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Accounting for economic evolution: Fitness and the population method

John Stanley Metcalfe

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Abstract The theme of this paper is the general population dynamics of evolutionary processes, and, in particular, a number of accounting concepts that are central to any understanding of evolutionary processes of the variation-cum-selection retention kind. A population perspective, for example, turns out to be crucial to the study of the competitive process in economic systems defined at the level of industries, sectors and markets. Business rivalry, underpinned by differential innovative activity, is the basis of the differential survival and growth of competing economic activities and the strategies deployed to create sustainable differences in competitive selection characteristics are at the core of the capitalist dynamic interpreted as an adaptive, evolutionary process. This kind of evolutionary argument is necessarily concerned with growth rate dynamics and the explanation of the diversity of growth rates across entities in a population. However, the following discussion does not provide any causal explanation of economic evolution in terms of the determinants of growth rate differences, rather it provides a bookkeeping scheme in which different causal theories may be set and compared. Growth dynamics and structural change are the two central features of variation/selection processes within populations and I explore them in terms of three themes: namely, Logistic Growth Accounting; Competition Accounting; and, the Price Theorem. The unifying theme that links all three is their relation to the population method in evolutionary theory.

Keywords Economic evolution · Economic fitness · Fisher-Price accounting

JEL Classification C00 · L10 · O10 · O40

J. S. Metcalfe (✉)
Manchester Institute of Innovation Research, The University of Manchester,
Harold Hankins Building, Oxford Road, Manchester M13 9PL, England, UK
e-mail: stan.metcalfe@manchester.ac.uk

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1 Introduction

The twin, general themes of this paper are quite abstract, namely the population dynamics of economic evolution and the related concept of economic fitness. My justification for this unworldly discussion is no more than the claim that an economic population containing suitably differentiated members turns out to be a fruitful way to approach the analysis of industrial and market dynamics, technological change, innovation and enterprise, competition and economic growth. Thus it connects ultimately, if remotely, with the central historical, economic question of how wealth is created from knowledge. It provides a route to the treatment of the adaptive consequences of economic novelties that no other method can yield, and provides an underpinning for the idea that what matters in explaining economic progress is not rationality alone but rationality in the context of differential behavior. Variation, as Marshall so famously put it, is the greatest source of progress, and it is ultimately to persistent entrepreneurial disagreement as to how economic activities should be conducted that we owe the remarkable increase in living standards since 1750.[1] Two issues thus dominate an evolutionary view of economic progress, the sources of innovative novelties in economic practice, and the adaptation of the economic system to the potential contained in those novelties.

Here I shall cover two of the foundational issues that relate to the economics of emergent novelty and economic adaptation. The first is the meaning to be attached to a concept of economic fitness. The second is the method of population accounting. Both are essential to the further development of an evolutionary economics of growth and development.[2] Modern capitalism is routinely understood as an instituted process for generating order, in economic activity but it is also a system for transforming that order and the interplay between self organization and self transformation cuts to the core of evolutionary thinking. Processes of structural change, of the creation and demise of activities are central to economic development as a process of 'becoming different'. Let me turn first to the notion of economic fitness.[3]

2 Economic evolution: Thinking fitness through

2.1 Activities and firms

What are the phenomena that an evolutionary approach to economics seeks to account for? In the broadest sense they include the development of the structure of the economy,

[1] Marshall (1920, p. 355).

[2] In modern evolutionary theory different concepts of development are applied to individuals and to populations, see Walsh (2003) for further elaboration. In economics, development also applies at different levels to firms, industries and economies. Generally speaking economic development means more than change and refers to cases of unbalanced growth in which activities expand at different rates while the set of activities is added to or subtracted from. My preference is to use the words 'development' and 'self transformation' interchangeably.

[3] From this viewpoint, business rivalry is the basis of the differential survival and growth of competing economic activities, and the strategies deployed (including co-operation with other organizations) to create sustainable competitive advantages are at the core of the capitalist dynamic interpreted as an adaptive, evolutionary process. See, for example, Lovas and Ghoshal (2000).

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the changing patterns of what is produced, including the appearance of new goods and services and the demise of existing ones, the changing allocation of resources, and the changing patterns of expenditure by firms and household consumers. The process of structural differentiation in how economic lives are lived is one of the primary signatures of the historical development of modern advanced economies and the proximate source of their ever increasing standards of living. It is a process shaped by the emergence of novelty, by the adaptation of production and expenditure patterns to that novelty, a process that operates at multiple levels from individual organizations to whole economies.

As we begin to unpack the idea of evolutionary agency we immediately become aware of the fundamental fact that economic evolution is not biological evolution for nothing exists in the economic world to correspond to the exact processes of biological inheritance, sexual reproduction and gene transmission over time. The genotype/phenotype dichotomy that plays such an important role in modern biological thought has no match in the economic world but the idea that evolution might occur in different, connected domains certainly does. Economic change is no less an evolutionary process driven by the fundamentals of variation selection and development of further variation even if it lacks a genetic counterpart. Like all evolutionary processes it depends on a functioning, integrated and continuing unit of evolutionary agency, and in capitalist economies that fundamental unit is an economic activity purposefully organized to produce a particular set of outputs with corresponding inputs. The spatiotemporal instantiation of this is a production site, a plant, establishment, office, whatever it may be. Moreover, organization presupposes purpose and so most but by no means all activities are operated by business units, that is to say by goal directed agencies that decide how the activity is to be designed and articulated to produce a certain good or service using particular resources in a particular way. Thus from a physical viewpoint, any activity is a transformation process operating on materials energy and information for a purpose and this purpose is usually conceived to be profit seeking over some appropriate time horizon; although any purpose that depends upon realized profit for its attainment is just as viable. Most activities can be equated with a single well defined class of closely related products and services such that we can approximate by associating each activity with a single homogeneous output. As an evolutionary agent a business unit has the attributes of an individual, it is an organized whole, it is 'born' and usually it will at some point 'die', and, quite crucially, it has the capacity to be different from any other business units with which it is competing. Birth and death are legal concepts in the first instance, the existence of the business being defined in terms of titles to dispose of certain resources. From an economic viewpoint, however, what matters in terms of survival is that over the relevant time horizon a business generates sufficient return to its owners for them to remain content to continue the activity as a coherent whole.

Where do firms fit into this scheme? In many cases, business unit and firm are one and the same, the typical small firm, but what is characteristic of the historical development of capitalism has been the emergence of firms that contain multiple business units, articulating different activities and serving multiple markets. Thus the firm is a broader category of entity than the business unit and the evolution of a firm is not the same as the evolution of its constituent business units. A business unit develops

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by changing the scale and location of its investments, building new plants, closing existing ones, and by changing the organization and technology of the activity it articulates so that it is the primary locus for application of product and process innovation. The parent firm develops in additional ways, primarily by changing the set of business units that it articulates, entering new areas of activity and departing existing ones, and by acquiring and disposing of business units. More grandly still, different firms may combine together through merger or acquisition by exchanging titles to resource ownership. These higher level organizing processes influence but are quite distinct from the articulation of particular activities to produce outputs and absorb resources. This suggests that there are different natural metrics for tracking economic evolution; one in terms of organizational units, the other in terms of the rate at which different activities, singly or in combination, are articulated.

2.2 Traits and performance characteristics

Whether we focus on a firm or a business unit much more is involved in determining their individuality than a legal title to dispose of resources. Action depends on knowledge and the fundamental source of business and firm differentiation lies in what ‘they know’ relative to their strategic objectives. Since the relevant knowledge is usually distributed across many specialized employees, organization is required in terms of a structured set of rules to establish the function and control of individual action in the business or firm. It is through this organized set of rules and human capabilities that we can draw an important distinction between the traits of a business unit or firm and its associated performance characteristics. The business traits are the practices that shape the operation of its activity relative to strategic purpose. They may be based on specific technologies, specific organizational rules, routines and structures such as, for example, information systems, and they necessarily reflect the employment of specific knowledgeable individuals. At the firm level the traits extend, in hierarchical fashion, to the overall organization of the several business units and the strategic perceptions and intent of the top management teams. Thus we define a business trait type as an organized, articulated bundle of practices designed to deploy the knowledge of the employees to meet specific goals. Some traits will be unique to the business or firm; others may be shared across firms, as when they use the same technologies, but whatever the set of traits the important point is that their mix, the trait type, will differ across different business units. When we speak of the development of a business unit we mean changes in its trait type the generic result of innovation in the practices or goals.[4]

Parallel to a concept of business traits is the concept of business performance characteristics, those dimensions of its activity that are the immediate and longer term determinants of its economic viability and growth. From the point of view of economic change it is the performance characteristics, not the underpinning trait bundles,

[4] The traits at business unit level will also be influenced by the controlling firm so that the mere exchange of business units between firms will influence their specific traits, not always to the good if our understanding of many mergers as failed marriages is correct.

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that are the operational dimension of business individuality, and it is the variations in economic performance that underpin the idea of fitness as an economic notion as we shall explore below. An evolutionary economic theory needs three distinct sets of performance characteristics, namely: the quality of the products and the methods of producing them, we call this the broad efficiency of the business; the ability to expand or contract the business to match the growth or decline in its market; and, the ability to innovate to change the nature of its activity. All three dimensions are essential to the process of economic evolution but they operate over different timescales with very different effects. In respect to all three dimensions it is to the underlying business traits that we turn to explain inter-business variation in performance characteristics.[5] Yet business units and firms are not infinitely adaptable, free as it were to position themselves anywhere in the economic design space. Strategy, the content and organization of rule bundles, and the knowledge of the employees certainly enable but they also constrain the performance and development of a business and its parent firm. The very factors that give firms and business units that continuity necessary if they are to act as functional evolutionary entities, also serve to strongly channel their innovative development and adaptive responses. It is this element of inertia, the constraining of development, often expressed in an inability to perceive the significance of shifts in the business environment, which plays such an important role in economic evolution and which conditions its creative destruction attributes. Because firms and businesses are necessarily adaptive only to a limited degree, a great deal of the process of adaptation in an economy falls on the changing relative importance of individual businesses. Thus populations of businesses contain far greater adaptive potential than do individual businesses. This is one of the chief evolutionary attributes of modern capitalism; adaptation within firms and businesses is at least matched in significance by market mediated adaptation between firms and their business units.

The reader may naturally be tempted to conjecture that a mapping from traits to performance characteristics plays a role here similar to the mapping between genome and phenome in biological evolution. This temptation should be resisted. Business traits do not evolve through reproductive processes, they are not transmitted over time in hereditary fashion, and it is extremely misleading to consider that they are. But this does not rule out the application of evolutionary ideas more generally, or prevent one separating the variation-cum-selection framework from its genetic roots. Evolution is not uniquely a biological concept; it is a general theory of change and development according to specified rules of causation.

2.3 Interaction and replication

So far we have explored the idea that what matters ultimately in economic evolution is the changing articulation of specific activities, and that this depends on the nature of the firms and business units that control and operate these activities for a purpose. Business units are the primary vessels of variation; they are the units on which the

5 The explanation is contingent on the business units operating in the same economic environment. See the three-step schema below.

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selection processes associated with a market economy operate. In recent literature the discussion of such variation-cum-selection processes has been augmented by the addition of two new concepts that have been used to expand the modern theory of evolution and to apply it to new domains. The new concepts define two distinct processes, replication and interaction, and different stylized entities, replicators and interactors (Dawkins 1986; Hull 1988; Harms 1996; Godfrey-Smith 2000; Nanay 2002; Gould 2002). The philosopher David Hull has described a replicator as 'an entity that passes on its structure largely intact in successive replications' and an interactor is 'an entity that interacts as a cohesive whole with its environment in such a way that this interaction *causes* replication to be differential' (1988, p. 408, my emphasis). What are we to make of these concepts in an economic context ?[6]

It should be clear from the above that business units certainly serve as interactors in a market process. Any business in the normal course of its operation trades with and exchanges information with customers and suppliers in a context in which its rivals are doing likewise, and it is these interactions that are at the core of the market selection process. It is this competitive process and the pattern of choices by individuals on both sides of the market that has the effect of causing rival business units to acquire or lose customers and suppliers differentially and is thus the immediate context for the transformation of a market order. Here a biological struggle for personal reproductive success plays no role and is replaced by a quite different struggle for a share in the total market and thus the total profit generated in a particular line of business. Interaction is fundamental; it is exactly what occurs in the market process and the purpose of an evolutionary economic theory is to spell out in detail the nature of that scheme of interaction.

While the concept of interaction is essential to any treatment of economic evolution the related concepts of a replicator and replication are far more problematic. The fundamental idea behind replication is the representation of a hereditary process that is equivalent to the making of more or less faithful copies of parent organizms. However, what might be being copied in the case of an activity, business unit or firm is not at all transparent. Certainly the continuity of the trait type is necessary to ensure the survival of a business as a cohesive whole but continuity does not imply replication. All that is required is that the trait type today must correlate with the trait type yesterday, not always identically but closely, as Winter (1963) pointed out many years ago.[7] A useful set of criteria for deciding when entity B is a copy of A is provided by Sterelny et al. (1996). A and B stand in a replicator relationship if A plays a causal role in producing B, if B contains information similar to and performs a similar function to A, and if B participates in a repetition of the process leading to C and so on. The important issue here is what is meant by a causal process of copying. Is there any context where we can say that an economic decision to produce a copy of something has occurred? There seem to be two possible candidates, one in relation to the copying of organization, and the other in relation to the articulation of an activity. Consider the investment

6 For related discussion see Hodgson and Knudsen (2004a).

7 In conducting evolutionary argument it is important to explain what does not change as well as that which does. Cf. Loasby (1991). For further discussion of routines interpreted as recurring action patterns see Cohen et al. (1996).

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process in a business as it adds to its productive capacity by building a sequence of plants identical to its existing plants. This surely merits the description of organized copying. The trait bundle applies to any new plant just as it does to the existing plant and so copying seems to have occurred. There is clear sense in which the business has replicated its traits into a new context and must train a new set of employees in the activation of these traits. This is replication by the Sterelny et al. test even though no vestige of biological reproduction is involved. What is copied, transmitted over time, and repeatedly used is the firm's knowledge and skill, scientific, technological, organizational and managerial, a set of templates to maintain its capability, in Nelson and Winter's (1982) terms the collectivity of routines. Extending the analogy, we can consider any expansion of capacity in any direction as a copying process, even though the copying processes might be of restricted scope, and cannot be expected to be perfect in the sense that we might expect favorable errors to persist while unfavorable errors are not repeated. Indeed, much managerial activity is associated with trial and error attempts to improve business performance. Modern business scholars recognize this fact and have proposed that we treat learning is an integral part of the modern capabilities perspective on the firm (Montgomery 1995; Foss and Knudsen 1996).[8]

Some warrant for the concept of the economic replication of organization follows from the above. However, if we delve a little deeper we must recognize that copying, in the capacity expansion sense, does not create a new business unit it simply expands the rate at which a given business can articulate its traits. Not replication but reproduction appears to be the issue at stake.[9] Moreover, what happens if copying goes into reverse? It is not at all clear that the negation of copying has any correspondence to the process of business contraction. Thus, it would seem that while interaction is an indispensable component of an evolutionary economics, the notion of replication as the analogue of biological copying is far more troublesome. What then might replace the notion of replication? Gould (2002, p. 611) has suggested the word 'plurification' or 'more-making' and this is surely helpful, provided that we can identify something of which more (or less) is made. Of what precisely is more being made economically? Certainly it is not more business units, for new entrants are not usually copies of existing business units. Neither more nor fewer economic individuals are created when a particular business grows or declines. Instead more-making corresponds to the rate at which activities are operated and to this degree a production line is similar to a photocopying device. More-making then involves two levels: more output, copies from a given activity, and more investment in the capacity of that activity to make copies. In each case it is the trait type which is being employed more intensively. This surely is the economic insight we need. When a business unit interacts with its environment, including its rivals, a causal process is set in motion in which the relative rates of increase of the outputs of the different rivals are mutually determined. Consequently, the future relative economic importance of the different trait types is biased and their composition may equally be said to evolve. In the Marshallian short run these

[8] Learning from experience, the incorporation and passing on of favorable practices as acquired behaviors which is characteristic of a Lamarkian process (Tuomi 1992; Laurent and Nightingale 2001). For further critical discussion see Hodgson and Knudsen (2004b).

[9] Correspondence with Michael Ghiselin on this point is gratefully acknowledged.

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processes utilize given capacities, in the long run they correspond to changing capacities including the economic demise of entire plants and businesses. Moreover, when a business unit or firm 'dies' its idiosyncratic trait bundle dies with it although any traits that it shared with other business units or firms will survive in that population. This is the sense in which economic evolution biases the overall composition of successive temporal populations of traits. It is the very stuff of economic evolution as any good economic history will testify (Landes 1998; Mokyr 1990, 2002).[10] This brings us inevitably to the deeply contested concept of fitness and its economic counterparts.

2.4 Fitness as differential growth

What fitness means in evolutionary terms has for long been disputed territory (Michod 1999; Brandon 1991) and the controversy shows little prospect of diminishing (Matthen and Ariew 2002, 2005; Bouchard and Rosenberg 2004; Ariew and Lewontin 2004). Moreover, the sense that fitness is a tautology remains alive and well, especially outside of the evolutionary community. Yet tautologies, relations true by the meaning of the terms they describe and relate to, are frequently very helpful in unpacking the content of multi-level theories of which variation-cum-selection based evolutionary theory is one. They serve as filing systems to place different concepts in the proper relation one with another. There is a tautological way of defining fitness and indeed the accounting which follows in Sect. 3 is, if it is correct, tautological. But this does not mean that fitness is intrinsically and only a tautology, far from it, it only means that we have to distinguish the expression and measure of fitness from the causes of fitness. From an economic viewpoint there are two obvious fitness candidates, viability, the economic survival of a business unit or firm, and the differential growth and decline of output, changing rates of more-making. It is obvious that fitness as differential more-making presupposes a concept of fitness in terms of viability. But viability is a static notion quite unsuited to bear the dynamic weight of evolutionary explanation.[11]

Because evolutionary economics is naturally growth economics, I focus on differential growth and decline as the expressions of fitness, recognizing that although the growth rates are scalar quantities derived from a common output metric, their causes will generally be multidimensional, interdependent and changing over time. I also interpret economic fitness in its Marshallian long period sense associated with the changing economic capacities of viable business units. But first we need to distinguish absolute fitness from relative or comparative fitness. By absolute fitness is meant the expansion or contraction over some given time interval of the capacity output of a particular business unit. This growth rate has some interest in its own right particularly in relation to how it varies over time but it is not what we need to capture evolution,

[10] As will the Financial Times and Wall St Journal!

[11] Alchian's (1951) famous exposition of economic evolution in terms of brute survival missed this point entirely. The same mistake was not made by Downie (1958) or Nelson and Winter (1982). Jack Downie was an English economist and civil servant who spelt out a coherent variation-cum-selection theory of competition and innovation, including a variant of Fisher's fundamental theorem in 1958. Sadly he died prematurely. See Nightingale (1998) for further discussion.

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for evolution is a matter of relative growth or decline. By relative fitness is meant the arithmetic difference between the absolute growth rates of two business units or collections of business units. One business unit is (relatively) fitter than another if its measure of more, making shows a greater geometric rate of increase, with the consequence that its relative importance in the population increases compared to the other. Notice the comparative nature of this statement it is the relative growth rates or relative ‘more-making’ that matter. Economic fitness in its most primitive form is relational, just as the idea of competition is relational. It can be thought of as a comparison of the differential growth rates of any pair of entities in a population including cases where one or both of the pair is itself a measure over groups of entities.[12] Indeed the standard expression of fitness in the replicator dynamics tradition establishes fitness by comparing the growth rate of an entity with the growth rate of the associated population average, the basis, as we shall see below, of the Fisher/Price evolutionary accounting scheme.

Several issues flow from this definition of fitness as comparative rate of increase. First, we note that fitness is a concept that can only arise in the context of the population approach to evolution. More directly, evolution always involves more than one entity. Here some further distinctions are necessary. By a population I simply mean a set of entities constituting an ensemble. By an evolutionary population I mean a set of entities whose changing relative importance in the set, however measured, is the caused outcome of specific selection and other processes. Thus the population of entities is interacting in such a way that the common causal processes to which they are subjected have the effect of generating changes in their relative measure, they are more-making at different rates. The consequence is that the population structure changes in such a way that it adapts to the logic of the selection process. It follows that a population of evolutionary populations is also an evolutionary population provided that it is acted upon by at least one causal process in common. If there is no such common process, then the ensemble is not an evolutionary population.[13] How does this work out in the economic context?

The obvious candidate for the status of an evolutionary population is an ensemble of business units that differ individually in terms of their behavioral traits, technology, organization, strategic purpose, but are members of an evolutionary population by virtue of being subjected to common, market selective processes operating on that population.[14] A usual requirement here is that their outputs compete closely in the choices of users so that the outputs are sold into the same market. Equally, however,

[12] I do not deny at all that other valid concepts of fitness can be constructed. Thus Bouchard and Rosenberg (2004) conceive of fitness as the answer to a design problem set by the environment (a relative design problem one should add) and call this ‘ecological fitness’. This concept is only connected remotely with the fitness concepts used below. From a viewpoint of analyzing business strategy this concept of ecological fitness merits further attention.

[13] A biological population is usually defined by the boundaries of reproductive processes, the basis of the species concept. This is another case where biology and economics diverge.

[14] Thus an economic evolutionary population is not any arbitrary collection of entities but an ensemble unified by the experience of a common environment. The thorny questions of the units of selection are covered up too hastily in this definition but space precludes further discussion. See Knudsen and Hodgson (2004) for further elaboration.

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the common processes could emanate from factor markets, if, for example, the business units drew on the same pool of labor or free capital. The notion of common selection pressure thus plays a dual role, as an inclusion criterion determining membership of the economic evolutionary population, and as a dynamic cause of the differential growth of its members. The relevant market forces causally influence the economic behavior of the business units, as evolutionary individuals, but individual responses alone do not define evolution. It is the comparative responses across different business units which allow us to say the population has evolved. This is the perspective which leads us below to identify population change as a statistical phenomenon within some common economic milieu. Notice that only one common causal process or force is required to define an evolutionary population in this sense. The individuals may be differentially subjected to other processes but they are still members of the evolutionary population defined by that shared market process. Thus, for example, a familiar model of international economic evolution would have business units in different countries selling their output competitively into a unified global market. At the same time the factor market environments for each country would be isolated and different (an argument about the limited mobility of factors relative to goods). The global goods market defines the evolutionary population, and the individual factor markets differentially affect the performance characteristics of the firms located within each country. To give two instances, steel firms in Brazil, South Korea and Holland are members of the same evolutionary population that defines the international steel industry, even though their national economic environments (tax regimes, wage rates, costs of capital) are very different. Conversely, Chinese restaurants active in these same countries are not members of the same evolutionary population despite the fact that as business units they will have much in common. They are members of the separate evolutionary populations, defined by local or regional markets between which there is little connection. The point is simple; any particular economic evolutionary population is identified by the presence of particular, common causal processes. Change the causal processes and you change the definition of the population.

2.5 The three-step schema

The relation between relative economic fitness and market processes is what a theory of economic evolution must uncover and in general this involves three steps:

- Step I. An account of the process of establishing a market order that generates prices and quantities for outputs and inputs such as to evaluate the operation of any business unit in terms of a revenue stream, a cost stream and, their difference, a profit stream.

Step I is the familiar stuff of economic theory, the establishment of a pattern of activities and a supporting price structure that is the outcome of deliberative choice in relation to the interaction between decisions to supply and decisions to demand particular commodities. Such a pattern of order, however it is established in its details, is essential to any claims about the rate and direction of change, for the fundamental fact is that economic evolution is premised on economic order. However, it is a

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characteristic of modern capitalism that the order changing processes are concentrated in business units and involve processes of investment and innovation. Thus we have:

- Step II. The difference between revenue and cost, the profit stream, provides the incentive and the wherewithal to attract capital to a business in order to grow its capacity to produce, and it is this capacity to produce that governs its long period ability to make more.

Step II underpins the fundamental evolutionary nature of capitalism as a restless system and highlights the link between investment and profitability as being of fundamental importance whether viewed in terms of incentives to grow the business or in terms of the flow of investible funds to facilitate that growth. Crucially, the investment–profit relationship will vary across different business units according to the relevant traits they possess, so there is no requirement that any business that is more profitable than average is also a business that invests more than average. By changing the pattern of long period supply these investment processes also lead to changes in the price structure and to revisions of the order defined in step I, it is a continually recursive process. Yet it does not exhaust the possibilities for economic evolution which are made vastly more powerful by the final step:

- Step III. The profit stream also provides the incentive and the wherewithal to invest in changing the traits and performance characteristics of the business through the adoption of new forms of organization, new models of business and new product and process technologies.

The fundamental effects of this step are written at large through modern economic history and crucially they provide the sources of renewal of variation that maintain the momentum of economic evolution. It is the innovation performance characteristics that condition the longer term development of the business and thus the degree to which its broad efficiency develops in comparison with that of its rivals. We certainly do not expect different businesses to innovate in the same way, for innovation is an expression of the creative side of entrepreneurial capacity and this is an expression of business imagination as much as it is an expression of anything else (Metcalfe 2006).

Given the controversial status of fitness in evolutionary biology some commentary will not be wasted. The first point of note is the connection between relative fitness and structural change. If business A is growing faster than business B, then A is expanding its market share relative to business B. Similarly, if A is growing faster than the average growth rate of its entire population then it is increasing its market share in the total output of the population. This is the significance of this notion of relative fitness, it links the transformation of the population to the processes that order that population, and it is essential to any claim that evolution is a dynamic process (Matthen and Ariew 2002, 2005). Does it make any sense to say that one set of business traits is fitter than another set? Yes it does, but only in a carefully crafted sense. Namely that the trait type of A as evaluated in step I to generate particular cost, revenue and profit streams, leads it to invest at a rate in step II which exceeds the corresponding rate for business B. There is yet a third level at which fitness might be elaborated, that of step III and the innovation process. We can readily define fitness in terms of comparative

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rates of innovation and just as readily recognize that fitness at this level will change the distribution of fitness at step II and step I. But this takes us into more difficult territory and it is set aside from here on so that we can focus on step II fitness as the long period differential rate of growth of output. Yet before doing so it is worth reiterating the logic of economic evolution as contained in steps I to III: business traits are evaluated by the market order to generate a distribution of performance characteristics the effect of which is to cause differential expansion (step II) and differential innovation (step III), such that the events in these later steps redefine the order at step I, back and forth in recursive fashion. Flux and order are part and parcel of the same economic logic, the logic of the competitive market process. It also follows from the three-step schema that the fitness of population members has a time dimension attached to it. A business unit or firm may exhibit high short run fitness as a result of its present strategies but low long period fitness if it fails to invest at the required rate or low secular fitness if it fails to adapt to innovations produced by rivals and eventually ceases to be viable. Fitness is relative to a particular dynamic problem of selection in the presence of variation, so it is not surprising that different temporal formulations of the evolutionary problem support different notions of fitness. Thus, any economic theory of fitness may also allow that the underpinning traits are altered endogenously by innovation or developmental processes, in part in response to the evolution of the population. Consequently, a complete account of the causes of fitness would allow that the conceptual fitness surface is not given but self-deforms as evolution takes place. Evolution is time-phased and not by selection alone.[15]

It should be clear by now that fitness, as we have defined it, is not a natural attribute of any business unit: it is a derived consequence of the market-based interaction between the traits of that business unit, the traits of all the other rival firms in the relevant population, and of the attributes of the market selection environment. Jointly these elements define a transmission process connecting the intra-population distribution of business unit traits and the corresponding distribution of fitness values. If the traits of any business unit are changed, the associated performance characteristics and fitness values of all the competing business units also change. Equally if the selection environment should 'value' the performance characteristics differently then the distribution of individual fitness will be readjusted. To this extent fitness is a contingent property distributed across a population, it is caused not causal. An evolutionary theory does not begin with fitness values, it deduces them from an underlying theoretical structure, and this dispenses with the tautology claim.

It is useful here to dwell on the distinction between sorting processes and selection processes elaborated by Vrba and Gould (1986). In a sorting process, the absolute growth rates are determined independently of one another even though they may vary individually over time. They are an internal property of the entities in question and do not reflect interaction between the entities in a common environment. Sorting through differential growth is also a population phenomenon but it is not an evolutionary population phenomenon as we have defined that term. In contrast, in an evolutionary population some shared causal process of interaction mutually determines the growth

[15] On the complementarity between selection and developmental processes see Walsh (2003).

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rates in a way that reflects the constellation of selective forces defining that population. The fitness values, absolute and relative, are simultaneously determined and this is the crucial difference with a sorting process. That is why the notion of interaction is so important in evolutionary theory. Fitness is contingently attached to each business unit in the same way that 'profit' is contingently attached to each business unit. So fitness is not an intrinsic property of any single member of the population, it is a predictable outcome of the selection based interaction between entities with different performance characteristics and thus different traits.

Finally, when interpreted in this way economic fitness theories have a number of important attributes. To begin, the traits of the business units are typically multi-dimensional, so the direction and rate of evolutionary change depends on the environmentally contingent relation between these traits and performance characteristics. Evolution is not only a matter of variation, it is a matter of correlation as well. Consequently, selection for some favorable characteristics/traits may entail selection against other deleterious characteristics/traits reflecting the nature of the trade-offs that the environment imposes; including trade-offs with characteristics/traits that are selectively neutral. Change the environment and the relevant trade-offs and patterns of correlation will change. Thus what the fitness notion does is to reduce the selection process to a common currency, fitness values are 'like, commensurable quantities' although the causal explanation of those values may, and usually will, depend on attributes of the entities that are fundamentally different. This is why fitness theories are naturally statistical in that they provide explanations of the variation over time in the moments and other summary statements of the state of a population (Horan 1995). This opens up a possible generalization of the economic fitness concept to include stochastic effects, small sample drift and bias, as well as causally deterministic elements. Moreover, we should allow that the very process of selection may change the performance characteristics of the different entities whenever selection is associated with positive or negative density-dependent effects. If there is negative feedback, selection will tend to eliminate differences in fitness between the members of the population resulting in their long period co-existence as equals. If there is positive feedback or even no feedback at all, then selection will almost certainly concentrate the population on a single 'winning' business unit type and related combination of performance characteristics (Witt 2003). Thus we meet the famous idea that selection destroys its own fuel (Lewontin 1974) and the corollary that evolution, if it is to continue, must be a three-stage process—variation, selection and on-going development of new variation (Foster and Metcalfe 2001). Economists would recognize these different states of feedback in terms of decreasing, constant and increasing returns with the possibility that the last may lock the population into a state that is protected by barriers to invasion. Nothing in this account requires fitness to be a solely deterministic but stochastic effects only matter when we have positive and thus irreversible feedback in the selection process, for then small chance events may have lasting effects on the evolutionary outcome.

It should be clear by now that evolutionary change in an economy can occur at different levels and in different domains. Thus, to paraphrase Sober, there is selection of the products and underlying activities and selection for the business units in which they are produced and thus selection for the traits and performance characteristics. Or, as

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originally stated, there is ‘selection of objects and selection for properties’. ‘Selection of’ relates to the effects of selection while ‘selection for’ relates to the causes of selection (1984, p. 100). In our case, the ‘causes’ are market processes feeding on the variation of business units and the ‘effects’ are the differential rates of expansion of the different activities. No wonder fitness is such a difficult concept.

Before moving to the next part of the paper, one final point is worth stating. It is that economic variation-cum-selection models open up the possibility of different kinds of dynamic explanation based on population analysis. In a typical, economic model, for example, the transient motion of some economic system will be described in terms of an approach to an invariant long run attractor, what we might term the distance from equilibrium method. Usually the explanation of the equilibrium position is quite separate from the explanation of the transitional dynamics so giving the theory a dual nature in which the dynamics are typically ad hoc, in the sense that they do not draw on the same explanatory factors as does the explanation of the equilibrium attractors. This type of dynamic argument faces a number of difficulties not least in conditions where the equilibrium is changing faster than the transitional adjustment dynamics can converge to it. This is particularly so if we abandon the restrictive assumption that the processes of transition have no effects on the postulated equilibria. In a proper evolutionary process this is not tenable.[16] By contrast, population thinking provides a different dynamic method, the distance from mean dynamic, in which the distribution of fitness values around the population average is causally related to the joint distribution of performance characteristics around their population means. In this method, the dynamics of the population system depend entirely on the changing variety and correlations that are contained within it and this variety is reflected in the evolution of the population structure. It is in this context that the empirical ubiquity of fat-tailed economic distributions of characteristics finds its evolutionary significance, for the more are fitness values distributed close to the population mean then the less the scope for the distance from mean dynamic to work. It is almost a truism but evolution takes place most sharply in the population tails, and the more a population is distributed in the tails then the greater is the scope for the distance from mean dynamic to work.

3 Evolutionary accounting

With these remarks in hand we can turn to our three exercises in fitness accounting.

3.1 Fitness accounting and the competitive process

The accounting concepts discussed here are naturally true by the meaning attached to the terms employed but this does not make them any less useful as devices for sorting out different ideas in relation to evolutionary dynamics. Indeed, once the

[16] I have explored this idea in some detail in relation to the idea of restless capitalism in which it is the internal, ongoing generation of knowledge that denies the possibility of equilibrium. See Metcalfe (2001) and Metcalfe and Ramlogan (2005) for further elaboration of the link between the evolution of knowledge and economic evolution.

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accounting concepts are clear it is a more straightforward matter to give an explanation of economic evolution in terms of cause and effect. The three accountings I describe have in common a concern with ‘population thinking’, to use the phrase coined by Ernst Mayr (1959), which is one of the central methods of evolutionary analysis. The sub-text is that a proper evolutionary accounting is essential to any understanding of the economics of creative destruction, and the ongoing process of self transformation that is the distinctive feature of economic development in modern capitalism.

For our first example of evolutionary accounting we consider the relation between the fitness of business units and processes of the entry and exit of businesses in a population. Fitness as an expression of competition is one of the central evolutionary ideas in economics but it is not the competition associated with equilibrium states that is involved but rather the creative destruction process driven by innovation and market selection. In this context, the population method is a remarkably general tool of analysis in that it provides an exhaustive way to account for all the competition related changes that occur in a population of economic activities over some time interval, say of length, Δt. In particular, it is a framework for understanding the developmental significance of the differential growth of activities, entry and exit, and causally linking those growth rate differences to the competitive characteristics of the members of a population. Let the population consist of a group of business units producing the same commodity and selling it to a single group of customers.[17] The output of this commodity is our measure of ‘more-making’; it provides the metric to trace changes in population structure in terms of the relative importance of the rival business units. Four processes exhaust the possibilities of economic change at the population level:

– Pure expansion or contraction of the activities of the continuing (surviving) firms that remain in the population over the interval, Δt, measured in terms of changes in the scale of output (activity) of each firm.
– Exit (death) of firms, alive in the population at the beginning of the interval Δt but departing the population within the interval.
– Entry (birth) of new firms in that population within the time interval, Δt.
– Recombination of firms through mergers and acquisitions and the converse the creation of new firms by fission processes in exiting firms.

To which we can add a fifth process acting on the developmental trajectories of the business units, namely

– Innovations (mutations) in the traits possessed by the continuing firms so that they vary individually between the initial and terminal dates defining the interval.

Any analysis of competitive selection conducted only in terms of the surviving firms alone will be quite unsatisfactory for it loses sight of extremely important processes in relation to the birth and death of firms, and more generally, the birth and death of entire economic activities. Innovation too in the surviving firms is an essential element in economic evolution, for it corresponds to a change in the characteristics of the entities and thus a change in the distribution of selective advantage in the population, and in

[17] See Metcalfe (1998) for a joint analysis of product and process differentiation.

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many cases it is coterminous with the entry of a new business unit or a new plant (Foster and Metcalfe 2000). Recombination and fission are particularly challenging notions. When two business units amalgamate, the performance characteristics of at least one of the partners will normally change so that the new business unit is not simply a linear combination of the old units, so here an element of innovation in the form of altered traits and performance characteristics is present. Similarly with fission, the new entities will normally have traits different from the parent business units.

We focus on the first three processes, growth (decline), entry and exit and how they modify the population structure, and introduce innovation in the next section. The first point to make is that an accounting for the number of business units is quite different from an accounting for their changing contributions to the total output of the population. It is the latter that matters for the evolution of the economic order not any changes in the number of business units. An analysis in terms of changes in the number of discrete organizations would be quite different. To establish this we consider our population over a given interval of time with the first census date, t, and the second, $t + \Delta t$. Let $X(t + \Delta t)$ and $X(t)$ be the aggregate output rates, the sum of the outputs of all the business units in the population at the beginning and the end of the census period. Define compound growth rates such that g is the growth rate of total activity, g_c is the growth rate of the activity of the continuing firms and g_e is the growth rate of the activity of the firms that exit during the interval. Thus, for example, $X_c(t + \Delta t) = X_c(t)\,(1 + g_c)$ defines the output profile of the surviving firms. Let $X_N(t + \Delta t)$ be the increment of output contributed by those firms that enter the population in the interval, Δt, and define the flow entry rate, n, such that $X_N(t + \Delta t) = n \cdot X(t + \Delta t)$. The business units that are 'alive' at the first date can now be divided into two groups, those that will continue to operate over the interval and those which will die and exit at some point before the second census date. Let c be the fraction of aggregate output at t that has been produced by those businesses which will survive and continue to operate over the interval. For the units that exit, let $X_e(t + \Delta t)$ be the aggregate output they contribute in the interval, whence, $X_e(t + \Delta t) = (1 - c) \cdot X(t)\,(1 + g_e)$.
It follows that

$$X(t + \Delta t) = X_c(t + \Delta t) + X_e(t + \Delta t) + X_N(t + \Delta t)$$

or

$$X(t + \Delta t) = X(t) \left\{ \frac{c\,(1 + g_c) + (1 - c)\,(1 + g_e)}{1 - n} \right\}$$

With a little substitution this becomes

$$\begin{aligned}(1 + g)\,(1 - n) &= c\,[1 + g_c] + (1 - c)\,(1 + g_c)\\ &= 1 + g_0 \end{aligned} \quad (1)$$

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where g_0 is the growth rate in the output of all the business units 'alive' at t, irrespective of whether or not they survive to $t + \Delta t$. If we eliminate the second order terms by letting Δt tend to zero, then this reduces to the expression $g = g_0 + n$.

We can explore further by defining an exit rate e analogous to the entry rate, n. Let the proportional change in the output flow rate of the exiting business units be defined by, $X_e(t + \Delta t) - X_e(t) = -e \cdot X(t + \Delta t)$, thus by elementary substitutions we find that[18]

$$(1 + g)(1 - n + e) = 1 + cg_c$$

Or, as a first order approximation[19]

$$g = cg_c + n - e \tag{2}$$

A special case of (2) provides a useful benchmark, it is one where the exiting firms cease operations exactly at the time the census period opens with the consequence that $X_e(t + \Delta t) = 0$.[20] Then, as the time interval tends to zero, the various growth rates are related by

$$g = g_c + n - e \tag{2$'$}$$

Thus g_c exceeds of falls short of g as the entry rate n is less than or greater than the exit rate e.

The relative fitness of the group of surviving firms is measured by $g_c - g$ so their relative importance in the population changes according to the relation

$$\frac{dc}{dt} = c\,(g_c - g) = (1 - c)\,g - n + e \tag{3}$$

This result is a simple example of the replicator dynamic principle to the effect that the population structure changes in accordance with the distribution of absolute growth rates relative to the population average growth rate.

Applying this principle, to the structure of the sub-population of surviving business units we find that

$$\frac{dc_i}{dt} = c_i\,(g_i - g_c) \tag{4}$$

where $g_c = \sum c_i g_i$ and $c_i = X_i(t)/X_c(t)$.[21]

18 It follows from the definitions above that $(1 - c)\,g_e = -e\,[1 + g]$. In the limit, $e = 1 - c$, when e is now defined as the limiting value of the exit rate as Δt tends to zero.

19 Equations (2) provides the necessary accounting relation between the growth rate of output at the population level, and the corresponding growth rates of the sub-populations of the continuing business units, the new entrant business units and the exiting counterparts.

20 This requires that $g_e = -1$ so that, $1 - c = e$.

21 The evolution of the shares in the total population, $s_i = X_i(t)/X(t)$ follow in similar fashion, noting that $s_i = c \cdot c_i$.

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These relations, like any accounting scheme, serve to provide a complete partitioning of the processes that describe the development of a population. They tie together the different kinds of competitive change and they also provide a frame in which to place competition in its developmental context. What we see through this population method is the fundamental evolutionary theme that the rate and direction of change is statistically contingent on the variety of fitness in the population. The structures of the populations change because the growth rates of the survivors are distributed around a population average growth rate and because the entry and exit rates differ. In short, population level development is an evolutionary process of displacement and replacement, a process of self transformation in which the population in question is transformed into something different. It is in this sense that competition is a regulator of development, a method of reallocating resources to different uses, a method for generating structural change. An economy can then be represented as a set of interdependent interacting populations of activities that utilize resources and the accounting method will apply at any level of disaggregation we choose. Developmental change is nested and we can focus the lens of population change according to the problem in hand.[22]

How does the recombination and fission of business units affect these relations? Not at all is the answer. If two business units merge they increase their weight (share in the aggregate output) in the population pro rata but that is all and conversely in the case of fission. If the characteristics of the new business are different from a linear combination of the characteristics of the two businesses pre merger, then this is akin to the effects of innovation and adds a further dimension to the analysis of population change but it does not alter the accounting relations as expressed above.

3.2 An example: accounting for competition and productivity growth

To put this scheme to work we apply it to the problem of productivity accounting in an industry (Metcalfe and Ramlogan 2006). We treat the industry as a population of business units and group the factors at work into 'selection related processes', defined in terms of the differential growth or decline of survivors and the elimination of exiting firms, and 'innovation related processes', defined in terms of new entrants and the innovation induced development of the characteristics of the surviving firms. Suppose that the characteristic in question is average unit labor input (the inverse of labor productivity) in this population of firms, labeled, z, and we want to know how the population average value, labeled, $\overline{z}$, changes over our time interval.

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

$$\overline{z}\,(t) = c\overline{z}_c\,(t) + (1-c)\,\overline{z}_e\,(t)$$

where, $\overline{z}_c\,(t) = \sum c_i\,(t)\,z_i\,(t)$ and $\overline{z}_e\,(t)$ is the average value of $z(t)$ for those entities that will exit over the interval Δt. Similarly, in relation to the 'innovation processes'

[22] On the micro–meso–macro distinction in evolutionary analysis, see Dopfer et al. (2004).

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$$\overline{z}\,(t+\Delta t) = (1-n)\,\overline{z}_c\,(t+\Delta t) + n\overline{z}_n\,(t+\Delta t)$$

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

$$\Delta\overline{z} = \overline{z}\,(t+\Delta t) - \overline{z}\,(t) = \Delta\overline{z}_c + n\,(\overline{z}_n\,(t+\Delta t) - \overline{z}_c\,(t+\Delta t)) \\ - (1-c)\,(\overline{z}_e\,(t) - \overline{z}_c\,(t)) \tag{5}$$

Expression (5) is a complete evolutionary accounting for the change in average population value of labor efficiency. On the right hand side, the first term is the combined effect of selection and innovation operating on the surviving firms, while the second and third terms respectively reflect the productivity levels in entrants and exits, expressed as deviations from the average productivity value for the continuing entities at the appropriate dates.[23] If we now focus on the first term, the innovation and selection term, this takes us to the second of our accounting topics.

3.3 The Price equation

Here we consider the so called Price equation for decomposing the change in some population average into component parts. This is by now a well known result in evolutionary population analysis (Price 1970; Frank 1998; Metcalfe 1998; Gintis 2002; Page and Nowack 2002; Andersen 2004; Knudsen 2004). Indeed, evolutionary economists have developed a rich set of explanations of economic growth that fit within this framework (Metcalfe 1998; Witt 2003; Nelson and Winter 2002; Dosi 2000).

It is a general method for decomposing the change in average value of some population characteristic into two additive effects, one due to selection the other due to innovation. Thus, following a proper accounting of our productivity change example at the two dates, we find

$$\begin{aligned}\Delta\overline{z}_c &= \sum c_i\,(t+\Delta t)\,z_i\,(t+\Delta t) - \sum c_i\,(t)\,z_i\,(t)\\ &= \sum \Delta c_i z_i\,(t) + \sum c_i\,(t+\Delta t)\,\Delta z_i\\ &= \frac{1}{1+g_c}\left\{\sum c_i\,(t)\,(g_i - g_c)\cdot z_i\,(t) + \sum c_i\,(t)\,(1+g_i)\,\Delta z_i\right\}\end{aligned}$$

or

$$(1+g_c)\,\frac{\Delta\overline{z}_c}{\Delta t} = C_c\,(g_i z_i) + E_c\left((1+g_i)\cdot\frac{\Delta z_i}{\Delta t}\right) \tag{6}$$

[23] The same decomposition, or a variant of it, has been used extensively in recent empirical work demonstrating the importance of selection for productivity growth (Carlin et al. 2001; Bailey et al. 1992; Bartelsman and Doms 2000). This empirical literature provides striking empirical verification of the dynamic nature of competition and of the importance of distinguishing selection of activities in plants from selection of firms. Its conclusions are deeply dependent, of course, on access to finely disaggregated micro data, since aggregation always masks evolution.

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Using relations (1) to incorporate entry and exit effects we can re-express this version of the Price equation as

$$(1+g)\,\frac{\Delta \bar{z}_c}{\Delta t} = \left(\frac{1-e}{1-n}\right)\left(C_c\left(g_i z_i\right) + E_c\left((1+g_i)\cdot\frac{\Delta z_i}{\Delta t}\right)\right). \tag{7}$$

Expression (7) is the Price equation for this problem of productivity growth, adjusted to account for entry and exit, in which, $C_c\left(g_i z_i\right)$, the measure of the selection effect, is the (c_i weighted) covariance between fitness values (the growth rates g_i) and the values of z_i at the initial census date. This captures the idea that the change in the average value of the characteristic depends on how that characteristic co-varies with growth rates across the population; in short, that evolution is a matter of correlation. The second term, $E_c\left((1+g_i)\cdot \Delta z_i\right)$, the measure of the innovation effect, is the expected value (again c_i weighted) between the growth rates and the changes in the efficiency values at the level of each firm. Notice the recursive nature of this formulation; for if the entities are also defined as sub populations of further entities we can apply the Price equation successively to each sub population. For example, if entity i itself consists of a sub-population of j entities we can apply the Price method and write

$$(1+g_{ii})\,\frac{\Delta \bar{z}_{ii}}{\Delta t} = C_{cj}\left(g_{ij},\ z_{ij}\right) + E_{cj}\left(\left(1+g_{ij}\right)\frac{\Delta z_{ij}}{\Delta t}\right)$$

and apply this to each of the i entities in the higher population. As Andersen (2004) suggests, the Price equation 'eats its own tail', an attribute of considerable significance in the analysis of multi-level evolutionary processes. It means that we can decompose population change into change between any number of sub-populations and change within sub-populations in an identical fashion, so that at each level of aggregation we can reflect the forces of adaptation whether through selection or innovation. Since these relations are accounting relations they are compatible with any theory of evolutionary change that combines together the principles of variation, selection and innovation. Yet innovation is fundamental for it creates the variety (including entry) on which selection depends and the ensuing process reshapes the conditions for further innovation to replenish variation. It is a population rather than an individual type of explanation but one that is based on the specifics of individual variation (Matthen and Ariew 2002).

The discussion in the previous paragraph also bears on the notorious group selection controversy, in which an individual entity is claimed not to be the only possible unit of selection and higher level group effects are said to operate. Formally speaking this is straightforward. Imagine the population to be divided into a series of business groups, in the process establishing for each group a mean value of the characteristic, z. Then using the Price decomposition we can partition the covariance term in (8) into two components, namely the covariance between group fitness and group average values of z and the weighted average value of the within group covariances between the

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individual fitness and character values.[24] The first of these effects is called the group selection effect in this literature, and only occurs if the mean characteristics vary across the groups. However, this group accounting method is not without its problems. If the groups are formed at random, for example, there is no reason to identify a group effect, for the partitioning adds no new information over and above that contained in the whole population of individuals. Yet the group population means may vary and give the appearance of a group effect where none exists. What is needed to justify group selection is some causally efficacious principle that provides a meaningful set of groupings in economic evolutionary terms. For then membership of a group has an effect on the traits and performance characteristics of individual businesses and changing one's business group changes one's traits and performance characteristics. The key point is not that the fitness values within the group are interdependent, for that is the meaning of selection; rather it is that some of the traits underpinning fitness are mutually and uniquely determined within the group.[25] Whatever, there is every reason not to dismiss group effects in economic evolution but only if they can be given a precise causal role in determining variation across business units.

3.4 A special case: Fisher's fundamental theorem

Finally, one special application of (7) is when the characteristic z_i is taken to be the growth rate g_i for; in this case we find that

$$(1+g_c)\,\frac{\Delta g_c}{\Delta t} = V_c\,(g_i) + E_c\left((1+g_i)\,\frac{\Delta g_i}{\Delta t}\right) \tag{8}$$

where $V_c\,(g_i)$ is the variance in the growth rates within the population of continuing entities. The first term on the right is a selection effect known as Fisher's Fundamental Theorem, after its originator, the distinguished biologist and statistician R. A. Fisher (1930). It captures one of the central doctrines of variation-cum-selection theory that selection has the effect of increasing average fitness in the population. Too much should not be made of it in this specific context. It is a direct consequence of defining the growth rates as we have, and it captures only the selection part of the evolution of the average growth rate. However, its significance lies in its being a very special case of a much wider principle, Fisher's Principle (Metcalfe 1998), namely that the statistical

[24] See Okashi (2004a,b) for elaboration and further references to the use of the Price decomposition in group selection analysis. The relation between the Price equation and group selection is discussed more fully in Sober and Wilson (1998), chap. 2.

[25] There is a compelling case to be made that group effects are analogous to externalities in which the behavior of each group member carries implications for the fitness of the other group members. One might conjecture, for example, that Marshallian external economies could be formulated in terms of group selection, the literature on industrial districts being an obvious candidate. More generally, when firms in an industry group agree to jointly fund marketing or research and development or to freely exchange technical information in order to gain a competitive advantage over rival groups, then, this too may serve as a basis for group selection. They sacrifice of resources that can contribute to their own fitness with the effect of creating a superior market of technology from which they all benefit.

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variability within the population accounts for the rate and direction of evolutionary change—the variation-cum-selection view of population development.[26]

3.5 Logistic accounting

The importance of the Fisher Price methods in accounting for the development of a population lie in the fact that they link structural change to relative fitness and through these structural changes create a pattern of evolution in the population. What creates the changes in population moments is precisely the changing pattern of relative importance of the different entities, as measured in the examples above by the relative market shares of the different business units. Our last task is to show that behind the dynamics of population change there is a logistic process which captures the pattern of structural change and links it to the trajectory of relative fitness. We show that the logistic process is a deep, general signature of an evolutionary process within populations that are governed by a variation-cum-selection dynamic. However, a logistic process need not normally generate the familiar '*S*' shaped logistic curve expressed as a function of time, indeed it may be associated with non-monotonic time profiles, quite non-logistic profiles, for the changing relative importance of many of the entities in a population. The logistic process has a degree of generality that the logistic curve does not possess and it mirrors the distance from mean dynamic that we have alluded to already. The proof is quite straightforward.

Again we consider a population of distinct business units with the measure of the scale of each entity being its output rate $x(t)$ at date t.[27] By the absolute fitness of each entity we mean its exponential growth rate of output defined over the interval to time t defined by $g(t)$ such that

$$g(t) = \frac{1}{t}\log\left[\frac{x(t)}{x(0)}\right]$$

The relative importance of each member of the population is defined by its market share

$$s_i(t) = x_i(t) \Big/ \sum x_i(t)$$

It follows as a matter of the definition of '$s(t)$' and '$g(t)$' that the dynamic process of selection for each business unit in the population will obey the following replicator relation connecting the changes in market share to the comparative fitness of the business measured relative to the whole population average.

[26] In fact, there is a deeper interpretation of the selection effect in the Fisher/Price accounting. It is that the rate of change of the nth cumulant of the distribution of any characteristic is proportional to the magnitude of the $(n+1)$th cumulant. I call this the 'cumulant theorem' (Metcalfe 1998).

[27] In a biological model $x(t)$ may represent the number of individuals said to be of the same kind. In an economic model it may represent the scale of activity of different producing units.

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$$\frac{ds_i}{dt} = s_i\,(t)\,[g_i\,(t) - g_s\,(t)] \tag{9}$$

with the mean absolute fitness value defined by $g_s\,(t) = \sum s_i\,(t)\,g_i\,(t)\,;\sum s_i\,(t) = 1$.

On integrating (9) for each of the members of the population we have

$$s_i\,(t) = s_i\,(0)\exp\left\{\int_0^t [g_i\,(t) - g_s\,(t)]\,dt\right\}$$

together with the adding up constraint $\sum s_i\,(t) = 1$.

To expose the logistic process contained within the replicator dynamic we can rewrite the mean absolute fitness as

$$g_s\,(t) = s_i g_i + (1 - s_i)\,g'_{si}$$

where $g'_{si} = \sum_{j \neq i} s'_j g_j$ is the weighted average of absolute fitness for the rest of the population, and it is different for each business unit.[28]

Then we can rewrite (9) as

$$\frac{ds_i}{dt} = s_i\,(1 - s_i)\left[g_i - g'_{si}\right] \tag{10}$$

In this expression $S_i(t)$ is a logistic function of current relative fitness $\left(g_i - g'_{si}\right) = R_i\,(t)$ and we can integrate (10) give

$$s_i\,(t) = \frac{1}{1 + A_i\,\exp - F_i\,(t)} = L_i\,(t) \tag{11}$$

with $A_i = \frac{1 - s_i(0)}{s_i(0)}$ determined as an initial condition. The integral function

$$F_i\,(t) = \int_0^t R_i\,(t)dt$$

is the relative fitness integral for business unit i, the fitness function for short. Thus the logistic process does not generate the conventional logistic curve over time but rather a logistic mapping that connects market share to the fitness function, business unit, by business unit to reflect the distributed nature of the evolutionary dynamics and the growth rate variety within the population.

The important point to comprehend is that the logistic process does not in general generate a logistic plot measured against time but the condition for a logistic process to generate a logistic curve, in the traditional sense, is easily uncovered. It is that we can express the fitness function in the form, $R_i\,(t) = \alpha_i \cdot t$, and that α_i is a constant. From the Fisher/Price theorems this can only be true if there are no more than two competing members of the population, and if the difference between their absolute

[28] We have defined $s'_j\,(1 - s_i) = s_j$.

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fitness values is independent of time.[29] Thus while the logistic process is general; the instantiation of it in a simple logistic curve is very special and is found only when relative fitness is constant, although this is compatible with changing absolute fitness.

3.6 Further implications

In many cases we are interested in whether the total output or more-making of a business unit, or ensemble of business units, will follow a logistic curve. Since the absolute output and market share are related by

$$x_i(t) = s_i(t) \cdot X(t), \quad \text{with } X(t) = \sum x_i(t),$$

it follows that the absolute growth rate is governed by the growth rate of market share and the growth rate of the total market, thus

$$\begin{aligned} \frac{d}{dt}\log x_i(t) &= \frac{d}{dt}\log s_i(t) + g_X(t) \\ &= \hat{L}_i(t) + g_X(t) \end{aligned}$$

Thus the output of the business unit can only follow a logistic curve if $g_X(t) = 0$, and if $L_i(t)$ also generates a logistic curve. In a stationary environment with $X(t)$ a constant this is possible but not more generally. Thus, to consider a familiar economic example, it is often assumed that the relevant market environment grows exponentially, in which case $g_X(t)$ is a positive constant, and $x_i(t)$ for all surviving entities will approach a non-logistic path of exponential growth, even though the movement of the relative shares follows the logistic process.

3.7 Hierarchical selection

Finally, consider again the problem of hierarchical selection. In some situations we are interested in the presence of populations nested within broader populations such that population j may be one of several sub populations within population k. As noted above, different selective forces may operate within and between these populations and the changing relative importance of an entity at the different levels will reflect the hierarchical nature of selection. For example, a business unit will have one measure of importance in its primary trade, another in its broad industry and yet another measure in the national economy and the way these measures evolve over time will reflect the interaction of different sets of selective forces at the different levels. Thus if entity i is a member of population j which, in turn, is a member of, an entity in, population k it would follow as a matter of accounting that

$$s_{ik} = s_{jk} \cdot s_{ij}$$

and that the rates of relative growth are related by

[29] The Fisher–Pry model (1971) is precisely a binary substitution model leading to the simple logistic curve.

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$$\frac{d}{dt}\log s_{ik} = \frac{d}{dt}\log s_{jk} + \frac{d}{dt}\log s_{ij}$$

Expressed in terms of the logistic processes at each level it follows that they are related by

$$\hat{L}_{ik} = \hat{L}_{jk} + \hat{L}_{ij}$$

whence,

$$L_{ik}(t) = CL_{jk}(t) \cdot L_{ij}(t)$$

where C is a constant of integration. Thus in terms of hierarchical selection, the logistic accounting leads to a chain rule within and across the sub populations in which the product of nested logistic processes is a logistic process.

Of course, these different examples reflect the fact that this logistic process is no more than a different accounting for evolution. The dynamic relations must hold for every population when we define the notions of population share and growth rate in the way that we have. It only becomes the basis for a refutable theory of evolutionary change when we impose a particular causal theory of why the individual growth rates differ and vary over time.

4 Concluding remarks

Accounting matters for a proper treatment of evolutionary processes, and I have explored this claim in terms of logistic processes, competition dynamics and the Price theorem to variation and selection models of evolution. The unifying theme that links all three is their relation to the population method and the concept of fitness in evolutionary theory. Since real economies are characterized by interacting populations at multiple levels, the propositions explored here might be useful in any attempt to comprehend more formally the process of creative destruction.

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