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**Theme A**

# THE PROCESS OF CREATIVE DESTRUCTION: FROM VISION TO MEASUREMENT AND EVOLUTIONARY EXPLORATION

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Abstract:
It was only late in his career that Schumpeter coined the concept of ‘creative destruction’, but this concept efficiently points to core aspects of his vision of capitalist economic evolution. The present paper demonstrates that the process of creative destruction can be handled efficiently by a set of methods for quantitative evolutionary economics. These descriptive methods are called evometrics, and they have been pioneered by researchers like George Price and Stan Metcalfe. Their starting point is the partitioning of evolutionary change into selection effects and innovation effects. On the background of this evometrics it becomes clear that what Schumpeter needed for the development of his concept of creative destruction was statistical tools for partitioning the aggregate effects of evolution in terms of the underlying population dynamics. This partitioning provides the basis for a clear-cut interpretation of creative destruction—both as a simple and as a multi-level process.

Keywords: Creative Destruction, Schumpeter, Measurement, Selection Effect, Innovation Effect

JEL – codes: O30, O33

## 1. Introduction

Among Schumpeter's many catchy expressions the most well known is probably that of creative destruction. The reason is that this expression is not only a piece of thought-provoking rhetoric but also that it clearly expresses his vision of capitalist economic evolution and the related socio-political conflicts. During the last decade the concept of creative destruction has gained precision through its use as a means of interpreting increasingly abundant data of evolutionary economic change. This gives some weight to its invocation by Alan Greenspan (2003), the chairman of the US Federal Reserve Board:

> The American economy has been in the forefront of what Joseph Schumpeter … called 'creative destruction', the continuous scrapping of old technologies to make way for the new. It presupposes a continuous churning of an economy in which the new displaces the old, a process that brings both progress and stress. … I do not doubt that the vast majority of us would prefer to work in a less stressful, less competitive environment. Yet, in our roles as consumers, we seem to relentlessly seek the low product prices and high quality that are prominent features of our current frenetic economic structure.

Economic evolution is a process that brings both productivity increase and socio-political stress, but these aspects of the process and their interconnection are in need for in-depth studies that are guided by precise and general methods. It is, for instance, not always obvious how the scrapping of old technologies influences the stressful displacement of jobs at the level of regions and firms. To study this and many other aspects of the process of creative destruction we need an adequate set of methods of quantitative evolutionary economics. In the present paper it is argued that this toolbox can be developed on the basis of methods that were originally developed within biometrics and that have already been generalised into what is here called evometrics that covers any kind of evolutionary process.[1] The starting point for this evometrics is the partitioning of evolutionary change into the selection effect and the innovation effect. The selection effect covers much of the immediate contents of the concept of creative destruction: the positive selection of novel economic activities to a large extent presupposes negative selection of other economic activities. This is the Darwinian aspect of evolution. But economic evolution is also characterised by a broadly defined innovation effect that includes elements of what may be called Lamarckian evolution. More specifically, the 'innovation' effect includes innovation in the narrow sense as well as imitation and learning. While the former clearly function as a part of Darwinian economic evolution (by providing new fuel for the selection process), this is not its only function. Innovation in the narrow sense also functions as an insurance against destruction for many regions and firms. When it comes to imitation and learning, this motive of avoiding destruction is even more predominant. Therefore, the question of the relative strength of the two effects is of crucial importance for the characterisation of the process of creative destruction.

The paper performs such an analysis in two steps: In section 2 a verbal reinterpretation of Schumpeter's creative destruction is made in relation to loosely defined evometric methods, while these methods are more systematically specified in section 3. More extensive accounts for the applied evometric toolbox and its background are found in Andersen (2003; 2004a; 2004b; 2004c).

## 2. Schumpeter's process of creative destruction

### 2.1. Vision and analytical scheme

Although Schumpeter named his concept of creative destruction late in his career,[2] it may be used as a heading of the theory of economic evolution that he held throughout his academic life. Both the structure of this theory and the expression of creative destruction points to its origin in reflections of a Nietzschean origin, but this issue cannot be covered in the present paper.[3] Instead we shall concentrate on the contents of the concept:

> [It is t]he process of industrial mutation—if I may use that biological term—that incessantly revolutionizes the economic system *from within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in. ... [T]he problem that is usually being visualized is how capitalism administers existing structures, whereas the relevant problem is how it creates and destroys them. As long as this is not recognized, the investigator does a meaningless job. As soon as it is recognized, his outlook on capitalist practice and its social results changes considerably. (Schumpeter, 1950, pp. 83 f.)

These formulations about creative destruction need some clarifications. First, Schumpeter uses the term mutation as a synonym for transformation at the macro level rather than according to the biological convention that points to a jump in the characteristics of entities at the micro level. However, when he talks of revolution 'from within' the economic system, he points to the inclusion of micro-mutations into the definition of economic activities. It is these innovations in the narrow sense that provides the fuel for the process of creative destruction. Second, the interrelated destruction of old structures and creation of new structures suggests a process of economic selection. This selection process is due to monopolistic competition that is described elsewhere in Schumpeter's book, but this competition is also about the change of 'capitalist concerns' in ways that allow them to avoid destruction. Third, Schumpeter suggests that creative destruction comes close of being a defining characteristic of capitalism. While feudalism and socialism might exist in stationary states without creative destruction, a 'stationary capitalism' would in his view be a contradiction in terms. Fourth, the emphasis on creative destruction as the essence of capitalism is part of a polemic against the standard economic theory that focuses on the efficient allocation of resources to uphold existing economic structures. The focus should be on revolution rather than on conservation, but other parts of Schumpeter's work emphasise that the analysis of the simple reproduction and growth of economic structures should not be totally dismissed.

Schumpeter's concept of creative destruction describes a unique process in historical time about which he has two main hypotheses: it is a waveform process and even its basic characteristics are undergoing change. The hypothesis of waves of evolution means that 'the perennial gale of creative destruction' (Schumpeter, 1950, p. 84) is not blowing constantly. Thus his above quoted expression about the incessant revolution of economic structures should not be taken too literally. Instead Schumpeter (1950, p. 83) emphasises that

> [t]hose revolutions are not strictly incessant: they occur in discrete rushes which are separated from each other by spans of comparative quiet. The process as a whole works incessantly however, in the sense that there always is either revolution or absorption of the results of revolution, both together forming what are known as business cycles.

Here Schumpeter suggests that creative destruction follows a path that is recorded in his basic scheme of economic evolution. According to this scheme the revolutionising of the routine economy tends to take place through the following stylised sequence of events:[4]

- Initial equilibrium: The analytical starting point is an economic system that is based on solid routine behaviour. This system is assumed to have found an equilibrium that allows the economic agents year after year to operate in their accustomed ways.
- Innovation and 'economic development': The initial equilibrium breaks down when a minority of innovators starts their enterprises. This leads to an economic upswing, but gradually the stream of innovations fades out because

of the depletion of innovative skills and the difficulties of innovating under disequilibrated conditions.

- Renewed equilibrium: Sooner or later the innovative impulse is insufficient to uphold the upswing. The downswing sharpens the competitive process of creative destruction, where many old firms are selected out of the economic system. At the end a renewed and well-established routine system emerges.
- Evolution: The economic evolution of the routine system consists in a series of routinised equilibria and innovative disturbances.

In a modified form,[5] this analytical scheme helps Schumpeter (1939) in his evolutionary analysis of different forms of business cycles, but the long-term reorganisation of the capitalist economy to some extent undermines the scheme. This reorganisation can be summarised in terms of two models (Schumpeter, 1928, p. 384):[6]

> Innovation in competitive capitalism is typically embodied in the foundation of firms …; improvement is forced on the whole branch by the processes of underselling and of withdrawing from them their means of production, workmen and so on shifting to the new firms … The new processes do not, and generally cannot, evolve out of the old firms, but place themselves side by side with them and attack them. [Schumpeter Mark I]
>
> All this is different in 'trustified' capitalism. Innovation is, in this case, not any more embodied *typically* in new firms, but goes on, within the big units now existing, largely independently of individual persons. It meets much less friction, as failure in any particular case loses its dangers, and tends to be carried out as a matter of course of the advice of specialists. [Schumpeter Mark II]

In the Mark II model established firms are not helpless victims in the process of creative destruction. Oligopolistic firms do not wait with their reactions until they are selected away. Instead they use innovation has a means of at least keeping up with other firms. This aspect of Schumpeter Mark II is included in Nelson and Winter's (1982, chs 12–14) simulation models of Schumpeterian competition with an economic evolution that after a shake-out of small firms goes on without much destruction.

### 2.2. Verification and theoretical refinement

In the 1930s Schumpeter was engaged in an empirical clarification and 'verification' of his hypotheses about economic evolution as a process of creative destruction (without using the term before 1942). His studies emphasised the Mark I model, and the results were published in the voluminous *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. These results were not convincing. Thus Kuznets' (1940, p. 270) extensive review concludes

> … that the book does not present a fully articulated business cycle theory; that it does not

> actually demonstrate the intimate connection between economic evolution and business cycles; that no proper link is established between the theoretical model and the statistical procedure; that the historical evidence is not used in a fashion that limits sufficiently the area of personal judgement; or that the validity of the three types of cycles is not established.

Although this harsh evaluation may be modified (Freeman and Louca, 2001), it correctly points to serious weaknesses in Schumpeter's coordination of his theoretical, statistical and historical materials. First, his evolutionary theory is not developed into a format that allows for the measurement and quantitative analysis of microevolution and macroevolution. Second, his statistical analysis is based on diverse, and mostly aggregate, time series data that does not explicitly deal with the evolutionary process; instead they are used to describe business cycles in a non-evolutionary way. Third, the sketchy accounts for the evolution of technologies and organisations are based on very diverse historical records, and the result is a narrative with many idiosyncratic elements. These aspects of Schumpeter's work have for a long time cast much doubt on the validity of his hypotheses and hindered the development of his ideas about creative destruction.[7] There is, however, another interpretation: Schumpeter was a very insightful student of economic evolution as creative destruction, but he lived in a period where the relevant time series data had not yet been collected and where the relevant tools for evolutionary analysis had not yet been developed. This is the interpretation that underlies the present paper.

Present-day data and analytical tools allow us to return to Schumpeter's unfinished work that was programmatically summarised in the preface to the fourth German edition of his *Theory of Economic Development* (translated and commented by Shionoya, 2004). Here Schumpeter applies his instrumentalist methodology to specify his conception of verification:

> We must first agree on what we mean by 'verification'. Any judgement of fact that is not analyses and *elaborated* cannot actually prove the truth or falsity of a theoretical statement. It would not even be true to say that observations of *statistical* or *historical* facts could show us whether or not a specific theory is consistent with them. For a very real relationship may be so concealed by other factors that we can understand nothing about it *without an analysis that digs deeply* into the situation itself. Therefore only a more modest goal can be attained—namely, to ascertain how the relationships asserted by a theory are *perceptible*, or to put it differently, how much a theory contributes to the understanding of the situation. (Schumpeter in 1935; after Shionoya, 2004, p. 134)

Schumpeter's own attempts to implement this form of verification of his evolutionary theory made relatively little use of statistical data:

> [T]ime series show only the quantitative contours of a historical process … If one believes one can manage with time series alone, he overvalues them very much. Rather a historical explanation of time series, i.e., an observation of what actually happened in economic life year by year—possibly month by month—is necessary not only to see the 'disturbances from outside' but also to understand even the normal course and its mirror images in statistical figures. Only by this investigation it is proved that actually working factors are in fact those stated by the theory. In this regard, we have to enter into details, i.e., the course of individual combines, but this is far beyond my ability. (Schumpeter after Shionoya, 2004, pp. 135 f.)

This statement reflects the fact that the economic time series studied by Schumpeter were of an aggregate nature and without any specification of the underlying firm-level data. For this purpose he only had mixed historical records of a largely qualitative nature. But today the situation is quite different since we to a large extent have access to the statistics of the underlying micro-data. These longitudinal micro-data has led to a renewal of the Schumpeterian research programme as indicated by surveys of e.g. micro-based productivity studies (Bartelsman and Dooms, 2000) and studies of creative destruction in terms of labour flows between firms (Davis and Haltiwanger, 1999; Armington and Acs, 2004).

The 'dialogue' with and development of Schumpeter's theory of creative destruction has been limited, however. In contrast, Schumpeter (after Shionoya, 2004, p. 135) suggests that

> … an inquiry into the empirical materials of business cycles [and the related evolutionary change] provides … inexhaustible sources of theory. Theory can always draw from them new viewpoints, new problems, and new methods …

The main reason why this possibility has only been exploited to a limited extent seems to be that too little emphasis has been put on the theoretical specifications and refinements suggested by relating Schumpeter's theory to empirical data. More specifically, the new availability of longitudinal micro-data suggests a statistically oriented reformulation of the theory of creative destruction, but this reformulation can only be implemented efficiently with the help of quantitative evolutionary analysis. Let us quickly consider how this can be done before we in section 3 study the details.

### 2.3. A preliminary evometric reformulation

The starting point for the evometric reformulation of Schumpeter's theory of creative destruction is the partitioning of evolutionary change into the selection effect and the innovation effect. The selection effect covers both the positive selection of novel economic activities and the negative selection of other economic activities. But economic evolution is also characterised by a broadly defined innovation effect that includes innovation in the narrow sense as well as imitation and learning. The relative strength of the two effects is of crucial importance for the characterisation of the process of creative destruction. This characterisation, however, depends on whether we analyse Schumpeter's process of creative destruction in terms of technologies and in terms of firms. In the first case we might try to describe cyclical creative destruction as a pure selection process at the level of subpopulations of adopters and non-adopters of a new cluster of technologies. According to this interpretation (which has some support in Schumpeter's *Business Cycles*) the initial state of the economic system has no significant variance with respect to productivity. However, the population consists of two subpopulations: a very small subpopulation that has already adopted a productivity-enhancing innovation and a dominant subpopulation that has not. During the upswing the subpopulation of adopters increases its weight, both by expansion of the existing firms and by recruitment of other firms that apply the innovation. Thus there is a selection effect during the upswing. Here the adopting subpopulation is facing positive selection, and the non-adopting subpopulation is facing a negative selection.

This analysis is illuminating, but firms and their employees are not interested in what happens at the level of subpopulations. Their main problem is whether they individually can avoid negative selection. During the upswing this negative selection can be avoided in two ways. First, non-adopters may avoid negative selection because of an inflow of unutilised resources into the economic system during the upswing (Schumpeter normally assumes away this possibility to keep the analysis simple). Second, the previous non-adopters may avoid decline of their resources by becoming adopters of the innovation. During the downswing these possibilities becomes harder to exploit. First, some of the economic resources become idle, and at the same time product markets and financial markets become more selective. Second, the firms that have not already become adopters during the upswing are the ones that are likely to have large difficulties in adopting. Therefore, the downswing a period where negative selection becomes widespread. Since economic agents normally react more strongly to negative selection than to positive selection, this destruction immediately points toward Schumpeter's (1950) vision of long-term socio-political consequences of the process of creative destruction.[8] In evolutionary terms the downswing is the period in which the productivity-enhancing innovation spreads throughout the system so that behavioural variance reaches a minimum. But Schumpeter allows for a limited presence of the innovation that will carry the next wave of evolutionary change, so variance will not become zero.

Even the long-term trend from Mark I to Mark II of creative destruction under capitalism may be specified in evometric terms. If all innovative activities are transformed from individual entrepreneurs that innovate by creating new firms to oligopolistic firms with permanent in-house innovation, then we should expect to see that an increasing part of evolutionary change is due to the innovation effect while a decreasing part is due to the selection effect. The reason is that such oligopolistic firms do not wait with their reactions until they are selected away. Instead they use innovation has a means of keeping up with the mean behaviour of the population of firms. Thus what in an earlier phase of capitalism was obtained through the selection effect will now be obtained through the innovation effect. Since this proposition this is not generally obvious, we seriously need empirical studies about the issue. In these studies we will have much need of the multi-level version of evolutionary change. The reason is that the Schumpeterian large-scale firms consist of many units, and some of the apparent disappearance of the selection effect may be due to a movement from selection between firms to selection within firms. It is, however, on balance likely that we shall find an increased importance of the innovation effect as a partial substitute for the selection effect.

## 3. The evometric analysis of creative destruction

It is amount of switching of economic resources between e.g. firms and regions that largely determines the socio-economic stress of creative destruction, and this amount, of course, depends on the level of aggregation at which we study the process. Thus there are different amounts of switching within and between firms, and within and between regions. Since the different forms of switching have different social costs, we need a flexible method of measurement. Such a method can be developed in relation to the general evolutionary metrics, or evometrics, that is presently being developed within evolutionary economics with much inspiration from evolutionary biology.[9] Given a measurement of creative destruction, a large research agenda immediately emerge—within evolutionary economics and development economics as well as in relation to sociology and political science. Presently we shall, however, concentrate on definitions and measurements.

### 3.1. The reproduction of firms and their routines

To study the switching of employment implied by the process of creative destruction we start by selecting a sequence of points of time, $t, t', t'', \ldots,$ and by defining a set of economically relevant entities for which we collect census data at these points of time. The time points, the set of entities (here called the 'population'), and the individual entities may pragmatically be defined in many ways. Thus the time period between our data collections may e.g. be one or ten years, the 'population' may cover an industry, a country or the whole world, and the entities may be plants, firms or regions. In any case, the basic task is to describe the creative destruction that takes place between the population state $P$ and the population state $P'$. This change is produced by the basic evolutionary forces of selection and innovation as well as by exogenous factors. Since we put some emphasis on selection, it is convenient to call $P$ the pre selection population and $P'$ the post selection population. For concreteness, we may think of $P$ and $P'$ as consisting of firms, and until section 3.4 we shall ignore the problem of handling new firms when collecting the necessary information for our analysis.

In biology the core concept of evometric analysis is denoted by 'fitness', and this naming is related to the phrase of 'survival of the fittest' that means something like the 'evolutionary success of the best designed' (Michod, 1999, 140). In the present version of economic evometrics the neutrality and non-theoretical character this concept are emphasised by using the term 'reproduction' rather than fitness. The degree of reproduction of a firm $i$ is measured by its resources $x'_i$ in the post selection population compared with its resources $x_i$ in the pre selection population. Thus the core variable is the reproduction coefficient $w_i = x'_i / x_i$. Following Marx, the firm (and any other socio-economic entity) may by said to be characterised by 'simple reproduction' if $w_i = 1$, 'expanded reproduction' if $w_i > 1$, and 'shrinking reproduction' if $w_i < 1$. These terms form the basis of an analysis of creative destruction that even in its simplest form require a good deal of notation.

The fact that the reproduction coefficients of firms are normally different and influenced by their characteristics implies that a process of selection is taking place. In the study differential reproduction we often concentrate on relative reproduction coefficients $w_i / w$, where $w$ is the population's (weighted) mean reproduction coefficient and the weights are the resource shares $s_i = x_i / x$. Some firms increase their resource shares because they have characteristics that imply that they have above average reproduction while others have characteristics that imply that their resource shares decrease. The former are 'positively selected' while the latter are 'negatively selected'. Thus we are clearly facing a process of 'relative creative destruction'. We are, however, not necessarily facing 'absolute creative destruction'. If the employment of the overall population is growing, the firms that are negatively selected in relative terms might increase their absolute employment. But when considering creative destruction, we normally think in terms of the increase and decrease of the absolute employment of the firms. The reason is that it is the movement of employment away from weak firms that is most closely related to the social costs of economic evolution.

The assumption that the reproduction coefficients of firms are influenced by their characteristics can now be made explicit. This can be done in terms of reproduction functions (in biology called fitness functions[10]) that are obtained by estimating the strength of selection by regressing reproduction coefficients on characteristics. Such reproduction functions may also be called selection functions, and they reflect an important aspect of the process of creative destruction. For simplicity we shall in the present paper only study the case where selection is based on a single characteristic, but it is possible to extend the analysis to multiple regression.

Since we cannot be sure that reproduction functions are straight lines, it is helpful to think in terms of polynomial regression:

$$w_i = \alpha + \beta z_i + \gamma z_i^2 + \varepsilon. \tag{1}$$

The polynomial in equation (1) describes the reproduction coefficient of a firm as influenced by its characteristic value $z_i$ as well as by a deviation term $\varepsilon$ (with a mean of zero). This influence is described by two coefficients. $\beta$ describes the slope of the reproduction function and $\gamma$ describes the degree with which the slope changes with increasing $z_i$. In the present paper emphasis is put on the case where $\beta > 0$ and $\gamma = 0.$ In this case we have *positive directional selection*. But for some characteristics we have that $\beta = 0$ and $\gamma \neq 0.$ If $\gamma < 0,$ then the reproduction function has a maximum toward which the selection pressure is moving the firms (*stabilising selection*). Thereby the population keeps its mean but decreases its variance. If $\gamma > 0,$

then the reproduction function has an intermediate minimum from which the selection pressure is moving the firms away (*disruptive selection*). Thereby the population increases its variance, and in the end it may split up into two populations. More complex reproduction functions are characterised by other combinations of the coefficients of the quadratic polynomial or by higher-order polynomials.

In the following we shall only consider selection that takes the form of a linear and positively sloped reproduction function. Here the more general form of equation (1) largely serves as a caveat: we cannot be sure that real selection is that simple. However, the linear case might be found when the selection criterion is the productivity of firms (or plants)—especially if we manipulate the selection criterion to obtain the linear form (e.g. by considering the logarithm of the productivities). Even if the ignored selection criteria (like access to financial resources) and the random elements in the process of selection imply rather large deviations of individual observations from the reproduction function, the selection process will transform variance of productivities into change of mean productivity. Therefore, we may start from a naïve picture of the evolutionary process. But this is only a start. The reproduction function is, for instance, describing the 'performance' of firms with respect to employment, but in the end we have to confront the obvious fact that firms are not normally competing to maximise employment. There are many mediating links between their normal productivity and their change in employment (Metcalfe, 1997). Thus the employment depends on the selection pressure from consumer search as well as on the prices set by firms. These prices depend on the price-setting power of firms as well as on their costs of production. These costs of production depend on the bargaining power of potential and actual employees as well as on the normal productivity of the firm. Since all these links are important and vary across industries and over time, it is obvious that there is no simple selection of firms with respect to their normal productivities. But it is important to note that the evolution with respect to productivities does not presuppose a high efficiency of the selection process. Even a fairly weak covariance between the reproduction coefficients of firms and their normal productivities may be sufficient to influence the long-term direction of the evolutionary process.

### 3.2. Partitioning of change in the mean reproduction coefficient

The fact that firms normally have different reproduction of their employment implies that a process of selection is taking place. From an evolutionary point of view the important issue is the relative growth rates: Some firms have characteristics that imply that they have growth rates that are above average while others have characteristics that only allow them below-average growth rates. Thus the former are positively selected while the latter are negatively selected. Thus we are clearly facing a process of ‘relative creative destruction’. We are, however, not necessarily facing ‘absolute creative destruction’. If the employment of the overall population is growing, the firms that are negatively selected in relative terms may increase their absolute employment. But when considering creative destruction, we normally think in terms of the increase and decrease of the absolute employment of the firms. The reason is that it is the movement of employment away from weak firms that is most closely related to the social costs of economic evolution. Therefore, there is a need of augmenting the standard analysis of relative creative destruction. In the following we shall see how this can be done.

***Table 1: Notation for population-level measurement of creative destruction.***

| Variable | Description | Definition |
|---|---|---|
| $\Delta w$ | change in mean reproduction coefficient | $w' - w$ |
| $\mathrm{Var}(w_i)$ | variance of reproduction coefficients | $\sum s_i (w_i - w)^2$ |
| $\mathrm{E}(w_i \Delta w_i)$ | expected value of change in reproduction coefficients | $\sum s_i w_i \Delta w_i$ |
| $\Delta z$ | change in the mean characteristic | $z' - z$ |
| $\mathrm{Var}(z_i)$ | variance of characteristics | $\sum s_i (z_i - z)^2$ |
| $\mathrm{Cov}(w_i, z_i)$ | covariance of reproduction coefficients and characteristics | $\sum s_i (w_i - w)(z_i - z)$ |
| $\beta(w_i, z_i)$ | regression of reproduction coefficients on characteristics | $\mathrm{Cov}(w_i, z_i) / \mathrm{Var}(z_i)$ |
| $\mathrm{E}(w_i \Delta z_i)$ | expected value of change in characteristics | $\sum s_i w_i \Delta z_i$ |

Note: The non-standard subscripts in the notation for variance and expected value are included to allow for hierarchical partitioning.

To give a full account for this process we need the aggregate information that is summarised in table 1. Let us for the moment concentrate on the first three variables of table 1 and start with the change of the mean reproduction coefficient between one period and the next period. To explain this change we consider reproduction coefficients as reflecting a combination of intrinsic properties of the firms (e.g. their ‘normal’ productivities) and characteristics of their environment. Then we can describe the change of the in the mean reproduction coefficient $\Delta w$ as the outcome of three effects: the selection of firms with different characteristics, the innovative change in these characteristics, and the change of the characteristics of the environment. The first effect is *selection effect* that may be defined as the relative variance of the reproduction coefficients ($\mathrm{Var}(w_i)/w$). According to this definition, selection is the evolutionary mechanism that assigns reproduction coefficients to the firms of the pre-selection population. The population-level effect of this firm-level selection is a change in the mean reproduction coefficient. There are, however, two additional reasons for this change. First, the environment of the population may have changed so that individual reproduction coefficients as well as the mean reproduction coefficient are different in the post selection period. Second, the individual firms may have performed (localised) innovations that influence their reproduction coefficients and the mean reproduction coefficient. Thus we have to add the combined effect of environmental change and innovation to the selection effect. For simplicity we shall call this combined effect the *innovation effect*—although environmental factors will often be its dominant determinant.[11] This innovation effect is defined as the relative expected value of the change of the reproduction coefficients ($\mathrm{E}(w_i \Delta w_i)/w$).

By means of these definitions it can be proven (see the appendix of Andersen, 2004c) that total evolutionary change can be partitioned in the following way:

$$T = \Delta w = \underbrace{\frac{\mathrm{Var}(w_i)}{w}}_{\text{Selection effect}} + \underbrace{\frac{\mathrm{E}(w_i \Delta w_i)}{w}}_{\text{Innovation effect}} = S^F + I^F. \qquad (2)$$

This equation (2) tells that the change in the mean reproduction coefficient can be partitioned into a selection effect and an ‘innovation’ effect. The selection effect is denoted $S^F$ to indicate that it is defined with respect to a population composed of firms. It describes how the aggregate change is influenced by the differences in the reproduction coefficients of the first period. $S^F$ is zero if all reproduction coefficients are equal. The innovation effect $I^F$ describes the outcome of the changes in the reproduction coefficients. It is zero if no reproduction coefficient undergoes any change. Although equation (2) is describing evolutionary change between two periods, it gives some information of future conditions for evolution. This is most obvious if we are facing a pure selection process (i.e. $I^F = I'^F = 0$). For such a process $S'^F < S^F$ since $w' > w$ and $\mathrm{Var}(w_i') < \mathrm{Var}(w_i)$.

From equation (2) we may quickly move to the discussion of *relative* creative destruction. To do so we note that half of the selection effect must come from firms with decreasing employment shares. The question is how these firms perform with respect to the change in their reproduction coefficients. To study this question we start by splitting the firms into two subpopulations *c* and *d*. Firms are members of subpopulation *c* that consists of relatively growing ('creative') firms if $w_i \geq w$. Otherwise they are members of the subpopulation *d* that consists of firms that are encountering any degree of relative decline/destruction. Then we split up the firm-level selection effect and the firm-level innovation effect of equation (2) according to the membership of these subpopulations:

$$\begin{aligned} S^F &= \underbrace{\frac{\mathrm{Var}(w_i)}{2w}}_{\text{Creative selection effect}} + \underbrace{\frac{\mathrm{Var}(w_i)}{2w}}_{\text{Destructive selection effect}} = S_c^F + S_d^F, \\ I^F &= \underbrace{\frac{\sum_{i \in c} s_i w_i \Delta w_i}{w}}_{\text{Innovation-response-to-increase effect}} + \underbrace{\frac{\sum_{i \in d} s_i w_i \Delta w_i}{w}}_{\text{Innovation-response-to-decrease effect}} = I_c^F + I_d^F. \end{aligned} \quad (3)$$

Let us consider equation (3) from the viewpoint of creative *destruction*. Here the important issue is whether or not the relative decline of firms in the first period is compensated by growth in the next period. The relative destructive selection effect $S_d^F$ is a positive contribution to the total evolutionary effect. The problem is how relative destruction in the first period is connected to the innovation-response-to-decrease effect of the next period. If weakened firms did not react or reacted through a negative innovation effect, then they would face an irreversible process of decline. But they may also have the possibility of compensating reactions to their weakened position. Thus Schumpeter emphasises that the response of weakened firms is often to imitate the growing firms. The response is even more radical in Simon's (1982) theory of satisficing behaviour. According to this theory, super-normal performers are satisfied and do nothing to improve their performance. In contrast, sub-normal performers are dissatisfied and engage in innovation. Thereby, they may be able to improve their position. The crucial question for the long-term process of relative creative destruction is, therefore, whether $I_c^F < I_d^F$. This is, of course, an empirical question, and it is not easy to answer. One of the difficulties is that random factors play a large role in determining growth rates, and therefore we see a large degree of 'regression' toward mean behaviour.

To include the issue of *absolute* creative destruction into our analysis, we only need to change slightly the above procedure. Firms are members of subpopulation *C* growing firms if $w_i \geq 1$. Otherwise they are members of the subpopulation *D* that absolutely declining. Then we split up the firm-level selection effect and the firm-level innovation effect of equation (2) according to the membership of these subpopulations:

$$
\begin{aligned}
S^F &= \underbrace{\frac{\sum_{i\in C} s_i (w_i - w)^2}{w}}_{\text{Creative selection effect}} + \underbrace{\frac{\sum_{i\in D} s_i (w_i - w)^2}{w}}_{\text{Destructive selection effect}} = S_C^F + S_D^F, \\
I^F &= \underbrace{\sum_{i\in C} s_i w_i \Delta w_i}_{\text{Innovation-response-to-growth effect}} + \underbrace{\sum_{i\in D} s_i w_i \Delta w_i}_{\text{Innovation-response-to decline effect}} = I_C^F + I_D^F.
\end{aligned}
\quad (4)
$$

Here any subeffect is zero if its subpopulation has no members.

The questions related to equation (4) are more or less the same as those related to equation (3). But now the problem of firing of employees enters into the discussion. In the long run the absolute destruction effect is obtained by moving employees from declining to growing firms. But this movement is seldom a smooth one. From the viewpoint of the moving employees there is often a welfare loss due to temporary unemployment and loss of social context. From the viewpoint of the declining firms the problem is that the loss of employees may in many ways influence productivity in a negative way. Thus we encounter not only new reasons for compensating responses to decline but also new difficulties of avoiding vicious circles.

If firms are composed of plants, the innovation effect of equation (2) may be due to two different subeffects. First, the plants (denoted by *ij*) within a given firm (denoted by *i*) may have different reproduction coefficients in the first period. Second, the plants may change their reproduction coefficients between the first and the second period. Thus the 'innovation' effect measured at the level of firms may be partitioned into a firm-level selection effect and a plant-level innovation effect. This partitioning is additive and it may immediately be included into equation (2). As demonstrated by Andersen (2004c, appendix),

$$
T = \Delta w = \underbrace{\frac{\mathrm{Var}(w_i)}{w}}_{\text{Firm-selection effect}} + \underbrace{\frac{\mathrm{E}(\mathrm{Var}(w_{ij}))}{w}}_{\text{Plant-selection effect}} + \underbrace{\frac{\mathrm{E}(\mathrm{E}(w_{ij}\Delta w_{ij}))}{w}}_{\text{Plant innovation effect}} = S^F + S^P + I^P. \quad (5)
$$

This version of the partitioning of the change of the mean reproduction coefficient allows us to consider two levels of selection: On the one hand, there is a selection mechanism that works at the level of the overall population. This mechanism promotes and demotes the employment of firms. On the other hand, the firm has its internal selection mechanism that promotes and demotes the employment of plants. If the firm consists of a single plant or of plants that grow at the same rate, this effect is zero. But often this is not the case.

In the context of firm-and-plant-based growth there is a need of augmenting our previous analysis of the process of relative and absolute creative destruction. Let us concentrate on absolute creative destruction. Here the task is to define the relevant subpopulations of firms and plants. On this background we may partition the innovation effects of equation (4):

$$\begin{aligned} I_C^F &= S_C^P + I_{CC}^P + I_{CD}^P, \\ I_D^F &= S_D^P + I_{DC}^P + I_{DD}^P. \end{aligned} \tag{6}$$

Here each of the innovation effects within both increasing and decreasing firms is partitioned into a selection effect and two innovation effects. The plant-based selection effects ($S_C^P$ and $S_D^P$) reflect the composition of firms with respect to plants of supernormal and subnormal reproduction coefficients in the first period. The innovation effects ($I_{CC}^P, I_{CD}^P, I_{DC}^P, I_{DD}^P$) represent the change of the reproduction coefficients of plants with positive and negative reproduction coefficients. The first letter of the subscripts of these innovation effects refers to the firm while the second letter refers to the plant.

Let us briefly consider the issues of absolute creative *destruction* suggested by these definitions. The possibility of declining firms to react by promoting relatively highly performing plants ($S_D^P$) depends on the variance of their plants with respect to growth potential. Over time this possibility will become exhausted unless new variance is introduced. It is, therefore, important how the plants of decreasing firms responds. Here we have to types of responses: the response of their growing plants ($I_{DC}^P$) and the response of their declining plants ($I_{DD}^P$). In both cases we may encounter the same responses as discussed with respect to the reaction of firms: imitation, satisficing behaviour and vicious circles. Thus it becomes obvious that the analysis of creative destruction is very complex. At the same time we come much closer to the realities of economic life than when applying decompositions that are directly imported from evolutionary biology. The crucial difference is that innovation effects are much more important and complex in economic evolution than in biological evolution.

### 3.3. Partitioning of the growth of productivity

In the previous section we only studied creative destruction in terms of reproduction coefficients of the employment of firms and plants. This evolutionary meaning of this analysis can be made explicit by relating the analysis to evolving characteristics that influence these reproduction coefficients. But as soon as we do so we have to confront the obvious fact that firms are not competing to maximise employment. There are many mediating links between e.g. their normal productivity and their 'performance' with respect to employment (Metcalfe, 1997). Thus the employment depends on the selection pressure from consumer search as well as on the prices set by firms. These prices depend on the price-setting power of firms as well as on their costs of production. These costs of production depend on the bargaining power of potential and actual employees as well as on the normal productivity of the firm. Since all these links are important and vary across industries and over time, it is obvious that there is no simple selection of firms with respect to their normal productivities. But it is important to note that the evolution with respect to productivities does not presuppose a high efficiency of the selection process. Even a fairly weak covariance between the reproduction coefficients of firms and their normal productivities may be sufficient to influence the long-term direction of the evolutionary process.

When studying the evolving characteristic directly, we may define total evolutionary change with respect to a particular characteristic of a population as the change in the mean of the individual values of that characteristic $\Delta z$. The calculation of this and other variables that include characteristics is described in table 1. For concreteness we shall take the productivities of firms ($z_i$) as our example, but we shall ignore the difficulties of productivity studies. Instead we note that according to the definition there is no evolution in the unlikely case where there is no change in mean productivity but instead a cancelling out of positive and negative changes at the level of firms.

Given that we observe evolutionary change (i.e. $\Delta z \neq 0$), the task is to partition it into a selection effect and an innovation effect. This partitioning is like that of equation (2), but we need a more general definition of the two effects. The *selection effect* with respect to productivity (or any other characteristic) is the relative covariance between the reproduction coefficients and the productivities, i.e.

$\text{Cov}(w_i, z_i)/w.$ According to this definition selection is the component of the evolutionary process that assigns reproduction coefficients to the firms of the pre selection population based on their productivities. For each member, selection determines the relative reproduction coefficient $w_i / w$ that corresponds to its productivity $z_i$. If there are differences with respect to productivities, then the post selection population shows a changed structure to the degree that the initial differences are exploited by selection.

The *innovation effect* with respect to productivity is the relative mean of the product of the change of productivity and the reproduction coefficients, i.e. $\text{E}(w_i \Delta z_i)/w.$ According to this definition, the innovation effect is determined by the weighted influence of the degree to which the members of the post selection population have changed their productivities when compared to the pre selection population. The definition may be rewritten to $\sum s_i' \Delta z_i,$ so the innovation effect is simply the sum of the changes of productivities weighted by the employment shares in post selection population. In the definition of the innovation effect we are obviously using another concept of innovation that the one used in neo-Schumpeterian innovation studies. While innovation in these studies is seen as the introduction of a positively evaluated novelty with respect to the overall population, we presently apply a neutral concept of innovation that covers any kind of local-level change. It simply means that something new has occurred with respect to firm-level productivities. Thus the productivity of individual firms may have increased or decreased. There are, of course, many potential reasons for both negative and positive values, but let us concentrate of the knowledge issue. In this respect productivity change may be positive because of innovation, imitation or learning processes. It might be negative because the firm does not have an effective system of reproduction of its knowledge.

Given these definitions of the selection effect and the innovation effect, it can be proven (see the appendix of Andersen, 2004c) that total evolutionary change is simply the sum of the effects:

$$T = \Delta z = \underbrace{\frac{\text{Cov}(w_i, z_i)}{w}}_{\text{Selection effect}} + \underbrace{\frac{\text{E}(w_i \Delta z_i)}{w}}_{\text{Innovation effect}} = S^F + I^F. \qquad (7)$$

This is Price's equation (identity) that can be derived for any evolutionary process in biological life, economic life, and elsewhere.[12] Although it has more empirical contents than the previous partitioning of the change in the mean reproduction coefficient, it can be partitioned in the same way as before.[13] Thus we may include the fact that firms consist of plants to see that

$$T = \Delta z = \underbrace{\frac{\mathrm{Cov}(w_i, z_i)}{w}}_{\text{Firm-selection effect}} + \underbrace{\frac{\mathrm{E}(\mathrm{Cov}(w_{ij}, z_{ij}))}{w}}_{\text{Plant-selection effect}} + \underbrace{\frac{\mathrm{E}(\mathrm{E}(w_{ij}\Delta z_{ij}))}{w}}_{\text{Plant innovation effect}} = S^F + S^P + I^P. \quad (8)$$

We may also make further partitioning of equations (7) and (8) to study absolute creative destruction like we did in equations (4) and (6).

To discuss the results it is useful to note that the present selection effects in terms of covariances can be expressed as the products of regression coefficients and variances—provided that we assume a linear reproduction function (cf. equation (1)). For instance,

$$\frac{\mathrm{Cov}(w_i, z_i)}{w} = \frac{\beta(w_i, z_i)}{w}\mathrm{Var}(z_i).$$

Here the variance $\mathrm{Var}(z_i)$ can be interpreted as the fuel of the selection process. Then the relative regression of reproduction coefficients on productivities ($\beta(w_i, z_i)/w$) can be interpreted as the efficiency with which this fuel is exploited to bring about aggregate productivity change. A similar interpretation can be made for the plant-selection effect.

When we study empirical processes of creative destruction, then it is not only productivity that evolves. But this fact is no hindrance for performing the type of analysis that has just been defined. If we study the process of creative destruction in terms of productivities, we normally make the hypothesis that some part of the actual change in the distribution of employments across firms (and plants) is due to the selection of firms according to their productivities. Thus we make the double assumption that there are differences with respect to productivity and that the complex selection mechanism is strong enough to exploit these differences to bring about increase in aggregate productivity. We may also safely make the hypothesis that some part of aggregate productivity change is due to innovative productivity changes within individual firms. But in general we can say little of the relative strength of these two aspects of the evolutionary process.

### 3.4. Introducing new firms into evometric partitionings

Since Price's equations (7) and (8) are totally general, it is not surprising that they may found by slight rewrites of a many formulas of applied economies—but here we also encounter the problem of handling new firms that is not easily integrated into the logic of evometric analysis. From the new wave of microeconometric studies based on longitudinal data, we shall take the already mentioned survey of productivity studies by Bartelsman and Doms (2000, p. 583; see also Foster et al. 1998).[14] They emphasise a partitioning of aggregate productivity change that serves as 'a framework to interpret the seemingly disparate findings in the literature'. The core part of this partitioning refers to the decomposition of productivity change in the set of continuing plants (i.e. plants that exist at both $t$ and $t'$).[15] They (or rather Foster et al., 1998, p. 16) decompose aggregate productivity change from the continuing plants in three components:

$$\begin{aligned}\Delta z &= \underbrace{\sum \Delta s_i (z_i - z)}_{\text{Selection effect}} + \underbrace{\sum s_i \Delta z_i}_{\text{Within-plant effect 1}} + \underbrace{\sum \Delta s_i \Delta z_i}_{\text{Within-plant effect 2}} \\ &= \underbrace{\frac{\mathrm{Cov}(w_i, z_i)}{w}}_{\text{Selection effect}} + \underbrace{\frac{\mathrm{E}(w_i \Delta z_i)}{w}}_{\text{Innovation effect}} = S^P + I^P.\end{aligned} \tag{9}$$

The first line in equation (9) is Bartelsman and Doms' preferred decomposition. From the derivations in the appendix it is easy to see that the first component of equation (9) is the selection effect of Price's equation (7). They call it the 'between-plant effect'. The second and third components combine to form the innovation effect, but Bartelsman and Doms argue to keep them distinct. Their within-plant effect 1 ($\sum s_i \Delta z_i$) is called the 'within-plant effect' while they misleadingly call the within-plant effect 2 ($\sum \Delta s_i \Delta z_i$) 'a covariance term'—a better name is the cross effect.

Although we may quickly derive Price's equation in quite diverse contexts, it should be emphasised that the data has not normally been handled according to the logic of evolutionary partitioning. This is clear from Bartelsman and Doms' work, and the consequence is that the partitioning in equation (9) is not really fully reflecting their work. To be more specific, equation (9)'s equalisation of the Bartelsman–Doms partitioning with Price's decomposition only holds if there are no entering plants in the industry. However, their partitioning includes components for both continuing plants, entering plants and exiting plants. If we denote the set of continuing plants by $I$, the set of entering plants by $J$, and the set of exiting plants by $K$, we may represent their partitioning of aggregate productivity change in the following way:

$$\Delta z = \underbrace{\sum_{i \in I} \Delta s_i (z_i - z)}_{\text{Incumbent selection effect}} + \underbrace{\sum_{i \in I} (s_i + \Delta s_i) \Delta z_i}_{\text{Incumbent innovation effect}} + \underbrace{\sum_{i \in J} s_i (z_i' - z)}_{\text{Entry effect}} - \underbrace{\sum_{i \in K} s_i (z_i - z)}_{\text{Exit effect}}. \quad (10)$$

The two added components in equation (10) are called the entry effect and the exit effect. They are very handy, but their inclusion means that the logic behind Price's equation is lost. The main reason is that the mean productivity is calculated for all firms. Therefore, there is no elegant interpretation of the individual components as covariances or expected values. An apparent solution would be to include the new effects in the old ones. This works for the exit effect, which can easily be included in the selection effects since in this case $\Delta s_i = -s_i$ (and my name 'incumbent selection effect' really suggests such an inclusion). However, the entry effect cannot be included. The reason is that we cannot define reproduction coefficients for entering firms (where we would have to put a zero in the denominator).

The problem of handling entering firms cannot be ignored in the analysis of the process of creative destruction. Both Schumpeter and many of his present-day followers in endogenous growth theory and industrial organisation are emphasising that this process is kept alive by the introduction of innovations by new firms that ultimately displace incumbent firms. Some researchers (like Caroll and Hannan, 1999) even suggest that evolutionary analysis can largely be performed in terms of a demography of firms that concentrates on 'vital statistics', i.e. the entry and exit events. This suggestion represents no fundamental problem for evometrics as long as any entrant can be connected to a member of the incumbent population. But the logic of selection and innovation that has been described in the present paper cannot work without the specification of such relationships (Price, 1995).

There are two complementary solutions to the problem of including new firms into evometric analysis. The first solution is to accept Schumpeter's idea that they represent genuine breaks with the past. In this case we have to handle new firms in an ad hoc manner like in equation (10). This means that the elegant parts of evometrics can only be applied to the incumbent population of firms. Since such a population may contain a mix of relatively new and relatively old firms, we are still able to most of the real-life processes of creative destruction. But we lack a full treatment of the process. The second solution is to consider entrants as representing less novelty than assumed by Schumpeter. The most obvious case is when new firms can be considered as spin-offs of old firms. In this case the employment of a spin-off is included in the calculation of the reproduction coefficient of its mother firm. To allow for this inclusion we often need quite detailed information on the founding of firms (Klepper 2002). In practice, the two solutions to the problem of handling new firms are applied in parallel, but there is a need of recognising that the mixing of different logics is likely to create some confusion for evolutionary interpretations of available microstudies and for the general analysis of creative destruction.

## 4. Conclusion

It was only late in his career that Schumpeter coined the concept of 'creative destruction', but this concept efficiently points to core aspects of his vision of capitalist economic evolution. The present paper has demonstrated that the process of creative destruction can be handled efficiently by a set of methods for quantitative evolutionary economics. These descriptive methods are called evometrics, and their starting point is the partitioning of evolutionary change into selection effects and innovation effects. On the background of this evometrics it becomes clear that what Schumpeter needed for the development of his concept of creative destruction and the formulation of testable hypotheses was statistical tools for partitioning the aggregate effects of evolution in terms of the underlying population dynamics. This partitioning provides the basis for a clear-cut interpretation of creative destruction—both as a simple and as a multi-level process.

## Notes

[1] Cantner and Krüger (2004) have recently suggested that the toolbox for applied evolutionary economics should be called 'evolumetrics'. This suggestion is based on their attempt to systematise different contributions to applied evolutionary economics. For the moment I shall, however, stick to the name 'evometrics'. The main reason is that this name emphasises the relationship to biometrics, which is still the dominant contributor to the development of measurements and analyses of evolution. But it should be emphasised that a name is just a convention, and in the long run the evolving naming convention will determine whether the toolbox will be called 'evolumetrics', 'evometrics', or something else.

[2] The term 'creative destruction' is only used in Schumpeter (1950, chs 6–7).

[3] An extensive discussion of the Nietzschean background of the concept of creative destruction is found in Reinert and Reinert (forthcoming). There is also a background in classical and historical economics (see Elliott, 1980; Streissler, 1994).

[4] This scheme is found throughout Schumpeter's (1934; 1939; 1950; etc.) works. His terminology was, however, changing. The term economic evolution was not systematically used to describe the overall

process of waveform capitalist change until *Business Cycles* (Schumpeter, 1939). Andersen (2002) explores the revolutionising of the economic system by means of railways ('railroadization') during the nineteenth century as Schumpeter's standard example of creative destruction.

5 Schumpeter's scheme assumes a sequence of equilibria that is seldom found in reality. Here innovation also takes place in relatively disequilibrated environments, and thus the system never becomes fully routinised. This was recognised by Schumpeter (1939).

6 Phillips (1971) introduced the distinction between Schumpeter Mark I and Schumpeter Mark II. Although Schumpeter (1950) extensively discussed his Mark II model of creative destruction, he never treated it systematically. For instance, it seems primarily on the background of his Mark I scheme of creative destruction that we should understand the attack on standard econometrics found in one of Schumpeter's last contributions. Here he emphasised the need of overcoming what he considered to be 'the most serious shortcoming of modern business-cycle studies', namely 'that nobody seems to understand or even to care precisely how industries and individual firms raise and fall and how their raise and fall affects the aggregates' (Schumpeter, 1949, p. 329). In retrospect, we may say that Schumpeter asked economic theorists and econometricians to include into their studies the shifting balance between the effects of innovation and selection during relatively long business cycles. But he did not know how to specify his requirements.

7 To some researchers creative destruction is one of Schumpeter's many hypotheses that should be dismissed as empirically false, so that only a very lose Schumpeterian inspiration remains (Reisman, 2004, s. 270 f.). To other researchers 'creative destruction' is a 'careless slogan' that should be replaced with Schumpeter's idea of creative response (Helmstädter and Perlman, 1996, p. 1), and these formulations might relate to the ambiguous results obtained in empirical studies of processes of creative destruction (e.g. Andreutsch and Fritsch, 1996). In the same vein, Arena and Dangel-Hagnauer (2002, pp. 14 f.) suggests that 'Schumpeter's theory of competition depicts a process of self-organisation and self-reinforcement rather than a process of elimination' and thus we cannot argue 'that the evolutionary nature of Schumpeter's theory derives from his conception of "creative destruction".' However, there are other researchers that Schumpeter's main contribution to be his emphasis on creative *destruction* through negative external effects, i.e. business stealing effects (Streissler, 1994, p. 22). It should also be noted that Perlman (1995) in another paper accepts the concept of creative destruction as representing innovative monopolistic competition.

8 Hirschman (1958, pp. 57–61) discusses the effect of different types of internalisation of the costs of creative destruction for evolution and growth.

9 This analysis is inspired by George Price as emphasised by Frank (1995; 1998) and Andersen (2003; 2004a; 2004b; 2004c). Metcalfe (2002, p. 90) has remarked that '[f]or some years now evolutionary economists have been using the Price equation without realising it' and similar statements are made in a more developed form by Knudsen (forthcoming). Such statements hold for Metcalfe's (1998; 2001) contributions to a statistically oriented evolutionary economics and for the discussion of group selection within evolutionary game theory (Bowles, 2004, ch. 13), but they also have some truth for Nelson and Winter's (1982) pioneering contribution to the field. Even in applied economics with no evolutionary pretensions, we find a groping toward a general evometrics.

10 Conner and Hartl (2004, ch. 6) give basic description of the issues and formalisms involved in the analysis of quantitative fitness functions.

11 Fisher's (1999) formal analysis of evolution did not include this effect, and thereby much confusion arose about his fundamental theorem of natural selection (see Price, 1972b; Frank, 1997). However, Fisher (1999, p. 41–42) treated the effect verbally and called it the 'deterioration of the environment'. Hereby he emphasised that the increase in mean fitness due to the promotion of individuals with the 'best' characteristics cannot in the long run imply an expansion of the whole population (the species or the industry). Thus the individual reproduction coefficients cannot be the same in the second period as they were in the first period.

12 See Price (1970; 1972a) and Frank (1998). Frank demonstrates that a large number of evolutionary problems can be clarified by means of Price's equation. He also gives a derivation of Price's equation (Frank 1995; 1998, pp. 13–15)

[13] It was Hamilton (1996, pp. 332–337) who in 1975 made the first systematic application of Price's equation for studying the combined effects of group-level selection and individual-level selection. Later applications are covered by Sober and Wilson (1998) and Henrich (2004). A deeper question is that is treated by means of Price's expanded equation is how individual selection at one level promotes the evolutionary transition to organisational solutions at the next higher level (Michod, 1999).

[14] Nelson's (1981) survey of productivity studies emphasised the Schumpeterian ideas of heterogeneity and institutional creative destruction, but it does not apply the methods for decomposition implicit in his and Winter's theoretical work. The reason for this omission is probably to some extent that longitudinal microdata were missing at the time he was writing, but it is was hardly necessary that we had to wait 20 years before another survey could conclude in a way that 'echoes Nelson's ... earlier analysis' and emphasises that 'it can now be addressed better quantitatively' (Bartelsman and Doms 2000, p. 591).

[15] Actually, they refer not to productivity but to the natural logarithm of total factor productivity.

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