter, Kaldor and modern evolutionary economists. What can we say on the nature of restless development and growth and the relation between the different stylised facts? The discussion is necessarily brief but we hope that it points to deeper questions about evolutionary growth.

VII. Restless Capitalism and the Stylised Facts

We begin by reminding ourselves of the basic dynamics of structural change. An industry is increasing its share of aggregate output precisely to the degree that its income elasticity of demand exceeds a value of unity, the population average income elasticity. Nothing more needs to be said, but when we come to the changes in employment shares, the outcome is a little less transparent, for employment and output shares do not automatically move in step. An industry is increasing its share of employment if $n_j > n$ which is equivalent to the requirement, $\hat{q}_e \psi_j > \hat{q}_j$. That is to say, the ratio of industry to average productivity growth has to be less than the income elasticity of demand for that industry. We can decompose this requirement even further using the increasing returns functions, so that an industry's employment share is increasing whenever

$$\frac{\psi_j\left(1-\beta_j\right)}{\psi_e\left(1-\beta_u\right)} > \frac{\alpha_j + \beta_j n}{\alpha_e + \beta_e n}$$

This is a condition which captures with neat symmetry the relation between industry and population characteristics in relation to technical progress and structural change.

Since the shares in output and employment are in continual flux, it is not at all obvious that the aggregate growth rate can be constant, a definitive test for states of steady state, balanced growth. For it is immediately apparent that when industry growth rates differ there may be no industry which grows at the average rate, and consequently the average growth rate cannot be constant. How does it change? This is where we reconnect with the work of Kuznets and Burns on retardation and growth rate divergence discussed in section II above. Using (4b) we find that the change in the aggregate growth rate is

$$\begin{aligned}\frac{dg_z}{dt} &= \dot{g}_z = \sum \dot{z}_j g_j + \sum z_j \dot{g}_j \\ &= \sum z_j\left(g_j - g_z\right)g_j + \sum z_j \dot{g}_j \\ &= V_z(\psi)\hat{q}_e + R_z\end{aligned} \qquad (16)$$

The variance in income elasticities multiplied by the productivity growth rate captures the structural change effect, while $R_z = \sum z_j \hat{g}_j$ is the average rate of change in the individual growth rates, and measures the retardation effect. If all the individual growth rates are constant this second term vanishes and the average growth rate is necessarily increasing because it is converging on the largest of the given industry growth rates at a rate that equals the population variance in the industry growth rates[43]. Consequently, the only way the average growth rate can

[43] This is a straightforward consequence of Fisher's Principle in which the change in one statistical moment is related to the value of other statistical moments. Just as the average is not in general stationary, neither is the variance, for the average is changing along with the output weights, and additionally the income elasticities have already been shown not to be constants in section III above. A little manipulation shows that

remain constant is if the individual growth rates are declining, that is to say that the Kuznets/Burns retardation principle holds on average. If it should happen that the average output growth rate is indeed constant then the required average rate of retardation is given by $R_z = -V_z(\psi)\hat{q}_e$, which increases with the average rate of productivity growth. Thus the Kuznets ad Burns analysis of individual industries has its aggregate counterpart in (15)[44].

Principal among the aggregate stylised facts is the constancy over time of the aggregate capital output ratio. Within our framework there is no necessity for it to be constant since the given capital output ratios differ industry by industry. Consequently the aggregate capital output ratio evolves with the output structure according to the relation

$$\hat{b}_z = g_v - g_z = \left[\frac{C_z(\psi_j, b_j)}{b_z}\right]\hat{q}_e \qquad (17a)$$

Only if the distributions of capital output ratios and income elasticities of demand are uncorrelated at the prevailing output structure will the aggregate capital output ratio be constant. This is an important clue to the nature of the evolutionary process; its aggregate consequences are conditional not only on the variety within the fundamental data of the economy but on their degree of correlation as well. Thus, as a general rule in an evolving economy, Harrod neutrality at industry level will not produce Harrod neutrality at the aggregate economy level, and the purpose of the aggregation procedure is to identify how and why the emergent aggregate properties do not mimic the corresponding properties at industry level. Of course, Figure 2

$\frac{dV_z(\psi)}{dt} = S_z(\psi_j) + 2C_z(\psi_j, \dot{\psi}_j)$. In this expression, $S_z(\psi_j)$ is the third moment of the income elasticities around their population average, and $C_z(\psi_j, \dot{\psi}_j)$ is the output weighted covariance between the elasticities and their rates of change.

[44] The reader can work through the consequences for other aggregate growth rates, for example the growth rate of the capital stock, $g_K = \sum v_j g_j$. Because $g_I = g_K - \hat{g}_K$ it follows that the rate of change of the aggregate accumulation rate can be expressed as $\hat{g}_K = -\left[\frac{C_z(\psi_j, b_j)}{k_z}\hat{q}_e + V_v(g_j)\right]$. In this expression, $V_v(g_j)$ is the variance of the industry capital stock growth rates constructed using each industry's share in the aggregate capital stock as weights. This variance effect reduces the growth rate of the capital stock but the covariance term may work either way. In figure 2, the two effects are in the same direction since the covariance is there assumed to be positive.

shows a case where the capital output ratio is increasing over time, so that structural change imposes an "evolutionary load" on the aggregate rate of growth.

Constancy of the industry capital output ratios also means that each industry's capital labour ratio, k_j , will be increasing at the same rate as labour productivity in that industry. At the population level this means that the aggregate capital labour ratio, is $k_e = \sum e_j k_j = b_z q_e$, so its movement depends on the changing patterns of employment and output. Consequently, from (16a) the growth in the aggregate capital labour ratio is

$$\hat{k}_e = \left[1 + \frac{C_z(\psi_j, b_j)}{b_z}\right]\hat{q}_e \qquad (17b)$$

Notice that in the case of the movement of both of the average ratios in (17a) and (17b), the rate of change increases with the rate of average productivity growth, precisely because the rates of structural change increase with the rate of average productivity growth.

Of course, we are not ruling out the possibility that Kaldor's stylised facts will hold in respect of these ratios (although the evidence in their favour is problematic). If they are validated empirically, it will not be because of the absence of structural change but rather because of the particular correlation structure between technology and demand across the ensemble of industries[45]. There is no necessity for steady growth to apply in an evolving economy; if it does it will be the result of an averaging process and to this degree an emergent ensemble property of the economy.

It should now be apparent that the point of coordination in Figure 2 is a restless position. It is restless because the economy wide averages that determine the positions of the accumulation and technical progress schedules are continually evolving. We have seen this in respect of the capital output ratio and the "Harrod" schedule, so let us conclude with a second example, which relates

[45] We leave it to the reader to explore the movements in the aggregate rate of profits, in the share of profits in income and in the rate of change of the average rate of technical progress, $T_z = \sum z_j \hat{q}_j^*$

to the change in the "Young" schedule. Consider then the change in the average rate of improvement on existing plants, α_e. This is a more complicated story. The rate at which this average changes has two components, one reflecting the impact of the changing employment structure, and the other reflecting any changes (accelerations of decelerations) in the industry specific rates of improvement in existing plants and capital structures, α_j. Thus

$$\frac{d\alpha_e}{dt} = \dot{\alpha}_e = \sum \dot{e}_j \alpha_j + \sum e_j \dot{\alpha}_j$$

About the second term we have little to say, since it is a sum of changes arising below the industry level and is ruled out of our discussion for this reason. However, the structural effect in the first term is far more amenable to analysis. By familiar steps it follows immediately that $\sum \dot{e}_j \alpha_j = C_e(\alpha_j, n_j)$. If this covariance is positive then the employment structure is increasingly concentrated on those industries with above average rates of improvement, necessarily increasing the population average rate of improvement. Taking account of the fact that the distribution of the employment growth rates around their average, $n_j - n$, is equal to $\psi_j \hat{q}_e - \hat{q}_j$, it follows that

$$C_e(\alpha_j, n_j) = C_e(\alpha_j, \psi_j) \cdot \hat{q}_e - C_e(\alpha_j, \hat{q}_j)$$

This is a typical product of evolutionary economic reasoning, in that the covariation between an endogenous variable (in this case n_j) and an exogenous variable (in this case α_j) reflects the deeper causal structure underlying the changing patterns of output and employment. This deeper structure is reflected in the covariation between income elasticities and rates of improvement and between rates of productivity growth and rates of improvement. The system is restless because of the variety contained within it and because of the correlation between those different dimensions of economic variety. All is flux, the product of variation, selection and the ongoing development of productivity within the causal structure of demand and output co ordination, industry by industry and in the aggregate[46].

VIII. Concluding Remarks.

When the uneven growth of the economy is driven by and drives the uneven growth of useful human knowledge, we can neither restrict our analysis of growth to the aggregate economy nor can we treat structural change as a passive epiphenomenon. Innovation and technical progress cause and are caused by the patterns of economic restructuring and differential growth in the economy. At its most fundamental level the system evolves because of the non representative behaviours contained within it. Unfortunately, a full treatment of the origins of wealth from knowledge must necessarily delve below the level of the industry to the connections between innovation and the competitive performance of rival firms. This further step will reinforce our claim that capitalism is restless because knowledge is restless; that capitalism grows unevenly because knowledge grows unevenly, precisely what Schumpeter meant by creative destruction. Diversity and correlation of determining characteristics are the keys to adaptive, restless capitalism; and it is the diversity in the conditions of technical progress, in capital output ratios, and in income elasticities of demand that we have shown to sustain the essential unity of our two sets of stylised facts. Aggregate growth and structural self-transformation are one and the same problem. Needless to add, in an open economy these evolutionary forces are further amplified through international trade and investment, although that really must be another story.

Acknowledgments

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[46] The reader can go further and eliminate the endogenous productivity growth rates in $C_e(\alpha_j, \hat{q}_j)$ by using the increasing returns functions (11). After some manipulation, using the different weighting schemes introduced above, we find that this is reduced to the rather complicated but readily intelligible expression $C_e(\alpha_j, n_j) = -V_e(\alpha_j) - nC_e(\alpha_j, \beta_j) + \hat{q}_e\left[C_e(\psi_j, \alpha_j)(1-\beta_n) - \psi_e C_u(\alpha_j, \beta_j)\right]$. A special case arises when the primary elements, α, β, ψ, are uncorrelated one with the other. Then this expression reduces to $C_e(\alpha_j, n_{,}) = -V_e(\alpha_j)$, the latter being the employment weighted variance in the rates of improvement. In this case, the effects of structural change result in a decline in the average rate of improvement.

This paper is an extension and revision of Metcalfe, Foster and Ramlogan, 2006. We thank Cristiano Antonelli, Harry Bloch, Dick Nelson, and Mark Setterfield for their comments and suggestions on earlier drafts. JSM gratefully acknowledges the generous support of Curtin University and its School of Economics and Finance, where much of the initial drafting was carried out.

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Figure 1

The Distributed Pattern of Technical Progress

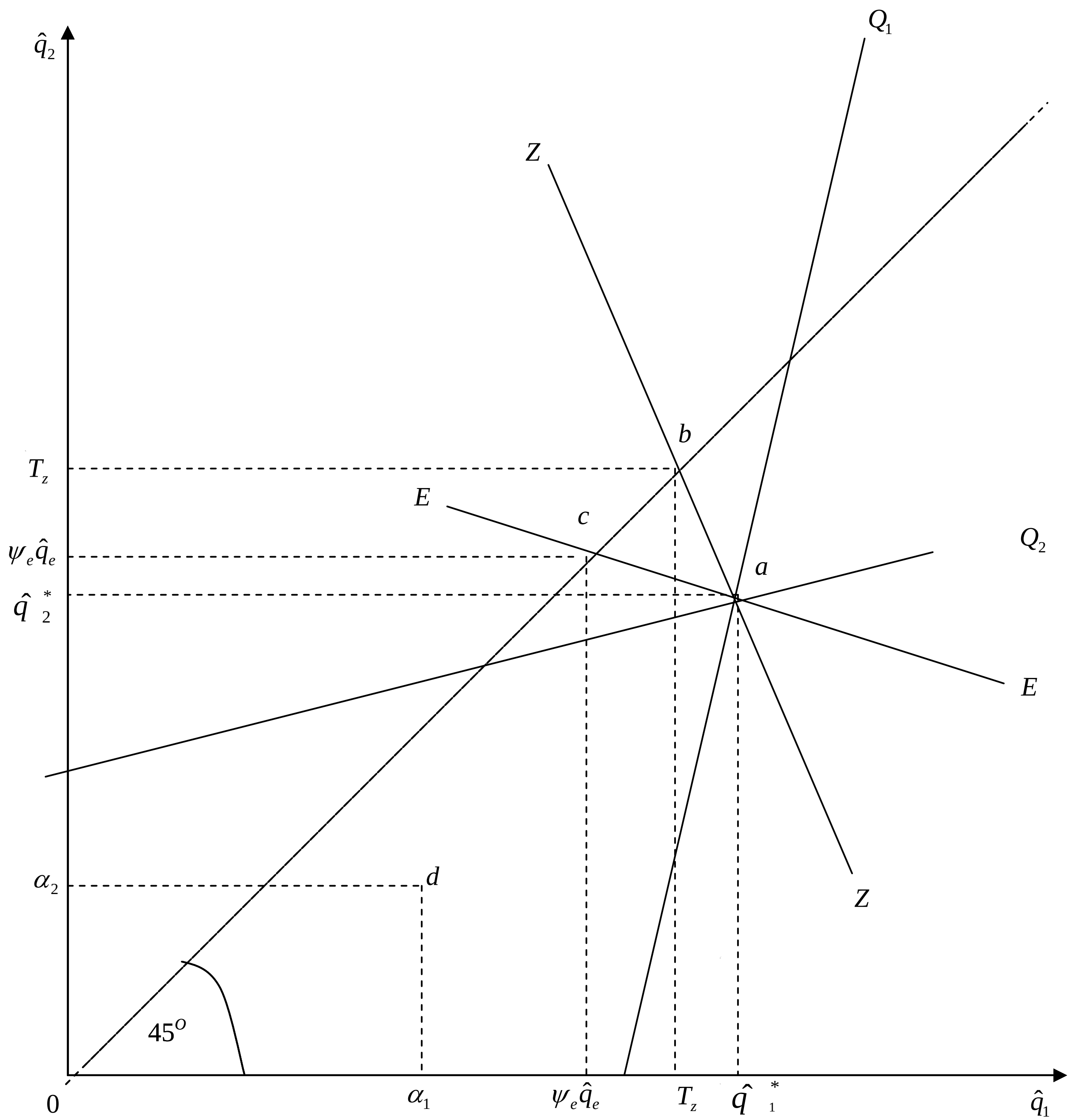

Figure 2

The Co-ordination of Aggregate Productivity Growth, Output Growth and Employment Growth