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Herr Schumpeter and the Classics

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1. Introduction

This paper is an exploration of the interface between two quite different strands of economic thought, the Schumpeterian, evolutionary theory of innovation and competition, and the classical, Sraffian theory of prices and distribution. Can the two methods usefully speak to each another? If they can, we would have in prospect a more general evolutionary economics (GEE) in which the classical emphasis on production of commodities by means of commodities would allow a far more sophisticated analysis of the place of technical change in economic development. Our understanding of the connection between innovation, competition, development and growth would be enhanced and sharpened. It might then follow that the classical long- period position, characterised by a uniform rate of profits within and between industries, would be a logical outcome of a process of evolutionary competition. To explore this question is decidedly not to propose a synthesis between classical and Schumpeterian economics; it is simply to enquire whether there are mutual lessons to be learned to enrich these very different approaches to the long period evolution of capitalist economies. Schumpeter's system is a system that is always out of equilibrium but it is not chaotic, rather it is a system strongly ordered by market forces and the ensuing relations between prices and profitability. Moreover, it is concerned with long-period market forces, that is to say the development of an economy in which innovation and investment to capitalise on innovation are dominant aspects of its working. The classical system is a long-period system of analysis too, and it has the great merit of working in terms of prices of production, those prices that enable the replication of the production process over time. Since much real world

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innovation is innovation in the produced means of production, within the network of inter-industry input-output relations, there are undoubtedly mutual lessons to be learnt.

This is not an idle exercise, for important economic questions are at stake. The modern, evolutionary and largely Schumpeterian theory of the competitive process places economic adaptation to innovation at the centre of its analysis (Nelson &Winter 1994, Metcalfe 1998, Downie, 1958). Yet, as Kurz (1998) pointed out, the evolutionary approach to competition has so far been developed largely within the confines of a single industry taken in isolation from the rest of the economy. It ignores the role of produced means of production and is, in its essential features, a combination of a Schumpeterian emphasis on the innovation-based differentiation of firms, and a Marshallian emphasis on partial methods of economic analysis. By contrast, the Sraffian theory of competition, prices and distribution explicitly deals with produced means of production and the economic interrelation between different industries, but under the implicit assumption that within each industry every firm is using the same methods of production[2]. This different emphasis on variety and uniformity in production methods connects directly with the two very different meanings of competition within these strands of thought. In the evolutionary view, competition is an out of- equilibrium process of resource reallocation within and between industries; it is a process that cannot operate in the presence of uniform methods of production and a necessary condition for its operation is the existence of differential pure profit. However, the classical concept of competition focuses attention upon the outcome of an unspecified process of allocating resources between different industries, an outcome that is characterised by a uniform rate of profits on invested capital across the economy, both within and between industries. The assumption of uniform methods of production within each industry is naturally

[2] Further elaboration may help at this point. Consider the numerical example of the "self-replacing" economy given in the very first section of Sraffa (1960), where Sraffa writes, 'There is a unique set of exchange-values which if adopted by the market restores the original distribution of the products *and makes it possible for the process to be repeated'* (p.3 emphasis added). Suppose, however, that in one of the two industries the various individual producers are not all using the same methods of production. Then, flukes aside, the exchange-values that Sraffa refers to will not lead each such producer to break even; some will make a positive profit and others a loss. Why should these latter decide to 'repeat the process'? Flukes apart, only the assumption of uniform methods of production makes 'repetition' plausible. (Note that, except when they discuss land, rent, royalties etc., Kurz and Salvadori (1995) always assume that, in each industry, every producer has unrestricted access to the most profitable method of production.)

essential for this outcome to be possible. In short, the evolutionary method investigates intra industry heterogeneity and a competitive process, the classical method investigates inter industry heterogeneity and a competitive outcome. Is there any common ground?

Our task is made more tractable by a recent paper by Kurz (2008), who explores the interface between Schumpeter's theory of development and the classical theory of competition by introducing innovation into a Sraffian model of inter industry pricing and distribution. He shows with great clarity how the possibility of a process innovation "invading" the existing economic order depends on the prevailing pattern of prices and distribution of income, and how the successful innovation defines a new long period constellation of prices and the distribution of income between wages and profits, thus altering the terms on which future innovations may invade. Many valuable insights follow from his exposition but it contains, from a Schumpeterian perspective, a major omission. Kurz does not address the process of transition or adaptation, the process through which an innovation is absorbed into the prevailing economic system, nor does he address the shifts of resources in favour of new combinations that this implies. That an innovation is profitable at the ruling price system does not mean that it will displace automatically the prevailing methods of production. If it does displace them, it may do so at very different rates and we should have an economic understanding of why the process of adaptation is "fast" or "slow". It is not unreasonable to say that, perhaps for good reasons, Kurz sets aside a major part of the Schumpeterian problem by staying resolutely within the realm of comparing long-period positions. Yet, and importantly, the focus of Schumpeter's work is on the process of quantitative adaptation to innovation and on the coexistence of rival production methods within a given industry. This is necessarily an out-of-equilibrium story, and the associated process of adaptation of quantities as new methods replace old methods has to be explained: it cannot be arbitrarily treated as a "tendency" that works so "quickly" as to render the comparative method of analysis sufficient for our understanding. This is not to say that prices do not matter: quite the contrary, as we shall demonstrate, the rate of creative destruction depends on the ruling price system. The rate and direction of adaptation to the possibilities created by innovation are ordered by market processes, and the prices and distribution of income characteristic of a particular order have a powerful effect on the rate at which innovations transform an economy.

What general principles govern this process of quantitative adaptation to the potential imminent in any profitable innovation? They must relate to an economy which is by definition out of equilibrium, an economy in which production methods of different profitability coexist. This is where the linking of the classical and evolutionary perspectives helps greatly, for it brings to the forefront the central role of what evolutionists term “Fisher’s Principle”, the notion that the rate and direction of economic change are contingent upon the economic variety that exists in the system at each point in time. As we shall see, the central point about innovation is that it creates economic variety, while the process of adaptation works to destroy economic variety and, in so doing, exhausts the potential for evolution. Indeed, the classical long- period position is precisely a state of affairs where all the evolutionary potential in the economy has been destroyed.

We do not underestimate the challenge that the suggested mutual learning process represents to evolutionary and classical oriented economists. The treatment of innovation is unavoidably complicated in both perspectives. Economies that experience innovation are by definition in transitional states; their industries are populations of firms distinguished by different methods of production, industries that are engaged in a process of adapting to the prospects generated by innovation. Since we are dealing with out of equilibrium processes of adaptation, we are dealing with a changing economic order, and all that may imply in terms of expectations that turn out to have been ill-judged. Once we allow for expectation errors, we must admit that individuals may revise their view of the world and imagine and calculate new possibilities as a direct result of their participation in the development process. This is a familiar evolutionary theme: enterprise induces enterprise, each innovation distributes gains and losses across the system and the response to these distributional effects is often further innovation but we have no possible way of predicting the form and economic content of these induced events. The system is restless and unpredictable because the evolution of human thought and conjecture is restless and unpredictable, and there is no obvious method to handle this problem other than to impound the difficulties. This is what Marshall achieved with his long-period-normal method of analysis, tracing the path an economy would follow if investment plans were realised and the extra output that investment justifies could be sold without incurring losses. We too follow this long-period method.

Our immediate task is to build on Kurz's analysis by exploring the quantity adjustments that are the essence of Schumpeter's theory, the adjustments that he ultimately captured graphically in the concept of creative destruction. The essential point about creative destruction, as we shall see, is that the "new" methods compete away resources from the "old" methods- that is the nature of innovation induced economic development. Before turning to the details of this process it will help to provide a précis of Schumpeter's theory of innovation, competition and economic development in so far as these concepts relate to out-of-equilibrium processes.

2. Schumpeter's Theory of Profit, Competition and Development.

As is well known, the *Theory of Economic Development* contains a body of analysis that Schumpeter kept essentially unchanged throughout his life. The central theme is the process of economic transformation that is rendered possible by innovation, a process of resource reallocation and structural change which Schumpeter took to be the distinguishing feature of capitalism. While the concept of a stationary state, or equilibrium circular flow, might be a useful analytical device it could not, by its very nature, be equated to the capitalist system which, for Schumpeter, was a system premised on uneven change generated from within. Three ideas dominate this Schumpeterian perspective; the meaning of innovation, the nature of competition, and the transience of the pure profits that are generated by innovation. Let us take each one in turn.

Innovations are the events that write and rewrite the history of the economic system and every innovation involves the use of existing resources in a way hitherto untried. Innovations, therefore, are novelties that invade and destabilise the economy and they come in many different forms. While economists and management scholars tend to emphasise innovations in product and process technology, Schumpeter's treatment is far richer. It includes, for example, commercial innovations (a new trade route) and innovations in business organisation, as exemplified by large scale methods of organisation. In many cases the innovation, especially one might say the radical innovation, will be associated with a new individual entrepreneur and a new business but this is not essential to the argument: innovations may be introduced by an existing business where the entrepreneur already has resources at his disposal. In fact, in Schumpeter's account the possible forms of innovation are extremely rich but, in each case, the fundamental point is that we have a new combination of means of production, a new approach to the business in hand.

Competition is the process by which the innovations are absorbed into the economy; in this dynamic sense it does not occur in the circular flow. There history records only the economic responses to exogenous events, wars, bumper harvests, crop failures, adverse weather events etc but not development from within. We must presume that these exogenous events have been experienced many times in the past, that their repetition does not generate any new information on the working of the economy. This is the sense in which the circular flow the economy is in equilibrium; no new knowledge or conjecture arises to challenge the status quo, there is only the incubus of tradition and established practice. Whatever the circular flow describes, it is not the capitalism that Schumpeter sought to understand. For, capitalism is a process of endogenous creative destruction in which old economic methods are displaced by new economic methods in an unending sequence, such that the new are destined to become old in their turn. It is a process of transformation that absorbs the new whenever it is economically superior to the old. The innovation test, therefore, is an economic test, a profit test, not a technical or scientific one, which is, no doubt, why Schumpeter went to such great pains to separate acts of invention from acts of innovation. In his scheme, the development constraining process is innovation not invention.

Profit in Schumpeter's scheme is a measure of the economic advantage that an innovation holds over established practices; innovations create an excess of price over cost where none previously existed. The existence of above normal returns is a primary measure of the scope and scale of development in an economy; profits provide the evidence that competition is taking place between old and new methods. But innovation-based profits are transitory, they are "the child and victim of development" (*TED*, p.154). No business can normally offer its shareholders a perpetual stream of high returns, for, in his colourful imagery, "No industrial company of the type indicated gratifies its shareholders with a constant shower of gold: on the contrary it soon declines into a stage that has the most lamentable similarity with the drying up of a spring" (*TED*, p.209). The transient nature of profits is evidence of the adaptation of the economy to the possibilities latent in any innovation.

Schumpeter never spelt out in any detail how this process of adaptation occurs. The primary response appears to be one of imitation; the innovator's profits signal to others the opportunities associated with the new combination and they "copy" the innovator. The rate at which this occurs depends on the distribution of business capacity in the population. According to Schumpeter the capacity of individuals in a particular economy to recognise and respond to innovation opportunities follows a "bell curve", and only a small number of individuals possess the will to action necessary to lead the economy into new paths of development. But as they demonstrate the possibilities, the less venturesome follow, first as individuals and then in crowds, and the rising cumulative total of adopters of an innovation makes it yet easier for the least venturesome to follow too. It is a "swarm of induced imitation" which brings the new method into general use, competes away the excess profits of the innovator and establishes a new price system, and those businesses that do not adapt are driven from the market. The psychology of the entrepreneur is undoubtedly an issue of great importance in any economy. But Schumpeter's reliance on a prevailing distribution of business psychology leaves a gap in our economic understanding of the rate at which an economy adapts to the innovations generated within it. Not only do we have no insight into the investment processes that it entails but we also miss an account of how imitators may even improve the innovation in the process.

These are the main elements of the Schumpeterian scheme but there is one further aspect that needs brief comment, the fact that the innovations occur in the context of a monetary economy. In the timeless equilibrium of a circular flow, money is the traditional veil, simply a convenient method of accounting for and tracking the pattern of economic life with no real consequences for the allocation of resources. When we come to development the picture is quite different. The system of credit, banks and the money market, is the essential means by which an entrepreneur (the purest form of which is the business promoter who is neither inventor nor manager) gains access to the means of production necessary to turn an invention into a business reality. Not only innovation but the rate of imitation too depends on access to bank credit if an old business needs to borrow in order to adopt the new technology. Hence Schumpeter's striking statement that the banks and money market are "the headquarters of the capitalist system" (*TED*, p.126); they are the instituted means to direct the economy to new paths. In *Business Cycles* this account is further refined with a distinction drawn between retail and investment banking, and the importance of having well informed disinterested bankers, able to judge accurately the prospective merits of proposed innovations, is made clear. Banks are the gatekeepers of the development process; they provide the credit by which the entrepreneur can bid resources away from established uses at all stages of the process. Once a firm has adopted the innovation it is making profits, and so it has the internal command over means of production to grow without the further assistance of the banks. This then is the differentiating role of the banks, to initiate development through the promotion of innovation. The interplay between innovation and differentiation of business plans, credit and profit is the defining feature of Schumpeter's theory of competition. It is a process of disequilibrium adaptation, not an equilibrium state of affairs.

In order to bring out the essential aspects of economic evolution in a long period context we shall work in terms of a single commodity economy, eschewing the presence of multiple industries. We capture the idea of production of commodities by means of commodities by allowing the single commodity to be used as an input. Nevertheless, this simplification is at the cost of losing sight of some issues that are important in relation to the dynamics of adaptation to innovation. The extension of the analysis to multiple, interdependent industries will be much more straightforward once this more elementary case is clear. Of course, it is difficult to fully comprehend Schumpeter's account of the development process without taking account of its monetary foundations but for the moment we set this aside, a one commodity economy not really being the context in which to introduce bank money in any meaningful sense. Yet, the one commodity framework allows us to set out clearly the principles behind the adaptation of an economy to innovation and the crucial role played by the innovator's profits.

3. A One Commodity Production System

Consider a single commodity economy, one that begins in a classical long-period position, with perfect markets (not to be equated with perfect competition), a uniform real wage and a uniform rate of interest[3]. All producers are using the same constant returns to scale production methods and the system operates as a stationary circular flow, reproducing itself exactly year by year. The dual purpose commodity (it is consumed as well as invested) is produced with inputs of homogeneous labour and of itself. Production takes one time period (a notional year) from the commitment of resources to the realisation of output, and the cost of the material capital is advanced but wages are paid *ex post factum*. Aggregate consumption is equal to the wage bill plus interest on capital invested. Saving and net investment are zero and no firm earns a profit over and above interest.

The technology is defined by the coefficient pair, (a,e), where a is the input of the commodity per unit of output, and e is the input of labour per unit of output. Given our long-period assumption, the real wage must be such as to allow each firm to exactly break even at the ruling rate of interest; so the real wage, w, and the rate of interest must satisfy the relation

$$1 = a(1+i) + we \qquad (1)$$

This relation defines the wage-interest frontier for this economy. It also defines the unit cost of production in real terms, which we denote by, h. We shall assume that the rate of interest is exogenously given.[4] A committed Schumpeterian might insist that the interest rate is zero in this stationary circular flow but nothing is gained or lost by this stipulation.

Consider now the quantities used and produced. Total employment is, $L = eQ$, where aggregate output, Q, is equal to aggregate consumption, C, plus gross investment, aQ. Aggregate consumption is equal to net output, so

[3] By a perfect market we mean a market where all participants are fully informed as to the terms of trade and the nature of what is traded and can trade without restriction. Costs of trading set aside, all trades will necessarily take place on the same terms. Perfect competition, of course, requires much more; moreover, a perfect market can just as well characterise a state of monopoly supply. The distinction is well drawn in Stigler (1957).

[4] For this system to be viable it is necessary that the interest factor $(1+i)$ is less than $1/a$, the output: capital ratio

$$C = weQ + iaQ = (1-a)Q \qquad (2)$$

It follows that the output of the commodity is equal to the aggregate demand for the commodity (consumption plus gross investment), whatever the scale of production. Since scale is indeterminate, at the level of the individual producer and at the level of the aggregate economy, we simply take the initial value of manufacturing output and its initial distribution between different producers as given.

Innovation

This normal circular flow of activity is disturbed by an innovation, introduced by one of the firms. We take it that this firm accounts for a "small" share of total output in the economy, although nothing of substance hangs on this assumption. This entrepreneurial event, the variation, entails the discovery of a new way of organising the production process. As with Schumpeter, we shall call this innovating firm the "new" firm to distinguish it from the non-innovating "old" firms. The new technical coefficients are denoted by $a*$ and $e*$. The innovation is viable if it has lower real costs of production, so, strictly speaking, we need only one of these coefficients to be smaller compared to the old technology; the other coefficient can be greater provided that the innovation implies lower costs of production overall. Unit cost with the new technology is defined by, $h^* = we^* + (1+i)a^* \prec h = 1$. In order to focus solely on the process of investing in the innovation, we assume that the innovator is able to keep this improvement in production methods a "secret" so there is no question of imitation by the old firms[5].

It may help to represent the relation between the old and new methods of production in a familiar form of diagram, Figure 1. On the vertical axis we measure the real wage, w and on the horizontal axis the interest factor, $(1+i)$. The old method is represented by the wage-interest frontier, labelled F_1, showing all the combinations of the real wage and interest factor at which the firms using the old method break even. At the ruling rate of interest, i_0, the corresponding real wage is w_0. The

[5] In Kurz (2008), by contrast, it is via a presumed process of imitation that the innovation diffuses through the economy.

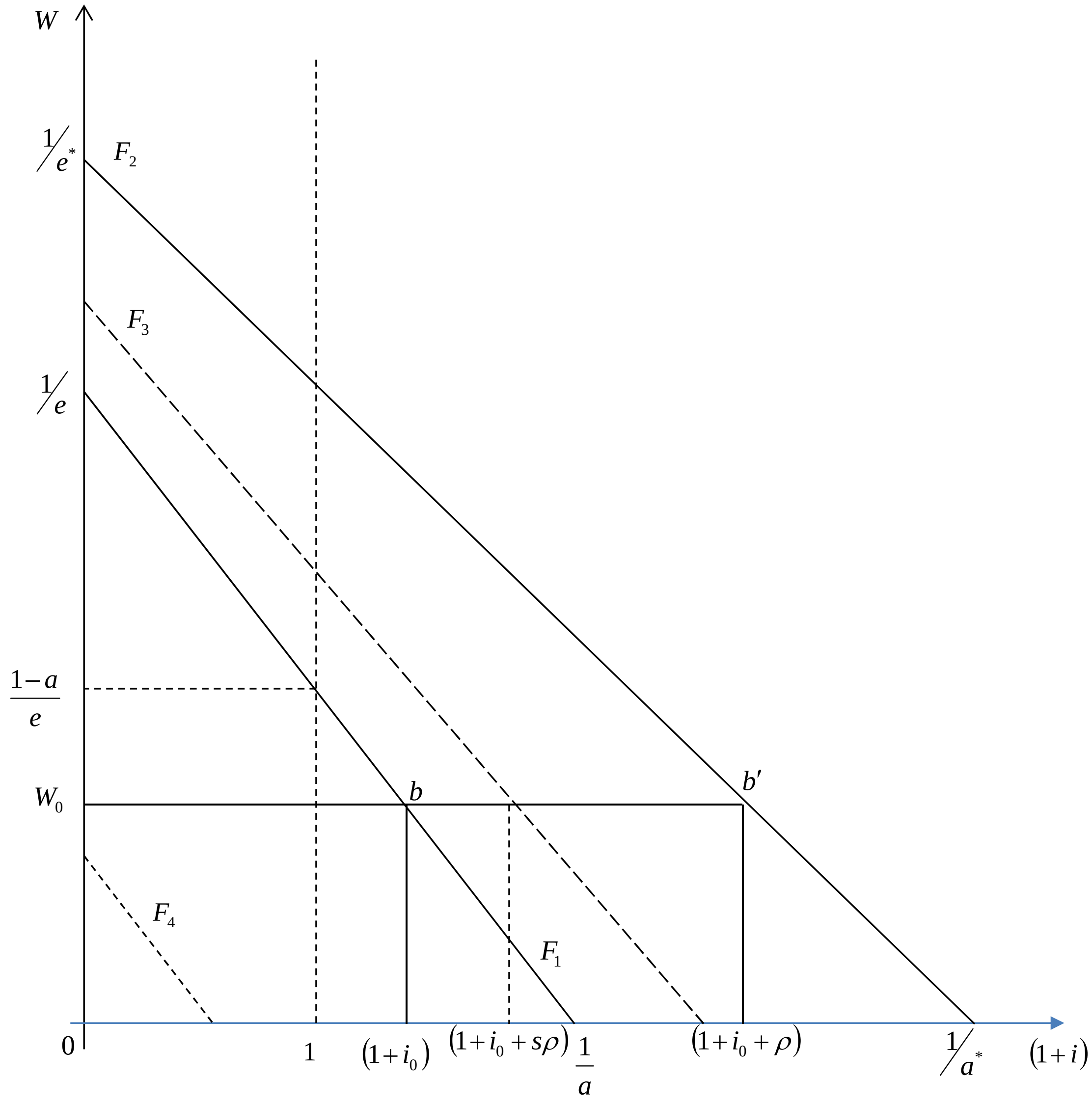

FIGURE 1

innovation is represented by the new frontier, labelled, F_2 which shows the corresponding real wage- interest rate combinations when the innovation has completely displaced the old method of production. It lies strictly above the old frontier because we have here assumed that the new method uses smaller quantities of both inputs to produce a unit of output. Consequently it is economically superior to the old method at all possible levels of the real wage.

However, as long as even one of the old firms continue in production at the given rate of interest, the price system necessarily remains that appropriate to the old methods and at these prices the innovation generates a positive pure profit. At the ruling real wage, w_0, the new method returns a rate of interest i_0 on the capital invested and makes a surplus (excess) profit at a rate per unit of capital invested of ρ. This rate of excess profits at the "old" prices is measured by the horizontal distance, $b - b'$. Not all inventions may make a transition to innovation, as indicated by the frontier, F_4, which corresponds to an invention that is not viable at any real wage. As Kurz has rightly emphasised, the superior profitability of any invention is not a matter of technique alone but depends additionally upon the economic environment in which it is to be adopted, the environment which in our case is fully captured by the prevailing price structure. Indeed, as an aside, Schumpeter held the view that less than one tenth of the possible inventions would be likely at any time to become profitable innovations (*BC*, Vol1, p.97)

Comparing the properties of different methods of production is one thing, establishing a process by which the one displaces the other is a quite different matter. Yet without such an understanding, however rudimentary, we have no prospect of addressing key aspects of a process of creative destruction. The fundamental point is that the new technology is more profitable, and thus more likely to displace the old technology, only to the degree that the price system remains the one associated with the old technology. Only when the new technology has completely displaced the old methods will the price system take on the characteristics made possible by using the new technology, and at that point the basis for the innovator's profit will have disappeared. Our approach to this problem is deliberately rudimentary. The innovator and its rivals differ only in their profitability, and the differences in profitability depend only on differences in the respective methods of production. This one dimensional take on the evolutionary process serves our immediate purpose but it will not do as a general statement of the variation cum selection dynamic[6]. How might one proceed?

The Adaptation Process

To begin we must pay careful attention to the timing of particular events. The discovery, (the invention we might say) is made in the "middle" of period, t, so the earliest that this new understanding can be acted on (the innovation) is the beginning

[6] We explore the more general case in appendix 1.

of period, $t+1$. This is when the discovery is put into practice, when it becomes an innovation. How does the innovating firm adapt to the new possibilities? There is no one, inevitable answer to this question. It could keep output constant and reduce the use of both inputs, or it could keep one of the inputs constant, but not generally both. We shall assume, for convenience, that in period, $t+1$, the innovator maintains the same level of gross investment as it did before the innovation but nothing of substance depends on this particular formulation of the initial step in the innovation process.

We now have a meaningful population of firms; a “two sector” economy with the two sectors “old” and “new”, differentiated by their production methods. Let the output of the innovating firm be x, and the total output of the old rivals be X, so that $X + x = Q$ (Henceforth, we shall indicate physical quantities associated with the new firm by lower case letters and those of the aggregate of old firms by upper case letters). Since gross investment by the innovator is the same as in the previous period, the output produced at the end of this period using the innovation will be equal to

$$x(t+1) = \frac{a}{a*} x(t) \qquad (3)$$

The immediate change in output depends only on the degree of “capital-saving” associated with the innovation, and not on the other characteristics of the innovation. Thus it is perfectly possible (with a capital using innovation) that the first period output is smaller than it was with the old technology. It then follows that employment in the innovating firm in this first period may rise or fall or stay constant, depending on the bias of the new process between “labour-saving” and “capital –saving”.[7]

It is important to remember that the innovation does not as yet have any effect on the configuration of prices in the economy, and that this will be so for as long as some output is produced by the old firms. If these old firms are to break even, the real wage must continue to satisfy relation (1) at the ruling rate of interest. In the long period normal method of analysis we do not allow any firm to make losses and continue in production; this is one of the method’s defining attributes. Thus the price system continues to be determined (at the given rate of interest) by the method of the old producers, and, as Schumpeter made clear, the continued existence of the old

[77] By “labour saving” we mean that $e^*/e \prec a^*/a$, and conversely for “capital saving”

method is the basis for the profitability of the innovator[8]. Using the "new" method at the prices generated by the "old" method, the innovator makes a profit per unit of output of, π, which is equal to the unit cost reduction associated with the innovation. Thus,

$$\pi = h - h^* = (1+i)(a - a^*) + w(e - e^*) = (1-\omega)T_a + \omega T_e \qquad (4)$$

Here we define ω as the share of wages in total output before the innovation, and T_a and T_e as the rates of input saving technical progress associated with the innovation[9]. This profit per unit of output is realised at the end of the production period, $t+1$. If we define, ρ, as the rate of profits with the innovation, then $\pi = a^* \rho$.

Two different methods of production are now in use in the economy; their output-share-weighted average defines the wage interest frontier F_3 in Figure 1 which lies strictly between the old and the new frontiers, and which is converging on the new frontier with every increase in the share of the new firm in gross output. At the ruling real wage, w_0 the average method "pays" interest at rate i_0 and generates an economy–wide average rate of profits of $r \leq \rho$ [10]

What quantity changes are associated with the immediate impact of the innovation? Since the old firms are producing an unchanged flow of output, the change in the output of the innovator must be equal to any change in aggregate consumption, plus any change in inventories held by the innovator. A change in aggregate consumption can only result from a change in employment in the innovating firm, since, by assumption, it makes the same gross investment as it did before the innovation and thus consumption out of interest is unchanged. From (2)-(4), we can express this as,

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[8] We do not deny that the innovation may cause short-period turbulence and that the old producers may be temporarily faced with losses as a consequence. We only insist that they cannot remain in business in such a state and that the loss of production would eliminate the losses. To open up these problems is beyond our current task.

[9] We define these proportional rates of input saving as $T_a = \dfrac{a - a^*}{a}$ and $T_e = \dfrac{e - e^*}{e}$

[10] This "economy- wide" average profit rate is related to the innovator's profit rate by, $r = \dfrac{a^* x}{aX + a^* x} \cdot \rho = \dfrac{a^*}{\bar{a}} s\pi$. We define s as the share of the innovator in gross output so that $\bar{a} = sa^* + (1-s)a$ is the average unit capital requirement in the economy.

$$\Delta C = C(t+1) - C(t) = w[e^* x(t+1) - ex(t)] = w\left(\frac{ea}{a^*}\right)(T_a - T_e)x(t) \qquad (5)$$

The input-saving bias to the innovation determines the change in employment and consumption, conditional upon the pre-innovation output level of the innovating firm. Whereas the increase in the innovating firm's output depends only on the change in the "capital" coefficient, the change in aggregate consumption depends on both this and the change in the labour coefficient. To use a familiar terminology, Hicks neutrality leaves consumption (and employment) constant; Harrod neutrality reduces consumption and employment; and, Solow neutrality increases consumption and employment. If the change in consumption is zero then all of the increase in the output of the innovator accrues as unsold inventory owned by the innovating firm, and it is greater or less than this as consumption declines or increases relative to the pre innovation situation. This change in the innovator's inventory at the end of the period is exactly its profit from the innovation[11].

We can summarise the overall effect of the innovation in this first period of use in the following terms.

$$\begin{aligned} &\Delta X = 0; \\ &\Delta x \geq 0; \\ &\Delta C \geq\leq 0; \\ &\Delta L \geq\leq 0 \end{aligned} \qquad (6)$$

It is in the subsequent periods that the potential arises for wider consequences, all of which depend on the idea that Schumpeter's innovators are not simple hedonists, ready to sit back and enjoy the fruits of their good fortune in greater consumption. Indeed, if they were, that would be the end of the matter, the innovation would have no further effects on the economy and there would have been a localised, once for all change in an otherwise ongoing circular flow. No doubt, some of the innovator's profit may be taken in extra consumption but by far the more important impact arises from the desire of the innovator to expand and generate yet more profit.

[11] That is to say, by the requirement that the change in aggregate supply equals the change in aggregate demand, $\Delta x = x(t+1) - x(t) = \Delta C + \pi \cdot x(t+1)$. Substituting from (5) for the change in consumption, gives the change in inventory per unit of output as, $\Delta x - \Delta C = (h - h^*) \cdot x(t+1) = \pi \cdot x(t+1).$ From (4), we see that this is exactly the aggregate profit that is generated by the innovation at the prevailing prices.

We call this the Schumpeterian case, where the investment of the innovator's profits puts the system onto an entirely different evolutionary path, the concomitant of which is the growing relative and absolute importance of the innovation in the economy's production system.

How this works out depends on both the investment strategy of the innovator, and the constraints set on the growth of the innovator by the availability of labour (the single primary input in this economy). That is to say, it cannot be reduced to the nature of the innovation alone. Different assumptions will generate different paths of adaptation but, of the many possibilities, we shall begin with a particularly transparent special case based on the following assumptions:

- The innovator invests its entire profit in the expansion of the firm, so that $\rho = g$. This is not identical to the classical saving postulate because it applies to the innovating firm not the whole economy. Moreover, because all wage and interest income is consumed, it follows that net investment in the economy as a whole is exactly equal to the profits made by the innovator. It is, of course, suitably Schumpeterian to link investment in the innovation to the profits generated by that innovation.
- Unlimited supplies of labour are freely available to the new and old firms at the ruling real wage

The most important point to grasp about this case is that it represents the evolution of this economic system in an unconstrained way. Because labour is freely available and because there are no constraints on the new firm's net investment other than its profitability, it provides a case of pure adaptation to the potential for change associated with the innovation. This benchmark will help us to see more clearly the deeper logic by which the system adapts to the profit potential generated by the innovation. In the subsequent section we bring the analysis closer to Schumpeter's scheme by explicitly allowing an employment constraint to influence the process of adaptation.

Investment, Aggregate Demand and Adaptation.

We have already established the output and profits of the innovator at the end of period one, now we can work through how the economy evolves under the chosen assumptions. In period $t+2$ the total investment by the innovator is equal to the capital invested in the previous period, $k(t+1)$ plus the profits generated in that period, $\pi \cdot x(t+1)$. It follows that the output produced by the innovator in the second period is given by

$$a^* \cdot x(t+2) = k(t+2) = a^* \cdot x(t+1) + \pi \cdot x(t+1) \qquad (7a)$$

This expression immediately gives the compound growth rate of the innovator as

$$g = \frac{x(t+2) - x(t+1)}{x(t+1)} = \frac{\pi}{a^*} = \frac{h - h^*}{a^*} = \rho \succ 0 \qquad (7b)$$

The same investment rule applies in each subsequent period, so this growth rate will apply period by period as long as the unit profitability of the innovation remains constant. This growth rate naturally measures the growth rate of employment and the growth rate of invested capital in the innovating producer after the first period.

By contrast nothing has changed for the old firms. At the beginning of period $t+2$, they invest exactly the same as in period $t+1$, and they employ the same number of workers to produce the same output. Consequently, aggregate output at the end of the period has only increased by the extra production of the innovator, which is equal to $g \cdot x(t+1)$. If this extra output is to be sold at the prevailing prices then aggregate demand must also increase by the amount, $g \cdot x(t+1)$. Is this the case? Indeed it is. The aggregate net output of the second period will be exactly equal to the rate of consumption plus the profits of the innovator, which are reinvested in their entirety in the expansion of that firm[12]. This means that the innovator is expanding both relatively and absolutely, while the old firms maintain their output but decline in relative terms. From a quantity (but not a price viewpoint) the economy behaves as if it has two independent sectors, with all the growth occurring in the new sector. But this means that the economy as a whole is no longer stationary. Innovation has

[12] We can express this as follows:

$$(1-a) \cdot X(t+2) + (1-a^*) \cdot x(t+2) = C(t+2) + \pi \cdot x(t+2)$$

Consequently, there is exactly the right aggregate supply to meet the level of consumption and the investment by the innovator, given the unchanged level of output of the old firms.

induced growth at an economy average rate equal to $\Gamma(t+1) \equiv s(t) \cdot g$, where $s(t)$ is the share of the innovator at the beginning of period $(t+1)$ -the end of period t[13].

Now the sequence continues. In each subsequent period the new firm invests as before and makes a profit, while the old firms maintain their output and are able to sell their output at the end of the period and meet their contractual costs without making a loss. The innovator continues to expand at the same growth rate, g , employing ever more labour so that total employment is growing This sequence of events will continue indefinitely in the postulated conditions with the innovator producing an increasing fraction of the total output and accounting for an ever increasing share of total employment. Since the old firms can produce and cover their costs, the price system remains that appropriate to the old technology, and it is this price system that sustains the innovator's profits.

Fisher's Principle

The net result of this innovation-induced process of quantitative adaptation is ongoing structural change in this economy. Even though there is no further innovation, the process of structural change and adaptation to the one innovation will lead to a sustained change in the average input coefficients in the economy. This change in economic structure is being driven by the evolutionary potential created by the difference between the two production methods, and the *rate* at which this occurs is captured by one of the most fundamental theorems in evolutionary thought, namely Fisher's Principle. This is a theorem about the changing relative importance of the entities in a population; in this case the entities are the firms that are using different but given technologies after the date of the innovation. The core of Fisher's Principle is the general idea that the evolution of a population depends on the variety contained within it. That is to say, the direction in which the average characteristics of the population change and *the rate at which they change* are direct consequences of the differences between the members of the population in these particular characteristics. The understanding of the velocity of change is as important as the understanding of the direction of change. The Principle is a statistical principle that provides an integrated account of the direction and velocity of evolution in a population. In its

[13] Note that $\Gamma(t+1) = (X(t+1) - X(t))/X(t)$ to be consistent with the definition of g .

most general form we imagine the population is divided into sub-populations, or groups, such that the overall rate of change can be expressed as the sum of changes occurring within groups and changes occurring between groups. In our example, no question of within group change is involved, since the group of old firms is using the same method of production, and there is only one innovator to define a group of profitable firms. Thus we deal only with the between group aspects of Fisher's Principle[14].

The wider significance of this particular evolutionary method of dynamic analysis should not be obscured. It provides a general method of dynamic analysis that does not depend on the prior specification of some ultimate state of rest of the system in view. By contrast, a frequent approach in non-evolutionary economic dynamic theory is to specify some equilibrium state of rest for an economy and discuss the approach to that equilibrium in terms of a quite separately articulated dynamic process, one that is driven by the distance of the economy from that equilibrium position. The specification of the dynamic process is not part of the specification of the equilibrium position, so an inevitable discordance of approaches is involved. In the evolutionary approach, however, the process is expressed not in terms of the distance of the system from equilibrium, indeed no such equilibrium need exist. Rather it is expressed in terms of the prevailing distribution of the variety in the economy. It is a population based process, in which the change in the relative importance of each member of the population at a point in time depends on how that member's characteristics compare with the average of the characteristics within the whole population. Change depends on the state of the prevailing order, not on a comparison of that state with some hypothetical future order.

Returning to our specific framework, although the innovation has been a "one-off" event, the process of adapting to it generates a pattern of ongoing change in the average resource productivity in the economy. The Schumpeterian version of this process is that the competition made possible by the innovation is progressive; it increases the average efficiency with which resources are utilised by increasing the

[14] In the appendix we extend the analysis to cover within group evolution as well as between group evolution.

relative importance of the innovation in the production of total output. Is this true in our simple economy?

The broad principle can be most easily expressed by concentrating on the evolution of average unit costs in the economy (the inverse of total factor productivity at the given real wage), which at time z are defined by

$$\bar{h}(z) = s(z)h^* + (1 - s(z))h \qquad (8)$$

The evolution of this average is driven entirely by the change in the output share of the innovating firm, $s(z)$, and the change in the output share is driven by the different growth rates of the innovating and non-innovating firms. The general rule is that the output share of a firm increases whenever that firm grows faster than the average for the economy as a whole. Hence, in our simple case of two types of firm, it follows that on comparing two adjacent periods,

$$\Delta\bar{h} = \bar{h}(z) - \bar{h}(z-1) = [s(z) - s(z-1)](h^* - h) \qquad (9)$$

The rate at which this average is changing is proportional to the change in the innovator's output share between the two periods, which, as a matter of arithmetic, is equal to

$$\Delta s = s(z) - s(z-1) = s(z-1)\cdot\frac{g - \Gamma(z)}{1+\Gamma(z)} = s(z-1)\cdot\frac{(1-s(z-1))}{1+s(z-1)g}\cdot g \text{ ....(10)}$$

remembering that, in this particular case, the growth rate of the old firms is zero, so that $\Gamma(z) \equiv s(z-1)\cdot g$ [15]. In this very simple case, it follows trivially that the output share of the innovator is increasing over time, and that the aggregate growth rate of the economy is converging on the growth rate of the innovator[16].

It is the process of adapting the economy to the innovation that generates sustained economic growth, not the act of innovation *per se*, and this is a distinguishing aspect of Schumpeter's theory of development. Growth follows from structural change, and

[15] Since $\rho = g$ for the innovator, it follows that $\Gamma(z) = s(z)\rho$. The relation between the average growth rate and the average profit rate is given by $r(z) = a^*/\bar{a}\cdot\Gamma(z)$, so $r(z) \prec g$, throughout the adaptation process. The equality between profit rate and growth rate only holds for the innovating firm, not for the economy as a whole

[16] The implied difference equation for the innovator's share of total output is given by the formula $s(z) = s(z-1)\left[1 + \frac{(1-s(z-1))g}{1+s(z-1)g}\right] = \frac{s(z-1)(1+g)}{1+s(z-1)g}$. The share increases monotonically and approaches but never attains the value of unity as time tends to infinity.

structural change follows from competition between the rival technologies, a process that is necessarily uneven. There can be no question of Schumpeterian growth being a steady state process in which all activities in the economy expand at the same proportionate rate. Indeed, this is how Schumpeter's theory connects to the evolutionary approach, for the essence of the latter is always contained in an explanation of why growth rates differ.

It is not difficult to see that the process of structural change captured by (10) defines a path of diffusion for the new method of a kind that is widely discussed in the literature on technical change and technology substitution. In fact the new method displaces the old method, in relative terms, along a sigmoid curve that rises asymptotically to unity as time stretches into an indefinite future. But this curve is not the familiar logistic curve, precisely because the aggregate growth rate Γ is increasing over time. In fact it is rising less quickly than a logistic curve when they both start from the same initial market share for the new technology[17].

Relations (4), (8) and (10) provide a complete account of the development of the economy and the consequential change in average unit costs of production. Fisher's Principle will now uncover the deeper structure of this process. To begin it will help to define the statistics that capture the economic variety in this economy. These are the variances in unit labour costs and each input coefficient and the corresponding co-variance between the two input coefficients across the new and old firms. To simplify the notation, write, $s(z-1) = s$, the innovator's output share at the beginning of the period, then[18]

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[17] In fact, as we let the length of the production period contract to zero, the limiting process exactly follows a logistic curve defined by the equation, $\ln \frac{s(t)}{1-s(t)} = \int_0^t g dt$ .The innovator's growth rate is the rate determining constant for this adaptation process. The logistic process is deeply embedded in the process of structural change, even though the logistic process need not, in general, generate a logistic curve when plotted against time. On more general approaches to sigmoid growth curves see Richards (1959)

[18] By definition the variance, say of unit labour requirements, is $V_S(e) = \sum_k s_k (e_i - \bar{e})^2$ when there is any number (k) of alternative production methods. In our case we have only two rival methods, whence, $V_S(e) = s(e^* - \bar{e})^2 + (1-s)(e-\bar{e})^2$. The formula in the text follows by substituting for the population average, $\bar{e} = se^* + (1-s)e$. The same procedure establishes the other formulae.

,

$$V_S(a) = s(1-s)(a-a^*)^2 = s(1-s)(aT_a)^2,$$

$$V_S(e) = s(1-s)(e-e^*)^2 = s(1-s)(eT_e)^2$$

These two variances are necessarily positive and they define the underlying degree of statistical variation within the economy. We can further derive the covariance between the production coefficients as,

$$C_S(a,e) = s(1-s)(a-a^*)(e-e^*) = s(1-s)(eaT_eT_a)$$

and the corresponding variance in unit costs as,

$$V_S(h) = s(1-s)(h-h^*)^2$$

The three variances and are necessarily positive but the covariance may be positive, zero or negative depending on the particular factor bias of the innovation.[19]. Taking the familiar boundary cases, for example, the covariance is positive in the Hicks neutral case, and zero in the case of Harrod or Solow neutrality[20]. Notice also that, because there are only two technical alternatives, each statistic attains a maximum value when the innovator accounts for half the economy's output. They are increasing up to that point and declining after that point.

It follows from relations (9) and (10) and the definition of the innovator's growth rate that the change in average unit costs is equal to

$$\Delta\bar{h} = \frac{s(1-s)\cdot g}{1+s\cdot g}\cdot(h^*-h) = -\frac{s(1-s)}{1+s\cdot g}\cdot\frac{(h-h^*)^2}{a^*}$$

Taking account of the definition of the unit cost variance above, we can write this as

$$\Delta\bar{h} = -\frac{1}{a^*+s\pi}\cdot V_S(h) = -\frac{1}{a^*(1+s\rho)}\cdot V_S(h) = -\Omega(s)\cdot V_S(h) \quad (11)$$

There can be no ambiguity at all in this simple case of one-dimensional selection; evolutionary competition reduces average unit costs in the whole economy as long as there is any statistical variance in unit costs.

Notice very carefully that, in evolutionary analysis, the members of the population are not given equal significance but are weighed according to their relative importance in the population.

[19] The fact that $[C_S(a,e)]^2 = V_S(a)\cdot V_S(e) \geq 0$ does not, of course, imply that $C_S(a,e) \geq 0$

[20] In the Hicks neutral case, $T_e = T_a = T$.

However, the point is not simply the direction of change, which in this case is obvious *a priori*, but rather the rate at which change is occurring; this is the insight that is contained in Fisher's Principle. The rate at which it does so for a given unit cost variance, depends on the coefficient $\Omega(s)$, (we call it the selection coefficient) that translates the variance in unit costs into the decline in average unit costs. Clearly, a large variance need not imply a rapid rate of cost reduction if the selection coefficient is small, and conversely. Moreover, the selection coefficient is not a constant, it is falling over time and it is smaller the greater is the unit capital coefficient of the innovator and the greater is the profitability of the innovator. This latter effect follows because a greater innovator's profit rate implies a faster growth rate of the economy as a whole. This is a first indication of how a more general evolutionary approach generates different insights into the rate of adaptation to innovation. In most partial treatments of economic evolution the selection coefficient is treated as a constant[21].

To summarise, it is the variance that drives the evolutionary process and the selection coefficient that conditions its rate, given the variety in the system. Equation (11) is the appropriate form of the Fisher Principle in this simple economy and it provides a clear understanding of the factors that determine the pace of economic evolution. The fundamental evolutionary rule is that change is driven by variation but at a rate that is endogenously determined and variable.

Exactly the same principles that condition the evolution of average unit costs also condition the evolution of the average unit input coefficients in the economy but here the outcome is ambiguous in that one of the average input coefficients (but not both) may increase over time. To illustrate, consider the case of unit labour requirements, the average of which is defined at time z by

$$\bar{e}(z) = s(z)e^{*} + (1 - s(z))e \qquad (12a)$$

Using the same steps as we used for the change in average unit costs, it then follows that the change in this particular average is given by

[21] As the innovator's share tends towards but never reaches unity, so the selection coefficient tends to the limit given by $1/(a^{*}(1+\rho)$

$$\Delta\bar{e} = \Delta s(e - e^{*}) = -\Omega(s) \cdot C_S(e.h) \quad .$$
$$= -\Omega(s)\{w \cdot V_S(e) + (1+i) \cdot C_S(a,e)\} \qquad (12b)$$

In this formulation, $C_S(e,h)$ is the covariance between unit labour requirements and unit costs, which is equivalent to the expression in the bracket in (12b). This is the appropriate but different form of Fisher's Principle, and how unit labour requirements evolve, in direction and rate, depends on how they are correlated with unit costs. This correlation may be positive, zero or negative, as (12b) demonstrates. Unlike the straightforward case of average unit costs, the driver of the change in unit labour requirements is now the sum of variance and covariance terms, weighted by the real wage and the interest factor respectively, so that the evolution of average labour requirements also depends on the prevailing distribution of income and its support in the old method of production. The mere fact that the variance in (12b) is positive means that this statistic is always working to reduce average unit labour requirements but this is no longer the full picture. We have a covariance term to consider, and this covariance term between the two input coefficients may be negative. For this to be so the innovation has to be ultra-biased, one of the input coefficients associated with the innovation has to be sufficiently greater than with the old method. Absent this, the covariance is positive, and the competitive process must reduce average labour requirements, increase average labour productivity, in the system as a whole. As a special case, for example, if the innovation is Harrod neutral then the relation takes an even simpler form, in which the rate of improvement in the average is equal to

$$\Delta\bar{e} = -\Omega(s) \cdot w \cdot V_S(e) \qquad (12c)$$

While if there is Solow neutrality the average labour input coefficient is by definition constant.

By similar reasoning, the evolution of average capital requirements is given by

$$\Delta\bar{a} = -\Omega(s) \cdot C_S(a,h) = -\Omega(s)\{(1+i) \cdot V_S(e) + w \cdot C_S(a,e)\} \quad (13)$$

Exactly the same considerations bear on the evolution of this average as do for average unit labour requirements, and it may increase or decrease over time depending on the distribution of income, and the relative magnitude of the variance and covariance terms. If the innovation is Solow neutral, for example, the covariance term disappears, if it is Harrod neutral this input coefficient is, of course, constant at its pre innovation level.

We can complete the account of Fisher's Principle by considering the rate at which the average growth rate of output is changing, even though the growth rates of both the new and old firms are constant- another aspect of the non-steady nature of evolutionary growth. Thus we find that

$$\Delta\Gamma = \Gamma(t+z) - \Gamma(t+z-1) = \Delta s \cdot g = \Omega(s) \cdot V_S(g) \geq 0 \quad (14)$$

where the variance is the variance in the growth rates across the two groups of producers. This is the most basic and original form of Fisher's Principle; economic evolution works to increase the average growth rate of the system as a whole by increasing the relative importance of the production method with the highest growth rate- in evolutionary terms the technology of the fittest firm. In this way the economy average growth rate converges on the growth rate of the innovator. Indeed, on combining the two relations, we find that the variance of the growth rates is an income distribution weighted combination of the variances and covariances in the methods of production. Thus,

$$V_S(g) = s(1-s)g^2 = \frac{1}{a^{*2}}\left\{w^2 V_S(e) + (1+i)^2 V_S(a) + w(1+i)C_S(a,e)\right\} \quad (15a)$$

The term in the bracket is exactly the variance in unit costs across the population of firms, so that

$$V_S(g) = \frac{V_S(h)}{a^{*2}} \succ 0 \quad (15b)$$

Because the average coefficients for all these statistics are changing along with the relative output shares it follows that the corresponding variances and the covariance are also evolving. At whatever level of variation we choose, the rate of evolution is not constant but varies period by period[22]. Consequently, all the variances and covariance must decline toward zero and the rate of evolution slow down and effectively cease when the new firm accounts for all but a negligible quantity of the

[22] The rate of change of these second order statistics is proportional to the third order variation in the population and so on through progressively higher orders of statistical effect. These higher order effects are far better expressed in terms of the successive cumulants of the joint distribution of the two input coefficients

aggregate output. Evolution has virtually destroyed the economic variety on which evolution depends, at which stage the economy grows at a rate approximating the growth rate of the innovator.

Our assumptions have provided a very special and greatly simplified case of the quantitative dynamics of adaptation to innovation. The investment of the innovator's profits is the basis for this process, which is a very Schumpeterian approach. But in other respects our conclusions are distinctly non-Schumpeterian. What is the nature of and reason for this discrepancy?

The source of the difficulty is not the assumption that all the innovator's profits are ploughed back into expansion, for we can let a fraction of the profits be consumed and all that will happen is that the process of adaptation is slowed down. The innovator and the aggregate economy grow at a slower rate, aggregate consumption at each date is greater but in all other aspects the outcome is the same. In particular, the old firms continue to produce at their traditional rate. Rather the problem lies in assuming that the innovator can expand without constraint, other than its immediate profitability, and without affecting the absolute scale of output of the old firms. The case of an unlimited supply of labour is a deliberately chosen artificial case in which we have creative destruction in a relative but not absolute sense. By contrast, Schumpeter explicitly formulated his discussion in terms of innovation in an economy where resources are given and fully employed: that makes a considerable difference to the outcome.

4. A Fixed Supply of Labour

Consider then the case when the innovator continues to invest all its profits in expansion but the available, homogeneous labour supply is fixed and fully employed. Now it is only possible for the innovator to grow in a sustained way if labour is reallocated from the old firms, which means that they must contract absolutely. Here is a mechanism to fulfil the Schumpeterian claim that the growth of the innovator is at the expense of the non-innovating rivals. A case where, "the new combinations must draw the necessary means of production from some old combinations" (*TED*, p. 68)

How this takes place requires a little thought, especially in the context of a labour market in which all firms pay the same wage. If the innovating firm is to attract labour from the old firms it will, in general, have to offer a differential wage, relative to that offered by its rivals. How great this differential is will depend on the instituted nature of the labour market, the more resistant is labour to reallocate the greater must be the required wage differential and it is not difficult to see that any resistance to mobility must eat into the innovator's profit and slow down the process of adaptation.. However, if the labour market is "perfect" by which we mean that the workers are fully informed of different wage offers and are completely mobile then the innovator can attract the labour it needs by posting a wage at the beginning of each production period that is only minutely greater than that paid by its rivals. This has a negligibly small effect on its profitability, which we can and will neglect.[23].

There is a second difficulty to attend to. If the old firms lose labour between production periods they will be left with carried-over stocks of means of production ("capacity") that they can no longer employ at the beginning of the next production period We assume initially that they are freely disposed of or consumed by the owners of the old firms. We shall reconsider this assumption below.

Drawing these themes together, we start in period two when the economy is established on a path of adaptation, just as before. The innovator is growing at rate, $g = \pi / a^*$, which is also the growth rate of employment in the new firm. But now the extra employment in the new firm is drawn from the old firms, so they are in decline at a rate equal to $\Delta X = -e^* / e \cdot \Delta x$. The old firms are being out competed in their access to labour, just as Schumpeter required, and the decline of the "old" is proportional to the expansion of the "new", the factor of proportionality being the ratio of new to old unit labour requirements. Consequently, the aggregate rate of decline of the old firms, G, between any two time periods is[24]

[23] This is an acknowledged evasion of a deeper problem, the working of the labour market in an economy that is out of equilibrium. Pack and Nelson (2002), for example, assume that the innovator pays a fixed wage premium. We might alternatively assume that a firm must pay a higher wage than the average if it is to grow faster than the average for the economy. Our approach slides over these dynamic issues without, one hopes, greatly influencing our understanding of the adaptive process.
[24] Again we let $s(z-1) = s$ in order to simplify the notation.

$$G = -\frac{s}{(1-s)} \cdot \frac{e^*}{e} \cdot g \qquad (16)$$

Let Γ' be the corresponding average rate of growth of the employment constrained economy; then this is the weighted average of the new and old firm growth rates and is equal to

$$\Gamma' = s \cdot g \cdot \left(\frac{e - e^*}{e} \right) = \Gamma \left(\frac{e - e^*}{e} \right) = \Gamma \cdot T_e \qquad (17)$$

Compared to the case where labour is freely available, the average growth rate of the economy is smaller if the innovation is labour saving and negative if the innovation is labour using. The increased output of the innovator is either partially or more than offset by the reduced output of the old firms. This is indeed the core of Schumpeter's growth theory; without innovation there is no potential for growth, but the sustained growth comes from adapting the economy to the characteristics of the innovation within the constraints set by the availability of productive inputs.

It is now a straightforward matter to establish how the structure of the economy is changing, and how Fisher's Principle succinctly captures the process of adaptation to the potential generated by the innovation. By following the same reasoning that led to (10), but using (15) and (16) above, we find that, for this employment constrained process, the change in the output share of the innovator is

$$\Delta s = s \cdot \frac{g - \Gamma'}{1 + \Gamma'} = s(1-s) \cdot \frac{g - G}{1 + \Gamma'} = g \cdot s \left\{ \frac{1 - s \cdot T_e}{1 + g \cdot s \cdot T_e} \right\} \qquad (18)$$

On comparing (18) with (10) we find that the innovator's share in total output is increasing faster in the employment constrained economy[25]. This is exactly as one

[25] At date z, the innovator's share is given (compare fn.16) by

$$s(z) = \frac{s(0) \cdot T_e \cdot (1+g)^z}{1 + s(0) \cdot T_e \cdot g(1 + (1+g) + (1+g)^2 + \cdot + (1+g)^{z-1})} = \frac{s(0) \cdot T_e \cdot (1+g)^z}{1 + s(0) \cdot T_e \cdot ((1+g)^z - 1)}$$

In this expression $s(0)$ is the initial innovator's share. Notice that the share becomes "equal" to unity at a finite date $z = N$. But, more exactly, this termination date will be an integer only by fluke. Thus $(1+g)^N \prec \left[1 + \frac{1 - s(0)}{s(0)} \frac{e}{e^*} \right]$ is the condition for $s(N) \prec 1$. For example, if $s(0) = 0.1$, and would expect from first principles, the labour constraint leads to the output share of the innovator increasing more quickly even though the innovator's growth rate remains unchanged. There is effective Schumpeterian competition between the innovator and the old firms that leads to the absolute decline of the latter.

Once we know how the structure is evolving, it is a straightforward matter to derive the appropriate form of Fisher's Principle in the new context, and it will be sufficient to demonstrate this for the case of the change in average unit labour requirements. Following the same steps that lead to (11) we find that

$$\Delta\bar{h} = -\Omega'(s)\cdot V_S(h) \qquad (18a)$$

The logic is the same as it was with unlimited supplies of labour but the rate at which this average evolves for any given unit cost variance is greater than when labour was freely available. In the labour constrained case, the selection coefficient, Ω'_S is defined by

$$\Omega'(s) = \frac{1 - sT_e}{(1-s)(1+\Gamma')a^*} \succ \Omega(s) \qquad (18.b)$$

where Γ' is given by (17). Fisher's Principle holds just as before, the introduction of the employment constraint has not changed the role of the statistical variety in the system but it has changed the rate of adaptation to that variety. Consequently, the rate of decline of average unit costs is, greater for any given variance in unit costs in the presence of the labour constraint. As before, the selection coefficient varies with the share of the innovator in aggregate output but it also now depends on the rate of labour saving progress attributed to the innovation, as expressed by ratio of the new to the old labour input coefficients.

The reader can readily establish that the new selection coefficient applies to the change in the other averages as well. So, for example, the change in the average unit labour requirement becomes

$$\Delta\bar{e} = -\Omega'(s)\{w\cdot V_S(h) + (1+i)C_S(a,e)\}$$

$e^* = 0.9e$, then $(1+g)^N \prec 11$. Suppose that $g = 0.05$; then N lies between 49 and 50 years. If $g = 0.1$, it lies between 25 and 26 years.

with corresponding results for the changes in the average unit capital requirement and the average growth rate.

We now have a process of creative destruction much closer to Schumpeter's design, precisely because the employment constraint means that the growth of the new now requires the decline of the old. The process is profit driven and the resulting rate of adaptation is exactly governed by the statistical variety in the system. Innovation has created that variety and the economy responds to that variety in proportion to the profitability of the new method. But clearly this process will not continue indefinitely as it did in the unconstrained case.

At some point in time all the labour will have been attracted from the old firms and their output will have declined to zero. No further growth by the innovator is possible and this is also the point at which the profit of the innovator is extinguished[26]. Without the "protection" the old firms had afforded the innovator, the real wage now rises to absorb all of the excess returns attributable to the innovation and all the benefits of the innovation are realised, finally, by the labour force (the level w^* in Figure 1). Thus the price system becomes the price system appropriate to the new technology. Of course, the growth rate of the economy has also dropped to zero, the destruction of the variety in the system has exhausted this economy's evolutionary potential and with it the potential for growth. If growth is to continue, further innovations must occur; without them we have only a return to the stagnation of the circular flow, albeit at a higher level than before the innovation.

As soon as we admit the possibility of a stream of innovations we lose some of the apparent angularity of the process of transformation that is so stark in our example. Now we can think in terms of many firms coexisting in the economy and, in principle, each one may operate a different method of production, the product of it having innovated differently at some point in the history of the system. All the firms that are profitable are expanding absolutely in proportion to their profitability, the exception being the marginal, highest cost method firm, which is just breaking-even, not investing and being squeezed out of the industry as labour is reallocated to the

[26] This occurs at date N, as defined in the previous footnote.

more profitable firms. However, even if we assume that all the firms reinvest all of their profits in expansion it does not follow any longer that a profitable firm with lower unit costs per unit of output expands more quickly than a less profitable firm. Rather, what matters is unit costs per unit of capital invested and these depend not only on a firm's unit costs but on its unit capital requirements as well. The certainties of one dimensional selection disappear, and two firms with the same profitability per unit of output may grow at very different rates. At each point in time it remains the case that the price system is defined by the prevailing marginal method; when it disappears we have an increase in the real wage by the amount necessary to bring the next worst method into the state of marginality, and so the process continues with a gradually rising real wage and continued productivity growth, and this will continue as long as there is a variety of methods in the economy. As we show in appendix 1, Fisher's Principle applies in this case too but in a richer and more nuanced way. When innovation dries up, so does the scope for evolution and growth. If competition destroys variety then the lesson of the evolutionary perspective is that the continuation of evolution requires ongoing innovation. This is exactly why Schumpeter's theory is a highly original account of an endogenous process of growth. Without innovation there is no adaptation and no growth.

Conclusion

It is for the reader to judge the degree to which we have achieved any effective dialogue between the evolutionary and classical approaches to economic growth. Our framework is deliberately simplified, profit drives the evolutionary process and the source of the difference in profit is the difference in unit cost associated with the innovation. Even within our deliberately chosen simplified framework we have met two of our more narrowly defined objectives. (a) We have shown that the insights provided by Fisher's Principle are by no means confined to the study of single industries without produced means of production, using partial methods of analysis. The idea that the rate and direction of economic change is a product of the economic variety in the system and that this variety can be summarised in familiar statistical measures is a proposition of great generality, and provides a viable alternative to thinking about economic growth in terms of the behaviour of representative, that is to say, uniform, agents. (b) We have also demonstrated the deeper content of

Schumpeter's justly famous analysis of economic change. Economic growth is a product of uneven economic development, and the impulse that renders development feasible is always the occurrence of innovation in some form or other; one should not be too prescriptive as to its nature or content. Yet innovation in itself is not enough, it is too localised to bear much weight, what matters is not only the impulse that innovation brings but the adaptation of the economic system to the potential generated by the new ways of doing things. Schumpeter sensed this with his account of imitative behaviour spreading the innovation but it remained an account that ignored the central role of investment processes to build the capacity to exploit innovations[27]. This is the theme that we have explored, the theme that naturally depends on long-period methods of analysis, not to uncover the attributes of a never attained future but to understand the immediate transformative forces operating on an economy.

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[27] Imitation of Schumpeter's kind would certainly speed up our process of adaptation but we know of no convincing way to deal with this in economic terms. Models of the spread of information are certainly relevant but they lie in a non economic realm.

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Appendix 1

The analysis of Fisher's Principle in the text is based on a very simplified account of the way in which an economic system responds to the potential for change created by an innovation. It has been expressed in this way to bring out some essential features of the competitive process in a general evolutionary framework but much is missed by the simplification of a single innovator confronting a uniform group of existing producers. In this appendix we generalise the framework to allow for many firms each operating a different method of production, and indeed for more than one firm operating the same method of production. In this way we can add a treatment of evolution within a group of profitable producers to the analysis in the text which focused only on between group evolutionary effects. The differences between the producers are the result of a past sequence of innovation events which we take as a datum. Otherwise we stay within the framework of the text; in particular, the price system at any date is defined by the technology of the prevailing marginal producer(s).

We now have two groups of firms in the economy. A marginal group, with identical unit costs, h_0, ($h_0 = 1$, at the ruling real wage and interest rate), and a profitable group with $h_j \prec 1$, $j = 1,.........z$, with each firm making a profit per unit of output of π_j. What this profit is depends on the prevailing real wage and interest rate and the particular innovation that the firm is using. As in the text, each profitable firm invests its entire profit in the expansion of its capital stock, so that its growth rate is, $g_j = \rho_j = \pi_j / a_j$. This growth rate is equal to profitability per unit of capital invested, so that firms with different profitability per unit of output may have the same growth rate, and firms with the same profitability per unit of output may have different growth rates of output (and capital stocks).

The Evolution of the Profitable Group of Firms

We consider first the evolution of the profitable group of firms, the rate and direction of which is a direct consequence of the prevailing differences in their profitability per unit of capital invested. As in all evolutionary analysis of a variation-cum-selection kind, the way in which we aggregate the variables of interest is of paramount importance. Because the profitable firms differ in their capital coefficients, their shares in group output, s_j, are not equal to their shares in the corresponding capital stock of the group, k_j. If we define v_j as the output capital ratio of the firm $(v_j \cdot a_j = 1)$ then the relations between the two measures of population structure are given by

$$s_j = \frac{k_j \cdot v_j}{v_k} \quad \text{and} \quad k_j = \frac{a_j \cdot s_j}{a_s} \qquad \text{(A1)}$$

where, $v_K = \sum_1^z k_j \cdot v_j$ is the aggregate output capital ratio for the group of profitable firms and $a_S = \sum_1^z s_j \cdot a_j$ is the corresponding aggregate capital output ratio- of course, $a_S \cdot v_K = 1$.

By switching between these different weighting schemes we can often greatly simplify the exposition of Fisher's Principle.

Since the profitability of firm j is, $\pi_j = h_0 - h_j$, its growth rate is

$$g_j = \frac{h_0 - h_j}{a_j} = v_j (h_0 - h_j) \qquad \text{(A2)}$$

Costs per unit of capital ultimately discriminate between the rival firms and we can write these as

$$c_j = v_j \cdot h_j = w \cdot l_j + (1 + i)$$

where, l_j, is employment per unit of capital. If we now aggregate to find the group average cost per unit of capital then

$$c_K = \sum_1^z k_j \cdot c_j = w \cdot l_K + (1 + i)$$

and the costs per unit of capital are distributed around their population average as,

$$c_j - c_K = w \cdot (l_j - l_K) \qquad \text{(A3)}$$

It then follows that we can write the growth rate of each firm as

$$g_j = v_j \cdot h_0 - c_j$$

It further follows that the growth rate of the group capital stock is given by

$$g_K = \sum_1^z k_j (h_0 - h_j) v_j = v_K \sum s_j (h_0 - h_j) = v_K (h_0 - h_S) = v_K \cdot h_0 - c_K \qquad \text{(A4)}$$

That is to say it is equal to the average output capital ratio multiplied by the average profit margin within this group of firms, which is equivalent to revenue per unit of capital less costs per unit of capital.

Consequently, the growth rates of the firm's capital stocks are distributed around their population average according to the relation,

$$g_j - g_K = h_0 (v_j - v_K) + (c_j - c_K) \qquad \text{(A5)}$$

We should also note that since, $h_j = a_j \cdot c_j$, in the aggregate average costs per unit of output are equal to

$$h_S = \sum_1^z s_j \cdot a_j \cdot c_j = a_S \cdot c_K \qquad \text{(A6)}$$

Although the growth rate of each firm's capital stock is the same as the growth rate of its output, in the aggregate these two growth rates diverge and so the measures of aggregate capital productivity are also changing, even though each firm is operating with an unchanging method of production. Aggregating across the group of profitable firms, using (A1), it follows that the output growth rate $g_S = \sum_1^z s_j \cdot g_j$ is related to the capital stock growth rate $g_K = \sum_1^z k_j \cdot g_j$ by the relation,

$$g_S = \sum_1^z s_j \cdot g_j = \sum_1^z \frac{k_j \cdot v_j \cdot g_j}{v_K} = g_K + \frac{C_K(v,g)}{v_K} \qquad \text{(A7)}$$

So the two aggregate growth rates are only equal if the (k weighted) covariance between the growth rates and output capital ratios is zero

The change in the aggregate capital output ratio for the profitable group of firms between any two time periods is equal, using (A7), to

$$\frac{\Delta v_K}{v_K} = \left[\frac{g_S - g_K}{1+g_K}\right] = \frac{1}{1+g_K} \cdot \frac{C_K(v,g)}{v_K} \qquad \text{(A8)}$$

Moreover, it is a simple matter of definition that

$$\frac{\Delta a_S}{a_S} = \frac{-\Delta v_K}{v_K + \Delta v_K}$$

We can now work through the logic of Fisher's Principle to this group of profitable firms. The most straightforward application is to the evolution of average costs per unit of capital, c_K. How this evolves depends on the change over time in the pattern of capital shares, k_j. Between any two time periods these shares evolve according to the rule,

$$\Delta k_j = k_j \left[\frac{g_j - g_K}{1+g_K}\right]$$

which means (from A5) that

$$\Delta k_j = k_j \cdot \frac{h_0(v_j - v_K) + (c_K - c_j)}{1+g_K} \qquad \text{(A9)}$$

The change in the group average is then given by

$$\Delta c_K = \sum_1^z \Delta k_j \cdot c_j = \frac{-1}{1+g_K}\{V_K(c) - h_0 \cdot C_K(v,c)\} \qquad \text{(A10)}$$

As we found in the text, the change in the average can be expressed in terms of second order moments around that average. Because the firms differ in their capital productivity, it is not immediately obvious that competition within this group is necessarily working to reduce average costs per unit of capital. Indeed, since, $h_0 = 1$, average unit costs are declining in this group only if the variance in unit costs is greater than the covariance between unit costs and output capital ratios across the group. If this covariance is negative, average costs decline as a result of the evolutionary process. However, if this covariance is positive and greater than the variance, average costs per unit of capital may increase between the two periods. We can further simplify (A10), in ways that are instructive. For it follows from the definition of costs per unit of capital that the covariance between unit costs and the output capital ratios of the firms is equal to

$$C_K(v,c) = w \cdot C_K(v,l)$$

while the variance in costs per unit of capital is

$$V_K(c) = w^2 \cdot V_K(l)$$

On combining these results it follows that

$$\Delta c_K = \sum_1^z \Delta k_j \cdot c_j = \frac{-w}{1+g_K}\{w \cdot V_K(l) - h_0 \cdot C_K(v,l)\} \qquad \text{(A11)}$$

This is the appropriate form of Fisher's Principle in relation to this statistic, the familiar weighted combination of variances and covariances, taking explicit account of the distribution of income, as expressed through the real wage.

There is a an often instructive way of re-expressing this formula in terms of the slope of a least squares regression of the output capital ratio on the employment capital ratio. This regression coefficient is defined by

$$\beta_K(v,l) = \frac{C_K(v,l)}{V_K(l)}$$

Remembering that $h_0 = 1$, we can rewrite (A10) as

$$\Delta c_K = \sum_1^z \Delta k_j \cdot c_j = \frac{-w \cdot V_K(l)}{1+g_K}\{w - \beta_K(v.l)\} \qquad \text{(A12)}$$

Hence, the condition for competition to reduce group average costs per unit of capital is

$$\beta_K(v,l) \prec w$$

That is to say, the regression coefficient must be smaller in magnitude than the prevailing (positive) real wage per unit of labour employed.

By exactly similar arguments we can establish that the group average output capital ratio changes according to the relation

$$\Delta v_K = \sum_1^z \Delta k_j \cdot v_j = \frac{V_K(v)}{1+g_K}\{1 - w \cdot \psi_K(l,v)\} \qquad \text{(A13)}$$

where, $\psi_K(l,v)$ is the slope of the regression line between the employment output ratio as dependent variable and the output capital ratio. Once again, the direction of change in this population average is not obvious, *a priori*, it depends on the distribution of the input output coefficients across the population of firms and on the magnitude of the prevailing real wage. That the direction and the pace of evolution are dependent on the prevailing distribution of income is a recurring and important implication of this evolutionary approach.

Once we know the way in which average costs per unit of capital and the average output capital ratio change, it is straightforward to derive, for example, how average costs per unit of output evolve. Thus, it is simply a matter of the definition of the variables that

$$\frac{\Delta h_S}{h_S} = \frac{\Delta c_K}{c_K}\left(1+\frac{\Delta v_K}{v_K}\right)+\frac{\Delta v_K}{v_K}$$

Hence from (A12) and (A13) we derive how this population average changes as well.

Evolution in the Economy as a Whole

Having established how Fisher's Principle applies within the group of profitable firms, we can combine this treatment with the concomitant changes that occur in the marginal group of firms to give the total pattern of adaptation in the economy. Taking the case of the labour constrained economy to illustrate, it follows directly that the marginal firms as a group contract at a rate G that is determined, along the same lines as in the text, by the condition

$$G = -\frac{e_S}{e_0} \cdot g_S \cdot \frac{s}{1-s}$$

where, as before, s is the share of the profitable group of firms in the aggregate output of the whole economy. In this relation e_0 denotes unit labour requirements in the marginal firms and $e_S = \sum_1^z s_j e_j$ denotes average unit labour requirements within the group of profitable producers. The growth rate in the economy as a whole becomes

$$\Gamma'' = (1-s)\cdot G + s\cdot g_S = s\cdot g_S\left(\frac{e_0 - e_S}{e_0}\right) = s\cdot g_S \cdot T_e(s) \qquad \text{(A14)}$$

which may be compared directly with (17) of the text. Here though, $T_e(s)$ is the proportional difference between unit labour requirements in the marginal producers and the average of unit labour requirements across the group of profitable producers. It is an indicator of the average effects of all past innovations on labour efficiency.

The argument now follows familiar lines in terms of the evolution of the statistics for the whole economy. To illustrate, focus on average costs per unit of output, defined by $\bar{h} = s \cdot h_S + (1-s) \cdot h_0$. Between any two time periods this evolves as

$$\Delta\bar{h} = \Delta s \cdot (h_S - h_0) + s \cdot \Delta h_S \qquad \text{(A15)}$$

The first term on the right hand side corresponds to the effect discussed in the text. To this we must add the second term, which captures the fact that average cost in the profitable group is no longer a constant but is changing over time in the way discussed in the previous section. Of course, by definition, there is no evolution within the group of marginal producers.

The change in the aggregate output share of the profitable group then follows as

$$\Delta s = s \cdot \frac{g - \Gamma''}{1 + \Gamma''} = s \cdot g_S \left(1 - s \cdot \frac{e_0 - e_s}{e_0}\right) = \frac{s \cdot g_S \cdot (1 - s \cdot T_e(s))}{1 + s \cdot g_S \cdot T_e(s)}$$

which is a more complex replacement for (18) in the text. It can still be seen that Δs is non negative and tends to zero and that s tends to unity. The time path of s however may be quite complicated because g_S and $T_e(s)$ are now functions of s.

Now define $\bar{V}(h)$ as the economy-wide variance in the average unit costs across the two groups of firms, then it follows that, $\bar{V}(h) = s(1-s)(h_S - h_0)^2$. Taking account of the value of g_S from (A7) and combining these different elements gives the appropriate version of Fisher's Principle as

$$\Delta s(h_S - h_0) = -\Omega''(s)\left\{\bar{V}(h) + (h_0 - h_S) \cdot C_S(a, g)\right\} \qquad \text{(A16)}$$

where

$$\Omega''(s) = \frac{1 - s \cdot T_e(s)}{(1-s)(1+\Gamma'') \cdot a_S} \qquad \text{(A17)}$$

is the appropriate selection coefficient for this economy.

This is how Fisher's Principle works across the two groups of firms. The analogy with (19) of the text will be clear, which is hardly surprising since both are instantiations of the same process. The difference from the text is that we have a profitable group of innovator's, not a single innovator to contend with. It is this difference which generates the covariance term in (A16). Since this covariance depends on the endogenously determined distribution of growth rates in the profitable group of firms, it is worth reducing it to its primary elements. Thus by successive stages we establish that

$$C_S(a,g) = \frac{-C_K(v,g)}{v_K^2}$$

$$C_S(a,g) = \frac{-1}{v_K^2}\{h_0 \cdot V_K(v) + w \cdot C_K(l,v)\}$$

$$C_S(a,g) = \frac{-V_K(v)}{v_K^2}\{1 - w \cdot \psi_K(l,v)\}$$

We find the total change in average costs per unit of output by combining (A16) with the value of Δh_S that follows from the analysis in the previous section. Thus we have a complete picture of the evolution of this economy expressed in terms of changes between the groups and within the profitable group of producers. The same method can be applied to any other average defined over the two groups of producers. In every case, the direction and rate of economic change depend on the statistics of variety in the economy and on the prevailing distribution of income.

Reprise

Of course, the ruling price system changes in the course of evolution. Since the marginal group at any time is in absolute decline, a date will be reached at which the method of production which supports the current price system becomes extinct. At that date, and given the rate of interest, the real wage "jumps" to the value that creates a new group of marginal producers, firms that up until then had been profitable. By how much the wage increases depends on a comparison of the production methods of the new marginal group with those of the last group of producers rendered extinct. At the new real wage there will be a different distribution of profitability across the remaining firms, the general rule being that profitability is lowered more the greater the labour intensity of the particular producer. Moreover, the general decline in profitability may be accompanied by changes in the ranking of profitability across the firms. So the process continues, with labour progressively being reallocated in favour of the fastest growing firms and, with each successive extinction of a production method, the real wage increase by the amount necessary to create the next group of marginal producers. But this process of structural adaptation cannot continue indefinitely; once the penultimate group of marginal producers is extinguished evolution comes to an end, precisely because adaptation has eliminated all the variety in the economy. At this stage a classical long period position has been established with a uniform method of production for every viable producer. This is the more general Schumpeterian story of creative destruction of which the text is a simple special case. If the real wage is to continue to increase there must be a continuing stream of innovations to restore the potential for adaptation. Ongoing evolution is always a three stage process- variation, selection and the further development of variation.