Evometrics: Quantitative evolutionary analysis from Schumpeter to Price and beyond

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Abstract: This paper argues that the development of a general statistical approach to quantitative evolutionary economics has for a long time been needed, that a limited form of this approach in to some extent already available in the practices of evolutionary economists, and that it is now possible to state it in a systematic form. The approach is called general evometrics, and it reached a relative stability through the work of George Price and his followers within evolutionary biology. The paper carefully describes this approach and derives Price's equation for the partitioning of evolutionary change. The need for an economic evometrics is illustrated by the problems of Schumpeter in handling economic evolution in a quantitative way and by the surprising ease in specifying some of his theories in evometric terms. The tendency toward an independent development of an economic evometrics is illustrated by productivity studies and by Nelson and Winter's work. These cases demonstrate that the developments within economics need to be supplemented with the generality and surprising fruitfulness of Price's approach to evometrics. But the analysis of economic evolution has its own requirements, which includes a much more systematic analysis of the innovation effect than is necessary in biology.

1. Introduction

In many respects the different types of new evolutionary economics—like evolutionary game theory, evolutionary computational economics, and the Nelson–Winter tradition of analysing Schumpeterian competition—have moved far beyond the old and verbal evolutionary economics of Adam Smith, Marx, Menger, Marshall, Veblen, Schumpeter and Hayek. The progress is especially clear with respect to the new degree of conceptual depth and formality in the treatment of evolutionary processes, which were never analysed systematically by older generations of economists. But other aspects of the study of evolutionary processes show less convincing progress. Especially, we have not yet seen a systematic and general combination of formal evolutionary theorising, statistical analysis of real evolutionary processes, and the historical analysis of long-term evolutionary change. If evolutionary economics is to become a real science, further progress has to be made in the development of this combination—which may be called economic evometrics in the broad sense. But before economic evometrics can emerge as the alliance between theoretical, statistical and historical studies of economic evolution, we need to develop economic evometrics in the narrow sense, i.e. as an evolutionary metrics, or an economic evometrics, that is able to analyse concrete processes of economic evolution (Andersen, forthcoming).

In retrospect, it is not difficult to recognise that the diverse representatives of the old evolutionary economics were groping for an economic evometrics—both in the broad and the narrow sense. This is especially clear in the case of Schumpeter who, from the very start of his academic career, was confronted with the need of overcoming the methodological battle between historically and theoretically oriented economists of Germany and Austria. The historically oriented economists—working on the research agenda defined by Schmoller—were fascinated by the phenomenon of economic evolution, but they lacked analytical tools for treating it systematically. The theoretically oriented economists—in the research tradition defined by Menger—studied economic phenomena that could be treated in an analytically clear-cut manner, and since this was not the case with respect to economic evolution, they tended to remove evolution from their research agenda. Schumpeter immediately recognised the merits of both research traditions, and he wanted to reconcile them. It was not least for this purpose that he developed his theory of economic evolution through innovative entrepreneurship and dynamic market selection. But although he in principle provided a theory that made sense of the work in the historical research tradition, no real reconciliation were obtained between theoretical and historical research. The main reason is that his theory was not empirically operational. This becomes clear from a study of the work in which he tried to make the full reconciliation, his *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. This was pointed out by a historically and statistically oriented economist (Kuznets, 1940), but is must also have been obvious to Schumpeter. In this context, Schumpeter's engagement in the creation and development of the *Econometric Society* may be seen as an attempt not only to increase the general level of economic analysis but also as a means of providing the missing link between his evolutionary theory and the historical study of economic evolution. This purpose became especially clear in one of his last contributions, a paper for the conference on business cycle research organised by the National Bureau of Economic Research (Schumpeter, 1949). Here he begged the assembled theorists and econometricians to organise a series of case studies of industrial and regional evolution. Although it was not understood at that time, the message of this paper is clear: the case studies were intended to provide an understanding of the basic mechanisms of economic evolution. Based on this understanding, the theorists and econometricians were assumed to develop analytical tools for the analysis of evolution and its macroeconomic effects. But nothing systematic was done towards the development of such tools.

Today we to a large extent have the historical and statistical data that Schumpeter was missing. They have been provided by studies that are directly dealing with innovation and evolution as well as by studies that are designed for other purposes, like the analysis of change in industrial productivity. For instance, Nelson's (1981) survey of productivity studies asks for a use of the Schumpeterian ideas of heterogeneity and creative destruction but at that time relevant data were missing, so 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). Although the suggested tools come quite far in describing evolutionary processes by means of quantitative statistics and phrase our hypotheses in terms of these statistics, they are specific to productivity studies and we still need general tools for overcoming the gap between on the one hand evolutionary theory and on the other hand quantitative and historical analyses of economic evolution. But even from the specialised work it is obvious that the tools of evolutionary analysis need a statistical orientation. This fact is a source of both the unity and the difficulties of modern evolutionary economics. We have to apply some sort of statistical analysis in any kind of evolutionary study—from the evolution that takes place within a large firm via evolution of an industry to evolution at the regional, national and global levels. In all cases, we have to specify the evolving populations, their behavioural characteristics, and the changing distributions of these characteristics. Whether we like it or not, we thus see that statistics enter even at the ground level of our thinking, where we define what to look for. The problem here is that few are accustomed to this kind of statistical thinking—partly because has poor support from commonly known analytic tools. To promote the unity of evolutionary economics there is thus a need for providing general statistical tools. The potential of such tools is not only to unify different theoretical approaches but also to unify theoretical and empirical analyses of evolution.

The tools that support evolutionary analysis are to a large extent available, but they have mainly been developed within evolutionary biology. Therefore, there is a need to consider to which extent these tools are not only relevant for biostatistics, or biometrics, but also as a general evometrics that can function as a starting point for an economic evometrics. That this is actually the case has become increasingly clear (Frank, 1998). It was R. A. Fisher (1999) who formulated the foundations for general evometric analysis through his combined efforts of developing modern statistics and modern evolutionary analysis. These foundations were largely formulated as a general theory of selection. At the very core of this theory is Fisher's so-called fundamental theorem of natural selection that says that the speed of evolutionary change is determined by the behavioural variance within a population. Fisher's immediate topic was biological evolution, but his analysis has full generality. He was actually proposing to treat selection in terms of what has later been called replicator dynamics or distance-from-mean dynamics. Thus the biologically oriented Fisher theorem may be seen as the application of a general Fisher Principle that is relevant for all forms of evolutionary processes (Metcalfe, 1998). However, Fisher's analysis is excluding what in the present paper is called localised innovation. Therefore, his equations do not cover the general case in which this phenomenon is present to a smaller or larger degree. George R. Price (1970; 1972a) solved this problem by developing a general method for partitioning of evolution. Thereby he not only clarified Fisher's main result about natural selection (Price, 1972b) and helped to lay the foundation for evolutionary game theory (Maynard Smith and Price, 1973). He also developed a general and very fruitful decomposition of *any* evolutionary change, and thereby he formulated the core of a general evometrics that can also be used for the analysis of economic evolution. In this paper it will be argued that this general evometrics and its specialisation into an economic evometrics to a large extent solves Schumpeter's problem of bridging between theoretical, statistical and historical forms of evolutionary analysis.

2. Price's general evometrics

2.1. Elements of general evometrics

Evolution is a unique process in historical time, and this is the main reason why the analysis of evolutionary change has proved difficult. This analysis presupposes a number of definitions and notational decisions that can be more or less scientifically fruitful. According to Price's solution, we start by selecting points of time in the unique evolutionary process. Our partitioning of time into steps is sometimes quite natural like in the case of agricultural crops, but often we have to enforce discrete time upon our data to allow for a simple treatment. In any case, we have a sequence of points of time, $t, t', t'', \ldots$ Evolution may then be described in terms of the states of the evolving system at subsequent points of time as well as by the function that transforms the state of the system between two points of time. In the simplest case, we have a transformation mechanism T that works on the state of our focal population P (called the pre-selection population) and the given state of the environment E to bring forth a new population P' (the post-selection population). Thus we have

$$(P;E) \xrightarrow{T} (P';E). \qquad (1)$$

By assuming an unchanged environment for the population, equation (1) obviously defines a simplified step in an evolutionary process. In this case we can concentrate on the evolutionary change in the focal population (which may consist of many subpopulations) as it is brought forth by the transformation mechanism under the condition of an unchanging environment (which to a large extent consists of other populations). In this context, we may consider two different questions. The first question presupposes that we know P and T. Then the question is which population P' will emerge. Our knowledge of T normally has the form of a theory. Therefore, the use of this theory to determine P' has the form of a theoretical prediction. This prediction may be falsified by means of experiments that often have the form of ‘natural experiments’, i.e. simple comparative cases of evolutionary change from real life. The second question can be put if we know P and P'. Then the question is what transformation T has brought about this change. In the present paper we shall concentrate on this question about the details of the evolutionary transformation that brings about an observed change of the population.

Table 1: Notation.

Variable	Description	Definition
X, X'	variables for initial population and end population	
x_i	size of entity i	
x	size of population	$\sum x_i$
s_i	population share of i	x_i / x
z_i	value of characteristic of i	
Δz_i	change in value of characteristic of i	$z_i' - z_i$
z	mean value of characteristic	$\sum s_i z_i$
Δz	change in the mean characteristic	$z' - z$
$\mathrm{Var}(z_i)$	variance of characteristics	$\sum s_i (z_i - z)^2$
w_i	reproduction coefficient (fitness) of i	x_i' / x_i
w	mean reproduction coefficient	$\sum s_i w_i$
$\mathrm{Cov}(w_i, z_i)$	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 in the end population	$\sum s_i w_i \Delta z_i$

From Andersen (forthcoming).

In order to describe the change from the pre-selection population P to the post-selection population P', we in principle need full individual-level information. Since each individual is characterised by a large number of evolutionary relevant characteristics, this is a very demanding requirement. In practise we may, however, concentrate on the evolution of a single or a few characteristics. Another requirement for our analysis is that we in an evolutionarily relevant way connect each member of the post-selection population to a member of the pre-selection population. In some cases, this is an even more demanding requirement, but in practice the connection can normally be done. Table 1 shows the information and the calculations needed for analysing evolutionary change of a population with respect to a single characteristic.

For concreteness, we may think of *P* and P' as consisting of firms. For exiting firms and for firms that are present in both *P* and P', the coupling between the two populations is unproblematic. But for radically new firms we cannot make the coupling. However, it is often possibility to connect new firms to old ones (like in the case of spin-offs). Given that we have solved this problem, we turn to the description of the population of firms and its change. First, firm *i* is described in terms of its resources x_i and their population share $s_i = x_i / x$, where *x* is the aggregate resources of the population of firms. Second, the firm is described by the value of an evolutionarily relevant characteristic z_i like productivity and the change in this productivity Δz_i. Third, the firm is described by its absolute fitness w_i. To avoid misconceptions, we shall use the more neutral term reproduction coefficient instead of fitness. We are also interested in the relative reproduction coefficient—or relative fitness—w_i / w.

Given this information, it is fairly easy to describe and analyse how P' is brought forth from *P*. This task is performed at the aggregate level.

> Definition: *Total evolutionary change* with respect to a particular characteristic of a population is the change in the mean of the individual values of that characteristic, i.e. $\mathrm{E}(\Delta z_i)$.

According to this definition evolution is about the change of a population with respect to one characteristic (or more characteristics). If there is no aggregate change, then there is no evolution. Thus we are not dealing with evolution in the unlikely case where there is no aggregate productivity change but instead a cancelling out of positive and negative changes at the level of firms. Given that we observe evolutionary change, we turn to the analysis of the elements of the mechanism of evolutionary transformation. This mechanism has two major components: transformation by selection and transformation by innovation.

Let us first consider transformation by selection, which in a certain sense it the most crucial part of our analysis.

Definition: The population-level *selection effect* with respect to a particular characteristic is the covariance between the relative reproduction coefficients and the values of that characteristic, i.e. $\mathrm{Cov}(w_i / w, z_i)$.

According to this definition selection is the component of the evolutionary transformation that assigns reproduction coefficients to the firms of the pre-selection population based on their characteristics. For each individual selection determines the relative reproduction coefficient w_i / w that corresponds to the value of its characteristic z_i (like productivity). If there are differences with respect to characteristics, then the post-selection population shows a changed structure to the degree that the initial differences are exploited by selection. This generalised definition of selection may by applied to a large number of cases—provided that we have an adequate mapping of the members of the pre-selection population and the post-selection population (Price 1995).

The definition of the selection effect tells us quite much about the phenomenon of selection. This is especially clear if we rewrite the definition into $\beta(w_i, z_i)\,\mathrm{Var}(z_i)$, i.e. as the product of the regression of the reproduction coefficient on the characteristics and the variance of the characteristics. The regression coefficient can be interpreted as the efficiency of selection to exploit differences in characteristics and the variance can be interpreted as the available differentials on with selection works. Another way of exploring the meaning of the selection effect is to rewrite the definition. Here we exploit the facts that $\sum \Delta s_i w = 0$ and that

$$s_i w_i / w = x_i w_i / xw = x_i' / x' = s_i'. \tag{2}$$

Given this information, we see that

$$\begin{aligned} \mathrm{Cov}(w_i / w, z_i) &= \sum s_i (w_i / w - 1)(z_i - z) \\ &= \sum (s' - s_i)(z_i - z) \\ &= \sum \Delta s_i (z_i - z) \\ &= \sum \Delta s_i z_i - \sum \Delta s_i z \\ &= \sum \Delta s_i z_i . \end{aligned} \tag{3}$$

Thus the definition of the selection effect reduces to the sum of the product of the changes in resource shares and the initial values of the characteristic.

The total evolutionary change is also influenced by the effect of what we here call innovation.

Definition: The population-level *innovation effect* with respect to a particular characteristic is the mean of the product of the change of the values of that characteristic and the relative reproduction coefficients, i.e. $\mathrm{E}(\Delta z_i w_i / w)$.

Here we define innovation as the component of the total evolutionary change that is determined by the weighted influence of the degree to which the members of the post-selection population have changed their characteristics when compared to the pre-selection population. This definition may be rewritten to clarify what innovation is about. We use the result of equation (2) in order to see that

$$\begin{aligned}\mathrm{E}(\Delta z_i w_i / w) &= \sum s_i (w_i / w)\Delta z_i \\ &= \sum s_i' \Delta z_i .\end{aligned} \tag{4}$$

Thus the innovation effect is simply the sum of the changes in the value of the characteristic weighted by the resource 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 valued 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 at the member level of the evolving population. Thus there is no assumption that the novelty is good for its carriers, so the value of the characteristic for individual members may have increased or decreased. In the case of the productivity of firms 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. The expected aggregate effects of both learning and forgetting are, of course, influenced by the capacity shares of the firms in the post-selection population.

2.2. Price's equation for partitioning evolutionary change

We now have all the elements for an analysis of evolutionary change. The problem is how to put them together. Price demonstrated that this task is actually quite simple. If we specify equation (1) as it was done above, then we find that evolution can be partitioned in the following way:

Total evolutionary change = Selection effect + Innovation effect.

Or, in formal terms:

$$\Delta z = \text{Cov}(w_i / w, z_i) + \text{E}(\Delta z_i w_i / w) = \frac{\text{Cov}(w_i, z_i)}{w} + \frac{\text{E}(w_i \Delta z_i)}{w}. \quad (5)$$

This equation is actually an identity that can fairly easily be derived, given our above analysis of the selection effect and the innovation effect. Let us—in terms of the notation of table 1—consider the first steps of the derivation:

$$\begin{aligned} \Delta z &= z' - z = \sum s_i' z_i' - \sum s_i z_i \\ &= \sum (s_i + \Delta s_i)(z_i + \Delta z_i) - \sum s_i z_i \\ &= \sum \Delta s_i z_i + \sum (s_i + \Delta s_i) \Delta z_i \\ &= \sum \Delta s_i z_i + \sum s_i' \Delta z_i. \end{aligned} \quad (6)$$

Thus we may rewrite total evolutionary change into two terms that we have already met. Equation (3) shows that the first term is the selection effect and equation (4) shows that the second term is the innovation effect. Thus we have demonstrated that Price's equation (5) is an identity.

Price's equation tells that any evolutionary change can be partitioned into a selection effect and an innovation effect, provided that we are able to perform the description discussed in section 2.1. Price's partitioning of evolutionary change may seem an obvious and rather trivial result, but this is not the case. Generations of evolutionary biologists and evolutionary economists have had the possibility of deriving this surprisingly fruitful partitioning, but they have failed to do so. The major reasons are that they have not had a sufficiently general concept of selection and that they have not been willing to make the necessary coupling of the pre-selection population with the post-selection population.

Before turning some of the many applications of Price's equation (5), it is important to explore some of its intrinsic properties. For this purpose it is convenient to study the equation in a slightly modified format:

$$w \Delta z = \text{Cov}(w_i, z_i) + \text{E}(w_i \Delta z_i). \quad (7)$$

One reason for using equation (7) is that it has a nicer typographical format than the other version. A more important reason is that it serves to emphasise the recursive nature of Price's equation. The possibility of recursive applications of equation (7) derives from the fact that the left hand side is structurally similar to the contents of the expectation term (i.e. $w_i \Delta z_i$). This means that Price's equation can be used to expand itself—if the members of the population (denoted by subscript *i*) are groups of submembers (denoted by subscript *ij*). This is often the case. For example, firms often consist of plants and the productivities of firms are often calculated as means of the productivities of these plants. Similarly, regional and national productivity statistics are often given as means of firms or plants. In all these cases, there are obvious possibilities of further partitioning of total evolutionary change. This means that

$$w_i = \sum s_{ij} w_{ij},\ z_i = \sum s_{ij} z_{ij} \ \text{ and } \ \Delta z_i = \sum s_{ij} \Delta z_{ij}.$$

Given this interpretation, it is obvious that we may apply Price's equation (7) to e.g. the evolution that takes place within firms considered as groups of plants. For each firm we find that

$$w_i \Delta z_i = \mathrm{Cov}(w_{ij}, z_{ij}) + \mathrm{E}(w_{ij} \Delta z_{ij}). \tag{8}$$

If we insert equation (8) into equation (7) and split the overall expectation term, we find that

$$w\Delta z = \underbrace{\mathrm{Cov}(w_i, z_i)}_{\text{Inter-group selection effect}} + \underbrace{\mathrm{E}(\mathrm{Cov}(w_{ij}, z_{ij}))}_{\text{Intra-group selection effect}} + \underbrace{\mathrm{E}(\mathrm{E}(w_{ij} \Delta z_{ij}))}_{\text{Intra-member innovation effect}}. \tag{9}$$

If we compare equation (9) with equation (7), we see that what was at the level of groups (e.g. firms) was considered an innovation effect is now partitioned into the expectation of the selection effects within the groups and the expectation of the more narrowly defined innovation effect within the members of the groups. For instance, we may study change of mean productivity at the national level in terms of three effects. First, there is selection between the firms of the industry. Here we can directly use the covariance between firm reproduction coefficients and firm productivities. Second, there is the expected value of the intra-firm selection between plants. If the mean of these selection effects is significant, it is due to the differences in the selection process in different firms. Third, there is the expected value of the innovation effects within plants—calculated first over plants and then over firms.

2.3. Problems of long-term evolutionary analysis

Price's equation id designed to analyse relatively short-term evolution. This becomes obvious if we follow the evolutionary process defined in equation (1) for more than a single step. As long as we are performing computer simulation of evolution, this recursive expansion of the evolutionary process is no big problem. However, in real life the focal population's environment may change both due a generalised transformation mechanism that affects several populations (so that E change to E') and because of exogenous environmental change (changing E to E'). Furthermore, even the transformation mechanism may itself change from T to T', etc. In this case the evolutionary process might generally be described as

$$(P, E; \mathrm{E}) \xrightarrow{T} (P', E'; \mathrm{E}') \xrightarrow{T'} (P'', E''; \mathrm{E}'') \xrightarrow{T''} \ldots \quad (10)$$

Here we have the analytically hopeless situation where everything is changing. But experience shows that although everything may change, there are widely different rates of change.

To handle these problems, we often assume that $E \approx E'$, $\mathrm{E} \approx \mathrm{E}'$ and $T \approx T'$. We may also try to extend these assumptions about equation (10) to the following transformations (e.g. $E' \approx E''$ and $T' \approx T''$). But as we move further into the future, the assumptions are less and less likely to hold. The problem with the environmental constancy assumption is that the environment changes because 'ecological' interactions between different populations and for reasons that are exogenous for the system of populations. There are also problems with the constancy assumption for the transformation mechanism, but they cannot be explored before we have analysed the main elements of this function. The possible lack of constancy of E and T means that we for pragmatic reasons often choose to study evolutionary transformation in the short run. Here 'short run' is defined as a period in which the population variables change significantly faster than the environmental variables and the transformation mechanism. According to this definition of the short run, we may pragmatically consider the slower changing variables as parameters. Presently, the major task for developing our understanding of economic evolution is, probably, to deepen our analysis of its shorter-term aspects where this condition holds.

3. Toward a practical economic evometrics

3.1. Schumpeter between econometrics and evometrics

On the background of Price's general evometrics, it is interesting to reconsider Schumpeter's (1939, p. 138, 143) efforts to find quantitative ways of analysing 'the cyclical process of economic evolution'. In this respect Schumpeter had great hopes that the emerging standard econometrics would help him in understanding this process, but in the end these hopes were frustrated. Schumpeter (1954, p. 1141) considered econometrics to be 'the alliance between statistics and theoretical economics', which might result in a 'dropping of the barriers between history and statistics and theory' (Schumpeter, 1931, p. 295). But with respect to his own work on economic evolution these hopes were not substantiated, although several young econometricians (including Frisch, Leontieff and Tintner) were eager to help him in transforming his theory into a quantitative format that would make it statistically operational. The failure of these efforts seem largely to be related to the lack of relevant microdata, but another problem was apparently an insufficient understanding of how the evolutionary process may influence the economic aggregates. Thus Schumpeter and his helpers were in vain looking for clues about the evolutionary process in the aggregate time series without even asking for statistical information about the underlying distributions of the behaviour of economic agents. However, while mainstream econometrics continued its aggregative analysis and showed no interest in the heterogeneity of behaviour, Schumpeter turned to historical studies in which this heterogeneity was the starting point.

It is probably on this background we should understand the attack on standard econometrics found in one of Schumpeter's last contributions. It was here that 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 innovation effect and the selection effect during relatively long business cycles. There was no immediate response to this plea, but now we have the relevant tools to study his propositions: During Schumpeterian economic upswings there is a relatively weak selection pressure that implies that the innovation effect dominates over the innovation effect, and the result is an increasing variance of economic behaviour. During economic downswings we instead see a dominance of the selection effect over the innovation effect because of a stronger selection pressure. Thus there is a relatively low variance of economic behaviour at the end of a downswing period. This low variance is considered to promote innovative activity, and through standard macroeconomic mechanisms this activity gives the impetus to a new upswing. Armed with Price's equation and plentiful longitudinal microdata, we can now confront these propositions more clearly that has hitherto been the case.

This exercise, which has to some extent already been performed in productivity studies, is just a first indication that Schumpeter was to a significant extent an empirically oriented thinker. Take his, somewhat mysterious, concept of creative destruction under capitalism (Schumpeter, 1950, p. 83). This concept immediately becomes clear in terms of the innovation effect in one period and the selection effect in the subsequent period. If we start from an economic system with no behavioural variance, then the only evolutionary change in the first period is only due to the innovation effect: this is the first part of creative evolution. In the next period the previous innovations will show up in the positive selection of economic activities with super-normal characteristics: this is the second part of creative evolution. In this period there is, however, also a negative selection of activities with sub-normal characteristics: this is the destructive evolution. Since economic agents normally react more strongly against negative selection than positive selection, this analysis immediately leads us toward Schumpeter's vision of long-term socio-political consequences of the process of creative destruction. More importantly, we have tools of measuring the size and the distribution of the destructive part of economic evolution.

In terms of Price's equation, it also becomes easier to understand the much-discussed change from Mark I to Mark II of Schumpeter's analysis of economic evolution under capitalism. If all innovative activities are transformed from individual entrepreneurs that create 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 Price's equation. The reason is that the Schumpeterian large-scale firms consist of many units, and come 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.

3.2. Hidden versions of Price's equation

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, 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 Price's general evometrics. Let us start with an example of the latter type of studies.

Since Price's equation (7) is totally general, it is not surprising that it may found by slight rewrites of a many formulas of applied economies. 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). 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'). Actually, they refer not to productivity but to the natural logarithm of total factor productivity ($\ln(z_i)$). They (or rather Foster et al., 1998, p. 16) decompose the logarithm of aggregate productivity change from the continuing plants in three components:

$$\begin{aligned} \Delta z &= \sum \Delta s_i (z_i - z) + \sum s_i \Delta z_i + \sum \Delta s_i \Delta z_i \\ &= \sum \Delta s_i z_i + \sum s_i' \Delta z_i . \end{aligned} \tag{11}$$

The first line in equation (11) is Bartelsman and Doms' preferred decomposition. Given our above rewrites (equations (3) and (6)), it is easy to see that the first component of equation (11) is the selection effect selection effect that can immediately be rewritten into the covariance form. 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. The former ($\sum s_i \Delta z_i$) is called the 'within-plant effect' while the latter ($\sum \Delta s_i \Delta z_i$) is called 'a covariance term'—a better name is the cross effect. In the second line of equation (11) a rewrite is performed to demonstrate that Price's equation immediately follows from their decomposition of productivity change.

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 (11) is not really fully reflecting their work. To be more specific, equation (11) only holds if there are no entering and exiting plants in the industry. However, their partitioning includes components for both continuing plants, entering plants and exiting plants. Thus they are really using a non-evolutionary indexing system where continuing plants indexed by *I*, entering plants by *J*, and exiting plants by *K*. In the notation of the present paper, the suggested partitioning of aggregate productivity change is

$$\Delta z = \sum \Delta s_I (z_I - z) + \sum s_I \Delta z_I + \sum \Delta s_I \Delta z_I + \sum s_J (z'_J - z) - \sum s_K (z_K - z).$$

The two added components are called the 'entry effect' and the 'exit effect'. As mentioned in section 2.1, it is simple to include the exit effect into the selection effect. However, the entry effect is more difficult to handle according to the logic of Price's evometrics. For obvious reasons, the entry effect is referring to the plants' productivities in the post-selection population, but we really would like to connect it to the productivities in the pre-selection population. In the case of spin-offs this it not difficult, but in general the issue requires further thought. Unless we resolve this kind of problems, but the mixing of different logics is likely to create some confusion in evolutionary interpretations of available microstudies. But if we resolve the problems, significant analytical possibilities are immediately available. The most obvious of these possibilities is to apply the expanded version of Price's equation (9) to study the multiple levels of selection that may influence productivity change.

Although it is obvious to try to apply Price's equation to empirical studies, it should be noted that Price (1970, p. 521) remarked that '[r]ecognition of the covariance is of no advantage for numerical calculation, but of much advantage for evolutionary reasoning and mathematical model building'. From the viewpoint of evolutionary economics, one of the main advantages is that his equation gives us a means of formulating theories and models in a quantitative way that, at least in principle, corresponds to measurable aspects of real evolutionary processes. But there are additional advantages. For instance, Price's equation may immediately be applied to the analysis of results from simulation models. Since it focuses on the core aspects of the evolutionary process, the result of its application can be very enlightening. Take, for instance, Nelson and Winter's (1982, Chs 12–14) simulation models of Schumpeterian competition. With respect to these models Nelson and Winter only applied statistical analysis to find the typical behaviour of simulation runs instead of studying particular runs that are heavily influenced by random events. The application of Price's equation implies a deeper analysis of the simulated evolutionary process. It immediately reveals that in the long run the Nelson–Winter models are dominated by the innovation effect. The reason is that the large firms show monopolistic restraint with respect to investment. Therefore, they do not transform super-normal productivity into super-normal reproduction coefficients. Instead they draw profits out of the industry. In such a setting there may still be some variance with respect to productivities, but the regression coefficient of reproduction coefficients on productivities is small. Instead mean productivity change becomes dominated by the innovation effect.

Although Nelson and Winter did not apply an evometric approach to their complex simulation models, they may nevertheless be considered as pioneers in the field. The reason is that they made significant use of such an approach in the analysis of their basic models of pure selection (Nelson and Winter, 1982, Chs 6, 7 and 10). Let us quickly review some of their results in the light of Price's equation. Nelson and Winter (1982, pp. 165–175) provided a pioneering statistical account for evolutionary change. They started by asking for reasons for an industry's increased productivity at time t' compared with time *t*. Thus describe in evolutionary terms how an industry's mean productivity has moved to z'. Here they consider both a selection effect and an innovation effect, but in their account they also open up for productivity change due to the routine adaptation to a change in the industry's environment (e.g. via changed prices). This adaptive change takes place in firms that apply given routines. Thus this change should be separated out because it is purely phenotypic (without a basis in a change in genotypic routines). The present paper makes no attempt to represent this third effect. Therefore, it is only possible to present a simplified version of the Nelson–Winter partitioning:

$$\begin{aligned} z' &= \sum s_i' z_i' = \sum (s_i + \Delta s_i) z_i' = \sum s_i z_i' + \sum \Delta s_i z_i' \\ &= \sum s_i z_i + \sum s_i \Delta z_i + \sum \Delta s_i z_i'. \end{aligned}$$

Nelson and Winter call the second component ($\sum s_i \Delta z_i$) the search effect. The reason is that they model innovation and imitation as search processes. In the present paper it is simply called the innovation effect. The third component ($\sum \Delta s_i z_i'$) is called the selection effect. The reason is that it is here the changed capacity shares that influence the industry's mean productivity. Nelson and Winter's choice of multiplying the changed shares with the *new* productivity might, however, be challenged from the viewpoint of the logic of selection (section 2.1). In the present paper the selection effect is defined in terms of the *old* productivity (or the *old* value of whatever characteristic we are dealing with). Since the first component of the equation ($\sum s_i z_i$) disappears when we study Δz, it is really an empty placeholder for what Nelson and Winter call the along-the-rule effect. Their effect emerges because even with given technology and given decision routines, the firm may respond to the environment by some purely phenotypic increase in productivity. Since the present paper does not formally distinguish between phenotype and genotype, the along-the-rule effect is included in the innovation effect.

In equation x there is no explicit inclusion of other statistical concepts than that of the weighted mean. It is, however, not difficult to make the statistical nature of the analysis more explicit. As an introduction to this issue, we shall relate to Nelson and Winter's (1982, pp. 240–245) pure selection model. In this model no innovation effect is included, so $z_i' = z_i$ for all *i*s. Another peculiarity of the model is that the selected characteristic is not measured as productivity but as unit costs of production. This means that lower unit costs that are selected for, so that the mean of the characteristic is decreased. But apart from the inclusion of a negative sign, this peculiarity does not influence the analysis of industrial change. Once more we shall consider a simplified version of Nelson and Winter's study. Given our previous derivation of Price's equation, we for their case immediately find that

$$\Delta z = \sum s_i z_i - \sum s_i' z_i' = -\sum \Delta s_i z_i = -\frac{\mathrm{Cov}(w_i, z_i)}{w}.$$

Thus Nelson and Winter should find Price's covariance terms in their models of pure selection. But they operate with a perfect selection process (i.e. $\beta(w_i, z_i) = 1$) and with an industry that does not change its mean capacity (i.e. $w = 1$). Thus they find that $\Delta z = -\mathrm{Var}(\mathrm{z_i})$, i.e. mean unit costs falls with a speed that is proportionate to the variance of the industry's unit costs. They observe that this is an analogue of Fisher's fundamental theorem of natural selection (Nelson and Winter, 1982, p. 243). It is, of course, remarkable that Nelson and Winter made an apparently independent discovery of a variant of Fisher's theorem. But they abstained from making a similar analysis for the case where there is both selection and innovation. This lack of generalisation created a gap between their formal models of pure selection and their complex simulation models that also includes innovation (and imitation, which is included in our innovation effect). The systematic application of Price's equation to evolutionary theorising may help to overcome this gap, which is widespread in evolutionary economics.

4. Summary and conclusions

This paper has argued that the development of a general statistical approach to quantitative evolutionary economics has for a long time been needed, that a limited form of this approach in to some extent already available in the practices of evolutionary economists, and that it is now possible to state it in a systematic form. The approach is called general evometrics, and it reached a relative stability through the work of George Price and his followers within evolutionary biology. They developed a general method for handling evolutionary change and a related partitioning of this change into what has here been called a selection effect and an innovation effect. This approach is designed to deal with relatively short-term evolution, but since long-term evolution is the result of short-term evolution, it also has some relevance in pointing out what makes long-term evolution so difficult to handle. The need for an economic evometrics was illustrated by the problems of Schumpeter in handling economic evolution in a quantitative way and by the surprising ease in specifying some of his theories in evometric terms. The tendency toward an independent development of an economic evometrics was illustrated by productivity studies and by Nelson and Winter's work. But these cases demonstrated that the developments within economics need to be supplemented with the generality and surprising fruitfulness of Price's approach to evometrics. This, of course, does not mean that we can borrow a fully operational economic evometrics from evolutionary biologists. It is especially clear that the analysis of economic evolution requires a much more systematic analysis of the innovation effect than is necessary in biology.

This analysis will include the issue of the interaction between the selection effect and the innovation effect as well as the consequences of the skew distributions on which economic selection works. It should, furthermore, be emphasised that the paper is far from giving a complete account for econometric tools. Obvious omissions are, for instance, the lack of discussion of the analysis of the inertia of economic behaviour and of the functions that determine the reproduction coefficients (fitness functions).

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