THE USE OF MODELING TOOLS FOR POLICY IN EVOLUTIONARY ENVIRONMENTS

Bart Verspagen

Paper prepared for the Netherlands Environmental Assessment Agency project ‘Environmental policy and modeling in evolutionary economics’.

Third version (October 2006)

Eindhoven Centre for Innovation Studies (Ecis)

Abstract

This is a position paper on the possibilities of informing the (economic and environmental) policy debate by using quantitative evolutionary models. I argue that an evolutionary worldview implies that the existing quantitative modeling tools used for policy analysis are problematic. Then I summarize the main elements of an evolutionary way of analysis, and the way in which it can be incorporated into quantitative models. I conclude with an outline of a proposal for how to apply the ideas in the analysis of energy transitions.
1. Introduction

Evolutionary economics has been presented as a more relevant alternative to mainstream economics. It is rooted in the economic analysis of technological change and innovation, and argues that it can provide a more realistic theory of these phenomena. Since innovation is a societal process with wide-ranging impacts, evolutionary economics is very relevant for policy.

But at the same time, the direct policy implications of evolutionary theorizing are far from clear. For example, it is not clear if the policy implications from evolutionary economics differ from those of mainstream economics. Even if the foundations of the two theories differ, the policy implications may be similar, especially when formulated at a general level (“stimulate technological innovation”).

Policy advice by economists has traditionally been based on quantitative simulation models that can be used to ‘predict’ the effects of policies, as if it were a laboratory setting. This has the advantage that the impact of policies can be assessed ex ante in a precise way (at least, if the model’s predictions are by-and-large correct).

This paper is concerned with the question whether such an approach is also possible using evolutionary economics (or evolutionary analysis in a broader sense). Is it possible to formulate quantitative evolutionary models that can be used to support policy? Given the tentative but affirmative answer to this question that I will give below, I will further ask whether the use of such evolutionary models differs from the use of the traditional economic policy models.

I will lay out my argument in the following way. In Section 2, I will briefly summarize the foundations of the mainstream economics approach to quantitative policy modeling. In Section 3, I will discuss the principle of evolutionary economic analysis, and define what I consider the most important elements of evolutionary thinking for the question formulated above. Section 4 will discuss two particular approaches to modeling, i.e., the use of confidence intervals and scenario analysis, and their relevance for evolutionary policy modeling. Section 5 will present a list of more concrete guiding points for evolutionary policy models. Finally, this list will be used in Section 6 to present the outlines of an example of an evolutionary policy model in the field of energy systems. More concrete, this model is aimed at modeling a potential transition to a hydrogen economy. Based on an existing model (Taanman, 2004), I
will discuss how such an approach may be implemented, what kind of results we may expect, and how these results should be interpreted.

2. Economic Policy Models and the Notion of Equilibrium

Economics has a relatively strong influence on policy thinking through the use of large-scale econometric models that are used for simulations to support policy. In these models, as in general in economics science, the notion of equilibrium plays a large role. The usual definition of equilibrium that is used in economics points to a state of the economic system in which none of the economic agents (firms, consumers) has an incentive to change behaviour (e.g., charge higher prices, or buy more of a certain good). Without such an incentive, there is no factor (apart from random fluctuations) that may induce any change, hence the term equilibrium. In such a static equilibrium, nothing changes in the way the economy works. Economic policy models are based on a notion of dynamic equilibrium. In its basic form, dynamic equilibrium is a sequence of static equilibria.

Take, for example, the case of a simple model of supply and demand. The interaction between demand and supply will lead to an equilibrium that is characterized by a unique price and quantity sold/bought. As long as this equilibrium is not reached (i.e., the price is either too high or too low), buyers and suppliers have an incentive to change. If the price is too high, suppliers cannot sell all products they wish to sell (there is a supply surplus), or, in other words, buyers are not willing to buy everything the suppliers offer. Hence there is an incentive for the suppliers to change their behaviour, for example by offering their surpluses at lower prices. This continues until the market reaches a point where demand and supply are equal to each other, and none of the parties has an incentive to change behaviour. We have reached static equilibrium.

However, if some of the external (exogenous is the usual technical term) factors that determine the market outcome change, the nature of the static equilibrium changes. For example, if the supply curve in our market example shifts to the left (e.g., due to climatic circumstances), the equilibrium market price will go up and the equilibrium quantity will go down. The result is a dynamic equilibrium path in which the price goes up from period to another, and the quantity goes down.

The economic policy modeling tradition that starts with Tinbergen is based on this framework of a dynamic equilibrium path. More specifically, it assumes that a) the dynamic equilibrium path is unique and
stable, b) that adjustment to static equilibrium is instantaneous, and c) we can calculate the equilibrium based on an empirical specification of the model that can be obtained by statistical procedures (econometrics).

These three assumptions, which I will discuss critically in Section 3, enable the policymaker to compare a whole range of policy options by plugging them into the model, and interpret the outcomes as in terms of various variables that are of interest for the maximization of policy outcomes. On the basis of such a comparison, the most favourable policy outcome can be selected, and the respective policy can be implemented.¹

Equilibrium is a cornerstone in this way of thinking, because it is an essential concept for the calculation of the effects of the policy variables. Changes in policy will change the equilibrium, and the measurable effect of policy is taken as the difference between those two equilibria.

The individual equations of the model that must be used to calculate the equilibrium are usually based on microeconomic theories of agent behaviour (this is the so-called micro-foundation of macroeconomics). For example, a supply curve will be based on a theory of producer behaviour (profit maximization) under restrictions set by market structure and production technology. In this step from micro to macro relations, the representative agent plays a large role. This is a notion that is used to aggregate outcomes of the microeconomic theory directly to the macroeconomic level, without the need to explicitly add up different behavioural patterns.

Uncertainty plays only minor role in this approach. It enters the equations in the form of a random disturbance term (with very specific characteristics) that is added to each equation. Thus, it can be expected that the actual outcome that will be observed in the real economy differs slightly from the outcome predicted by the model, due to these random disturbances. But for policy analysis, the disturbances do not matter, since one may compare the different policy options on an 'equal basis' by always setting the disturbances to zero.

3. Evolution, Equilibrium, Policy, and Modeling

¹ An additional problem is how the different variables (e.g., income growth, distribution, unemployment) should be weighted, but we will abstract from this here.
Before I compare the above approach to policy modeling to a more evolutionary way of thinking, there is a need to define what is meant by such an evolutionary approach. Quite often, an evolutionary process is defined as one in which novelty and selection work hand-in-hand to produce change. Although this is obviously a correct, and often useful definition, I will not adopt it here. The reason is that it does not help us outline what the specific consequences of evolution for policy modeling are.

Instead, I define the following four crucial characteristics of a socio-economic evolutionary process. First, such a process is characterized by bounded rationality at the micro level, leading to significant variety of behavioural patterns. When faced with the same external environment, different agents (individual consumers, firms) may react in different ways, and show different behaviour.

Second, evolutionary processes are characterized by a certain degree of persistence of random events. In simple words, small random events may change the course of history. Rather than being additive to a deterministic equilibrium, small random events in evolutionary processes may accumulate into larger factors that may change the nature of the system and its history.

Third, if equilibrium plays any role in an evolutionary process, it certainly is in the form of multiple equilibria. A dynamic system that has a single, stable equilibrium, will, at least in the long run, always tend towards this single equilibrium. This makes prediction simpler (if, as I did in Section 2, we assume that the equilibrium can be calculated). But in an evolutionary context, there generally are multiple equilibria, meaning that which particular equilibrium state is reached, depends on where the system starts (or, to take an advance on our discussion below, where it is pushed, for example by policy).

Fourth, in any evolutionary system, the speed with which equilibria are approached may vary over time (so-called punctuated equilibrium), but reaching equilibrium may take a long time. Moreover, and equilibria themselves are changing as a result of change in the system itself. As a result, equilibrium points in an evolutionary system are rarely actually reached. Instead, they serve as an attractor that pulls the system towards itself for a prolonged period, before giving way to a new attractor. The consequence of this is that we cannot take the equilibrium of an evolutionary model as a useful description of an actual future state of the world. Instead, we must model the path towards the equilibrium as an approximation of what the world may look like.
Note that each one of these four characteristics may be found in some specific economic modeling approaches, but that only in a truly evolutionary economic model, the four are found jointly. For example, Sargent (1994) uses the theory of bounded rationality and behavioural variety to model macroeconomic process. Krugman (1990) makes extensive use of the notion of multiple equilibria, the notion of persistence of random factors is central in the econometric debate about unit roots (Nelson & Plossner, 1982), and the debate on convergence in living standards (Barro and Sala-I-Martin, 1991) puts strong emphasis on transitory dynamics towards dynamic equilibrium.

The result of these four characteristics of evolutionary processes is that that evolution is very difficult to predict. Extending the argument from prediction in the (usual) time domain, it is also true that it is very hard to produce dependable “counterfactuals” in an evolutionary model. In the biological/paleontological debate, this had led to the famous question (asked by Stephen Jay Gould) “What would be conserved if the tape were run twice” (see also Fontana & Buss, 1994). This question refers to the thought experiment in which we would be able to run two parallel worlds, initially similar to our own, both in which evolution would take its course. After a significant amount of time had lapsed, would the two worlds look anything like each other, or like the one that we know now?

We can see how each of the four characteristics of evolution described above would contribute to producing widely diverging worlds. Bounded rationality and behavioural variety may lead individuals (once they had evolved) to go entirely different ways even when initial environments are similar, and this may in turn lead to different outcomes. The persistence of random events will lead to an accumulation of random events that is different from every realization of a stochastic process, again leading to completely different outcomes in the hypothetical parallel worlds. Multiple equilibria may equally fork the parallel worlds into completely different directions. Finally, when speed of the evolutionary change process differs between periods in each parallel world, this will induce again an element of difference between them.

One would thus tend to answer that “not much” would be preserved if the tape were played twice. This implies that evolutionary processes are characterized by a high degree of strong uncertainty. If \( n \) (where \( n \) is fairly large) “parallel worlds” that start out as being similar, may evolve to be quite different from each other after a while, this implies, first, that a large number of possible outcomes
are thinkable, and, second, that it is impossible to predict which of these outcomes will actually prevail.

In such a situation, traditional methods of assessing risk may loose their relevance, since these are based on probability distributions. A probability distribution assumes both that the possible outcomes are known in advance, and that (an estimate of) a probability can be given for each. But when uncertainty is strong, the possible outcomes are unknown, and the probability distribution cannot be conceived.

Despite this strong level of uncertainty, there must be some bounds to evolutionary outcomes, if only because the laws of nature (which, at a higher level, may be subject to evolution themselves). Thus, evolution is a process in which the two factors of chance and necessity (Monod, 1970) are intermingled and determine the direction that a system takes. In evolutionary biology (see, e.g., the popular works of Dawkins and Gould), there seems to be some consensus that the chance side of this relationship is dominant, but I will argue below that the balance may be different in socio-economic evolutionary systems.

These characteristics of evolutionary processes largely invalidate the approach in building economic policy models that I discussed in Section 2. Bounded rationality and the associated behavioural variety invalidate the idea of a representative agent, and hence makes the usual aggregation procedures impossible. Multiple equilibria invalidate the calculation of the single equilibrium that varies under policy variations, and introduces the need to consider starting conditions and define basins of attraction. The effects of stochastic processes and uncertainty invalidate the idea of a unique and calculable equilibrium. Finally, the importance of transitory dynamics detracts from the importance of the equilibrium notion itself.

Although it is obviously possible to discuss these issues at greater length, I will not do so here. Instead, I will focus the largest part of the essay on the positive implications of these four evolutionary principles for policy modeling.

4. Evolutionary Analysis and Existing Modeling Traditions

The main challenge to building evolutionary policy models is the fact that evolution is a process in which chance plays a significant role. The key feature of evolution is that small, random (and therefore unpredictable) events may have severe long-run consequences.
This means that any simulation exercises performed with a policy model must be taken with extreme caution.

In this Section, I ask the question whether any existing ways of dealing with uncertainty in quantitative models can help us deal with this feature of the evolutionary process. Two specific issues come to mind: first, sensitivity analysis and the augmentation of model simulations with confidence intervals and standard errors, and, second, scenario studies.

Initially, the outcomes of the policy models as described in Section 2 were taken as point estimates, i.e., the specific dynamic equilibrium path that was produced by the model for a given set of policy parameters, was taken as the direct estimation of the impact of the proposed policy. This obviously does not consider the uncertainty that is embedded in these models. There are at least two sources of such uncertainty: potential parameter variations, and imperfect estimations of exogenous variables (including the variables related to the policy itself).

However, given that we have some information on the potential amount of (stochastic) variation in these two dimensions, we may actually produce not only the single dynamic equilibrium paths, but also produce an indication of how variable they are under reasonable stochastic variations. Hence, instead of using the parameter values obtained in econometric estimation, we may vary the parameters by using the standard errors of these estimations. Similarly, we can undertake sensitivity analysis of the model outcomes as a result of variation in exogenous (policy) variables. In this way, instead of a point estimate of the policy effect, we can obtain a confidence interval.

While confidence intervals are obviously a step forward compared to points estimates, they do not solve any issues related to the model structure itself. For example, a model that is based on the notion of a single equilibrium that is characterized by traditional economic reasoning, does not chance in nature by having it produce confidence intervals instead of point estimates. If the structure of the model and the main ideas underlying it is flawed, a more sophisticated sensitivity analysis will not rescue its predictive power.

Scenario analysis may be a more sophisticated tool of analysis that comes closer to the core evolutionary ideas. Scenario analysis is usually associated with the systems dynamics way of modeling (e.g., Hughes, 1999), but it is also used in more mainstream (economic) policy models such as those used by the Netherlands Bureau of Eco-
nomic Policy Analysis. In scenario analysis, an existing policy model is used to generate a number of outlooks on the future. A scenario is specified as a combination of specific assumptions that can be associated with a broad narrative about potential ways in which the system that is being modeled will develop. It is not the intention of the scenario analysis to predict which scenario will take place, and this is a major difference with the mainstream policy models discussed in Section 2.

Instead, the aim of scenario analysis is to explore the variety of potential outcomes under alternative assumptions. For example, in a model of the global (macro) economy, one may wish to investigate the general nature of different scenarios for the development of world trade. Then, one could specify one scenario in which world trade will stagnate (e.g., as a consequence of the outcome of international negotiations about liberalizing trade), and one scenario in which international trade will grow. One may then investigate how a range of variables (e.g., global income distribution, CO2 emissions, etc.) will differ between the scenarios. In this way, an impression is obtained of how whether or not world trade will grow will change the world.

Scenario analysis is less pretentious in prescribing specific policies than the models we discussed in Section 2. It gives insight into the available range of policies and the order of magnitude of their effect, rather than analyzing the exact impact of a specific policy. In this sense, it is closer to the principles of evolutionary systems as outlined above, because it recognizes the large degree of uncertainty present in the real world.

Although scenario analysis may certainly be useful, I maintain that, as a potential centerpiece of evolutionary model building, it is not very useful. As I will argue below, evolutionary models may well be used to conduct scenario analysis, and this is likely to add insights, but scenario analysis is not the saviour of evolutionary model builders. The reason for this is that at the heart of the models that are used for scenario analysis, we still have the same approach that is used to build the policy models I discussed in Section 2. If the model itself is not built on evolutionary principles, using it for scenario analysis does not make it evolutionary.

5. Towards Evolutionary Policy Models

Although, as argued above, we must be pessimistic about the possibility of existing risk-treatment techniques in quantitative policy models for dealing with “evolutionary uncertainty”, the prospects
for using quantitative model tools in evolutionary policy analysis are not hopeless. This Section will attempt to outline some possible ways of proceeding in this way. The key issue is about the mix between chance and necessity in the evolutionary processes that we wish to analyze for policy. What is the relative contribution of chance and necessity to evolutionary processes remains a matter open to debate. Arguably, the outcome of this debate will differ between pure biological and socio-economic evolutionary systems.

In biological evolution, the main source of novelty is random genetic mutation. Genetic mutation consists of errors in copying genetic information, and can be characterized as a truly blind process. Any specific genetic mutation that occurs in the history of a biological process may or may not lead to a “useful” design change, but whether or not the change is “useful” plays no role at all in generating the mutation itself. Hence Richard Dawkins’ metaphor of the blind watchmaker: mutations are not purposeful, although they may, ex post, prove to be “useful”.

In socio-economic systems, more complicated sources of novelty exist. An important source is behaviour of the micro-entities in the system (let’s say firms and consumers). This behaviour, although not fully rational in the sense of mainstream economics, certainly has a purpose (as conceived by the agent). Behavioural change is implemented for a reason, and in general terms we may say that this reason is to generate better performance of the agent who implements the change. In addition, while genetic mutations are memory-less (there is a positive probability that a copying error is reversed later on), socio-economic agents have the ability to learn on the basis of their previous experiences. This opens up the possibility of experimentation aimed at finding a “good” strategy.

This has important consequences for the outcome of the evolutionary system. In the first place, the non-purposeful mutations in biology have a far greater potential range of impacts than the purposeful changes in socio-economic behaviour. Of all possible changes in behavioural patterns, the conscious economic agent will immediately rule out a number as non-sensible (even if they might make sense beyond the decision horizon of the individual agent). Biological evolution does not, at the level of the mutation itself, include any such selection. Thus, novelty in socio-economic evolutionary systems will be confined to a narrower (but possibly still rather broad) range than in biological systems.

Second, because agents in socio-economic systems can learn, as well as apply selection at their own micro-level, the speed at which evo-
evolution may take place will be much higher than in biological systems. In other words, the relevant time horizons in socio-economic systems are much shorter than those in biological systems. The emergence of mankind took millions of years, the emergence of the Industrial revolution several decades.

These two differences between biological and socio-economic evolution have consequences for the nature of the two evolutionary processes. In biological evolution, the potential for predicting which direction evolution will take is an impossibility. Carbon-based life on earth is a "magnificent accident" indeed, and we should not expect something even broadly similar to emerge in a parallel world. But in socio-economic evolution, the range of directions that evolution may take may be smaller.

This does not imply that predictability of socio-economic systems is perfect, or even close to the level that is assumed by the policy models discussed in Section 2 above. Socio-economic evolution remains a historical process in which contingencies play a role. It is different from a mechanistic process with perfect predictability. Predicting the motion of planets and other heavenly bodies using a Newtonian model remains a quite different affair from interpreting and analyzing evolutionary change in socio-economic systems. These latter systems are somewhere in between the clockwork world of Newton and the magnificent accident of Stephen Jay Gould.

Where exactly the systems that we are interested in are on this continuum, depends on the scope that we are taking, both in terms of time (how long do we want to look ahead?), and the range of phenomena we wish to look at. Contingencies and random factors are more likely to play a decisive role in making outcomes of evolutionary processes indeterminate when we look either at large scale systems of many interconnected components, or when we look at small-scale (micro) systems.

In the case of large-scale systems, indeterminacy is large because each of the interconnected components itself is unpredictable. Because of the dependency between the components in the system at large, unpredictability multiplies at the system level. The scope for building a precise quantitative evolutionary policy model for problems that require such large-scale systems analysis is thin.

At the micro level the problems are of a different nature. They stem from two sources. First, at the micro level, we have a large amount of external factors, each of which is the result of the large-scale system that we have discussed above. Second, behavioural patterns at
the micro level are subject to a large degree of heterogeneity, and evolutionary theory as such does not have much to add about the way in which this heterogeneity can be analyzed. This is the domain of psychology, and possibly sociology or even (mainstream) microeconomics.

Evolutionary theory in the field of socio-economic processes, on the contrary, is a theory of the intermediate range (Merton, 1973). When and if we can formulate problems that can be analyzed in an evolutionary system in which not too many different domains of interaction are involved, the scope for using quantitative models for policy purposes are good.

What exactly an “intermediate range problem” is, is hard to specify in more concrete terms. Probably the question of how Chinese economic growth will have an impact on the income distribution in the Netherlands in 2025 is an example of a too large-scale system to be analyzed in a precise quantitative way using an evolutionary policy model.

A sufficient but not necessary condition for an intermediate range problem can be formulated using the notion of multiple equilibria. If a specific policy problem is characterized by a small, but larger than one, number of equilibria, that can be clearly separated from each other, we may characterize this as a typical problem that can be modeled by evolutionary dynamics. Typically, problems in the field of transition analysis, e.g., environmental-friendly technological trajectories can be characterized in this way. I will therefore attempt to sketch the steps in modeling such transitions using evolutionary dynamics in the next Section. Before doing so, however, I will formulate in the remainder of this Section a number of general issues regarding the nature of evolutionary policy models.

In a pure technical sense, evolutionary models differ from more mainstream models in at least two ways that are important for policy analysis. The first one is the existence of multiple equilibria, and the second is the importance of variety in behavioural patterns.

Multiple equilibria provide a different perspective on policy than the one that is found in mainstream policy models. As summarized in Section 2, the usual way of looking at policy analysis in quantitative models is to assume that policy may change the nature of the (single) equilibrium in the model (world). With multiple equilibria, this changes. In addition to policy changing the character of the equilibria, there is also an option to move the system out of the
basin of attraction of one equilibrium, and into that of a different one.

This is a significant change of perspective in different ways. For example, it is not so clear that the “Lucas-critique” is valid in the same way in the case of a world with multiple equilibria. Lucas (1976) argues that if economic agents have rational expectations, government policy may in many cases be inefficient, because agents calculate the effects of government policy, adjust their actions accordingly, and the effect of the policy may be counteracted by this. In a technical sense, the equilibrium of the model is the same whether or not government policy is affected. But if there are multiple equilibria, the response of the agents to government policies may leave the equilibria unchanged, but may still put the economy on a track towards a different equilibrium.

Also, if there are multiple equilibria, government policy has more options. If, for reasons of efficiency of policy instruments, some policies are not effective, other options may still be open. For example, it may be the case that the nature of each of the multiple equilibria depends on technology (e.g., the case of alternative energy systems), but government has insufficient information to select the agents that are best situated to advance a certain technology (this is the argument often used by those who oppose a government policy based on “picking winners”). In this case, policy may be geared towards bringing the system in the basin of attraction of a different equilibrium, without having to pick winners (i.e., specific firms to subsidize) within or between alternative technologies. Instead, a general policy aimed at stimulating consumption may do the trick.

Thus, an evolutionary policy model must take the existence of multiple equilibria serious. But it is hardly to be expected that a generic model (i.e., set of equations that can be run on a computer) will tell us how many and which equilibria exist for a specific policy situation of interest. This is a task for exploratory analysis that must be performed before any particular model can be built.

This 'treatment' of multiple equilibria has two implications. First, it reinforces the argument about evolutionary policy model being theories of the intermediate range. We cannot build a generic model of the multiple equilibria that may attract the economic development of our society at large. We can only hope to build a model of the multiple equilibria of a problem in the intermediate range that we have carefully outlined by non-quantitative analysis before attempting to build a policy model.
Second, it implies that evolutionary model builders must work in close association with experts in a particular field, as well as experts in different kinds of (technology) foresight studies. This includes interacting with, for example, technical experts that work in a quantitative engineering tradition and who can help outlining the technology options, as well as using the heterogeneous ‘art’ of foresight studies in all its guises. The ‘roadmaps’ that foresight studies can produce should not be taken literal, but they can help in outlining in a general sense the various equilibria that serve as attractors in a socio-economic evolutionary system, as well as the factors that play a role in bringing the system towards one of these basins of attraction.

The second specific technical issue addressed by evolutionary (policy) models is behavioural heterogeneity. I have already argued that it is not the domain of evolutionary analysis to specify theories of individual behaviour. Instead, evolutionary theories take the population perspective, i.e., they describe the various types of agents that can be found in a population, and the way in which their behaviour may change under the pressure of selection and the generation of novelty.

There are two principal sources of behavioural variation in a population. The first is different characteristics between members of the population. Firms may differ in such dimensions as size, the products they produce, the technologies they use, their location, etc. Consumers may differ with regard to income, their preferences, their physical characteristics, etc. Such differences may induce differences in behaviour. The second source of behavioural variety lies in the notion of bounded rationality. Each individual agent may react differently to similar incentives, even in comparable circumstances. Exactly because individual behaviour is not completely rational (in the neo-classical economists' way), it is rather unpredictable, at least when analyzed from a population perspective.

In actual practice, these two sources of behavioural variety will interact, and it is difficult, if not impossible to separate them in terms of the empirical data that we have available. This is in strong contrast with the theoretical work in evolutionary economics, which has, traditionally since Nelson and Winter (1982), focused on the side of bounded rationality as a source of variety. This focus is at least partly the result of a desire of evolutionary economists to differentiate themselves from neo-classical economists. Critique of the assumption of strong rationality in mainstream neo-classical economics is obviously a cornerstone of evolutionary economic the-
ory. Thus, the existing evolutionary economic models, without a single exception, put a lot of emphasis on variety between agents that results from agents using different rules of thumb, or other decision rules. Variety that is related to differences in agents' characteristics has attracted much less attention.

In my view, this is a tendency that, although it may have merits in a theoretical context, is not very useful for the type of evolutionary modeling perspective that I propose here. In the intermediate range empirical model that I propose, we must arrive at a single, or at most a few, aggregate behavioural patterns by aggregating variety at the micro level. In order to be able to aggregate, we need both detailed data on the differences in characteristics in the population, and information (or an assumption) about variety in behavioural patterns (bounded rationality). In this aggregation process, the idea of fully modeling bounded rationality at the micro level is not very useful, for at least two reasons. The first is that the question of what motivates and drives an individual agent is, in most cases, simply not relevant for the more aggregate population-level outcome. The second is that, under many circumstances, it will be impossible to specify bounded rationality in a different way than by exogenously specified varieties of 'rules of thumb'.

As a way out of this, I propose two potential solutions. The first is that we use micro-level (evolutionary) theories to specify a limited number of "archetypal" patterns of bounded rationality, and link these to different population "scenarios" in the overall model. As an example, one may derive from a detailed (psychological) theory of consumer behaviour a taxonomy of consumers into "early and late adopters" (a real-world example would probably have a slightly more sophisticated classification), and link these to a specific fraction of the population to arrive at scenarios for overall population behaviour.

A second approach, however, may exist in simply using a single and rather straightforward assumption about actual bounded rationality in the population. This approach puts less emphasis on bounded rationality as a source of variety, and, instead, relies more on individual characteristics to generate the population diversity. When the single assumption on bounded rationality involves a (stylized) notion of optimizing, this strategy might appear as somewhat alien to the idea of evolutionary dynamics. Nevertheless, I argue that, if properly combined with variety in the characteristics of the population members, even such a simplified 'optimizing' approach can be useful at the level of intermediate range evolutionary models. Specifically, in the example of a modeling strategy that I will discuss
in Section 6 below, I will proceed along these lines, and use an explicit (although short-run) maximizing strategy for the population of adopters in the model.

Either way, these strategies depend to a large extent on the population variety that is generated by different characteristics in the population. Thus, there is, again, an important role for preliminary exploratory research. In this case, this must be aimed at describing, depending on the specific policy problem at hand, the user population, the way in which they may be affected by various factors in the model, and the way in which they may contribute towards moving the economy between equilibria. It can easily be seen that this requires different inputs than the type of foresight studies mentioned above. In this case, statistical information on user populations, as well as psychological, sociological and economic theory is needed to provide an adequate input to the model.

The emphasis on population dynamics in evolutionary models suggests a novel element in policy models in the form of game theory. Recently, so-called evolutionary game theory (Maynard-Smith, 1982) has asked the question under what circumstances novel “strategies” (behavioural patterns) can “invade” a population of existing behaviours. The concept of an evolutionary stable strategy (ESS) specifies a strategy that cannot be successfully invaded in this way. Possibly, evolutionary stable strategies are mixed strategies, i.e., a situation in which a part of the population plays one strategy, and another part plays a different strategy. Hence, behavioural heterogeneity plays a large role in evolutionary game theory.

The box on evolutionary game theory provides an example that illustrates the notion of an evolutionary stable strategy. The concept is important for the present analysis because it provides an analytical tool to analyze the potential switching between multiple equilibria in the case of heterogeneous populations. If an existing “constellation” of behavioural patterns can be characterized as an ESS (say, a user population locked-into a particular technology), the prospects of for switching between equilibria may be much more thin than if the existing “constellation” is not an ESS. In the latter case (not an ESS), a policy of attracting lead users may start a process of more or less automatic switching to a different equilibrium. In the former case (an ESS), policy may be more difficult and involve both coordinated user actions (persuading large amounts of consumers to switch at once, possibly by regulation) as well as specific policies aimed at changing the (relative) pay-offs of the two technologies (i.e., directly intervening at the level of technological innovation).
We use the well-known example of the game of Doves and Hawks to illustrate the main idea of an evolutionary stable strategy (EES) in a repeated game. Imagine a context in which each individual in a population of players repeatedly meets a different individual to fight over a resource (e.g., food). In each meeting (fight), the player can play one of two strategies. The Dove strategy is not to fight, the Hawk strategy is to fight. If a Dove strategy meets a Hawk strategy, the Hawk takes control of the resource, and no fight takes place. If the two players both the same (either Dove or Hawk) strategy, both have a 50% of taking the resource, and they both face a cost. The cost is lower when both players play the Dove strategy than when both players play the Hawk strategy. The players do not have any knowledge of their opponent’s strategy before the meeting. A specific numeric example is in the following pay-off matrix.

### Pay-off matrix for each meeting

<table>
<thead>
<tr>
<th>Own Strategy</th>
<th>Opponent’s strategy</th>
<th>Hawk</th>
<th>Dove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawk</td>
<td>-30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Dove</td>
<td>0</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Now suppose that the whole population is made up of Hawks. Clearly, all meetings will end with a pay-off of -30 for both players. What if, in this situation, one of the players considers switching to a Dove strategy? Obviously, this player will only meet Hawks, and therefore it will always get a zero pay-off (its opponent will have a pay-off equal to 50). Since 0 > -30, switching to a Dove strategy is beneficial for this individual player. What, on the contrary, if the whole population consists of Doves? Then, all meetings will end with a pay-off equal to 15 for both players. The player that considers switching to a Hawk strategy will be able to increase its pay-off to 50.

Clearly then, neither of the pure strategies Dove or Hawk is an evolutionary stable strategy. If the whole population consists of players with an identical strategy, it pays for the individual player to move to a different strategy. But now suppose that the players play so-called mixed strategies. This means that every time they play, they have a (fixed) probability of using a particular strategy.

As an example, let’s assume that all players have a 40% probability of playing Dove, and a 60% probability of playing Hawk. If a player plays Hawk, the expected pay-off is -30x0.6 + 50x0.4 = 2, while if it plays Dove, the expected pay-off is 0x0.6 + 5x0.4 = 2. Thus, the overall expected pay-off is 0.6x2 (Playing Hawk) + 0.6x2 (Playing Dove) = 2. Now let’s consider whether changing this strategy is beneficial for an individual agent. If it is only this agent who changes strategy, it will face the same expected pay-off (since the frequency of strategies with neither its opponents nor the pay-off matrix has changed). Hence there is no incentive for an individual to change strategies.

What if the whole population is playing strategies at a different frequency than the 0.6/0.4? Let’s suppose we have a 0.5/0.5 probability for the two strategies. Then, the expected pay-off for Hawks is -30x0.5 + 50x0.5 = 10 and the expected pay-off for Doves is 0x0.5 + 5x0.5 = 2.5. Clearly, the higher pay-off for being a Hawk will induce players to play the Hawk strategy more often, i.e., to increase the frequency. This will remain beneficial until the Hawk frequency is 0.6, at which point the pay-offs of the two strategies even out.

We conclude that in any population that does not apply the 0.6 Hawk frequency, mutant strategies can successfully invade the population. Hence only the 0.6 Hawk frequency is an evolutionary stable strategy.
The application of applied evolutionary game theoretic models seems a promising avenue to investigate these issues for concrete policy situations. There is still a major challenge involved here, because evolutionary game theory is a highly abstract field, in which the theoretical models tend to make highly simplified assumptions about both the strategies that are open to agents (players), and about the degree to which (expected) pay-offs can be measured. Moreover, the default setting of evolutionary game theory, i.e., a context of repeated meetings with multiple other players, may not be very adequate for most problems found in the reality of environmental policy.

Although one of the first applications of evolutionary game theory has been to the ‘Tragedy of the Commons’ problem (e.g., Axelrod, 1984), which is certainly an environmental problem, it is not easy to see how the context of repeated interactions between multiple players extends to a broader class of environmental problems.

Thus, some of the same arguments that I raised against the use of mainstream economic models in policy analysis, may be valid against evolutionary game theory models. But it is also conceivable that specific (intermediate range) problems may be identified in which evolutionary game theory can be usefully applied. I will therefore recommend in the Section below that applied evolutionary game theory becomes a standard element of evolutionary policy thinking. The purpose of applying evolutionary game theory in this way is to apply a wide range of potential behavioural patterns (including those that are hard to imagine for a present-day observer) in a stability test of existing behavioural patterns.

6. Some Specific Ideas on the Modeling of Transitions

In this Section, I will reflect on how the ideas expressed above can be put into practice in terms of developing an actual evolutionary model aimed at supporting policy decisions in the field of environmental analysis. The case I will consider is that of a potential transition towards a hydrogen economy. How exactly this hydrogen economy is defined, and what current systems it will replace, will be defined below.

My argument will be based to a large extent on the work of Taanman (2004), which is summarized by Taanman et al. (2006). This contains a detailed diffusion model of alternative technological trajectories towards a hydrogen economy. The core of this model, so I will argue, may well serve an evolutionary policy model.
The hydrogen economy: policy issues

The hydrogen economy (Rifkin, 2002) is now a much hyped vision of the future of the world’s energy system. Central in the hydrogen economy are the fuel cell and hydrogen. A fuel cell is a piece of machinery that generates electricity in an electrochemical way. It works by separating an electron from a hydrogen atom. Various types of fuel cells exist, and these can be classified both in terms of their technical characteristics (such as operating temperature, the material used for the electrodes, the type of fuel used, etc.), or in terms of their functional characteristics (such as mobile fuel cells, micro fuel cells, etc.). Thus, fuel cells may be used for a range of applications, such as in cars (instead of an internal combustion engine), in houses (for electric heaters, boilers, etc.), or in factories.

The fuel used in fuel cells is either pure hydrogen or some other fuel, such as methane, from which hydrogen is reformed inside the fuel cell itself. Hydrogen must be produced, and this can be done in various ways, some of which are sustainable, and some not. For example, one may produce hydrogen from water using solar power, which would be sustainable, or one may reform hydrogen from fossil fuels such as methane, which does not differ much from the existing methods of using fossil fuels in terms of sustainability.

With the range of different types of fuel cells and their varying applications, as well as the various ways of producing hydrogen, it is clear that hydrogen is a rather flexible way of providing energy. Hence the vision of a ‘hydrogen economy’, i.e., a complete system of production and consumption in which fuel cells and hydrogen are the sole carrier of energy.

I will set the task of formulating a realistic evolutionary policy model that can help us answer the question whether it is likely that the hydrogen economy can really replace the current fossil fuel economy. A secondary question is which particular policy measures can be envisaged to facilitate this transition.

The general way in which I will attempt to tackle this, keeping in mind the ideas expressed above, is to formulate the policy problem as one that typically fits the intermediate range for which evolutionary models can be used, and then to apply the principles of evolutionary analysis, such as a population approach and the (game theoretic) idea of mutant strategies. In general, this approach will imply that we collect and use a lot of specific information about the (future) hydrogen economy, rather than treating it as an ab-
Problem conceptualization

The set of factors that determine energy production and use can be characterized as a large-scale techno-economic system, with many complementarities. There are several factors that induce path-dependence in these systems. The first is that large-scale specific (infrastructural, but also non-material, e.g., in terms of knowledge) investments are necessary to support the system. A single actor is usually not able to finance these investments. Once in place, these investments represent a vested interest of the established players, which makes them less willing to switch to other technological trajectories. For a system that is challenging the vested interested (e.g., hydrogen), the large-scale investments represent a financial hurdle that is hard to overcome.

The second factor that induces path dependence is the fact that technological progress inside the system is strongly related to learning-by-doing and learning-by-using (i.e., dynamic increasing returns to scale). Hence new systems necessarily have to start at relatively low levels of productivity. Only by actually being implemented and used can productivity of the system grow. But with a more mature system in place, a new system may never reach levels of productivity that are competitive vis-à-vis the established system.

Theoretical work on competition between these technological systems has been presented by, among others, Arthur (1994) and David (1975). Models representing these processes have usually been formulated as dynamic models with multiple equilibria (e.g., Arthur et al., 1983). Each technological system is represented by one equilibrium (path). Depending on where the system starts, it locks-in to one of these equilibria. Once the lock-in has occurred, it is hard for the system to select a different equilibrium.

Thus, the specific problem area that I have chosen can be seen as one of multiple equilibria, lock-in and competition between (large-scale) technological systems. I have argued above that such a situation of multiple equilibria is a potentially good case of an intermediate range problem that can be successfully tackled by evolutionary models. I will consider the specific policy problem as one of potential transition from the current mode of energy production and use, towards one in which hydrogen and fuel cells play the central role. Obviously, this context is closely associated to current debates in environmental analysis and policy. Obviously, a large body
of existing literature exists on this topic, much of which is applied to the specific Dutch policy context (e.g., Hoogma et al., 2002, Kemp and Loorbach 2005).

Preliminary field work

As I have argued above, I see an important task for technology foresight studies, as well as a general engineering understanding of a particular technology in the modeling process. The main purpose of this type of analysis is to outline the possible configurations of the equilibria in the process that is being modeled. This includes both the existing energy system (based on fossil fuels) and the system of which we wish to investigate the probability of transition, i.e., the hydrogen economy.

It is obviously beyond the scope of this paper to present a complete assessment of this type. I will therefore suffice by giving some general directions that this preliminary analysis should take.

For the existing energy system of fossil fuels, two major problems exist. The first is CO₂ emissions. This is increasingly seen as a large-scale problem by policymakers because of the greenhouse effect. However, since the greenhouse effect is (politically disputed), commitment among policymakers to reducing CO₂ emissions is still not complete. Potential solutions for the CO₂ problem exist both within and outside the fossil fuel energy trajectory. Within, technological innovation may reduce emissions for a given amount of energy produced, or CO₂ may be captured and stored in a less harmful way.

Outside the fossil fuels trajectory, the hydrogen economy is a potential source of complete reduction of CO₂ emissions. The fuel cell itself does not produce any CO₂ or other harmful waste. Hydrogen can be produced both by using fossil fuels and without doing so. In the first case, CO₂ is produced, although it can potentially be captured and stored.

The second major challenge for the fossil fuel trajectory is the increasing scarcity of fossil fuels and the associated rise in energy prices. This cuts both at the supply side and the demand side. In terms of supply, it is true that the historical record shows a long history of discovery of ever-more amounts of oil and natural gas. But still, we know that these reserves are finite, and the day will that the reserves are so small that fossil fuels will become a too valuable resource to be the raw material for a global energy system. On the demand side, the industrialization and development of large
countries such as China, India and Brazil is already putting pressure on oil prices, and this affects the traditionally developed countries.

Hence three major factors about which we need to form some kind of foresight in order to characterize the equilibrium development path of the current energy system based on fossil fuels, are the effects of scarcity of fossil fuels, the expected benefits (mainly in terms of CO₂ emissions) of technological innovation, and the societal attitude towards CO₂ emissions and the greenhouse effect. These foresights must be operationalized into three model variables/parameters: the future development of oil prices, the expected rate of reduction of CO₂ emissions in the use of fossil fuels, and the expected social pressure towards reducing CO₂ emissions.

For the hydrogen energy system, a detailed outline of technological possibilities and the technological efficiency that can be expected for each of them must be constructed using foresight techniques. Taanman (2004) focuses on the use of fuel cells for micro cogeneration (micro warmtekrachtkoppeling). This means that the fuel cell produces electricity and heat at the same time, and hence can be used to supply in the need for electricity and heating in buildings (both residential and non-residential). This means that the model in Taanman (2004) does not consider the complete hydrogen economy, but his modeling strategy can be applied to the more general case by replicating the model for other uses of fuel cells (e.g., automobiles).

Within the micro cogeneration application, based on an outline of foresight studies, Taanman distinguished different technological options. These differ in three dimensions. First, whether the electricity demand or the heating-demand is leading. If electricity demand is leading, the fuel cell is switched on when electricity is demanded (e.g., when the resident switches on the light). In this case, heat is produced as a by-product, stored and used when needed. In the case where heating demand is leading, the fuel cell is switched on when heating is demand and electricity is produced as a by-product. In this case, electricity can be supplied back to the electricity network, fetching a price paid by the electricity company.

A different dimension in which technologies differ is the way in which hydrogen is produced. The crux here is that the fuel cell is installed in the building itself, and hence the hydrogen needs to be available at the local level. This can either be produced centrally and transported to the locality by means of a new pipe system, or by
mixing hydrogen with natural gas, for which an extensive transport infrastructure exists in the Netherlands. Taanman only considers the latter case, but his modeling strategy can also be applied to a completely new infrastructure. Hydrogen can also be produced locally (at the are level), in which case missing is not necessary. The costs of installing a local hydrogen production and distribution infrastructure differ between existing buildings and newly-built areas.

By combining the various options, a number of technological clusters can be formulated (e.g., heat-demand following fuel cells, decen-trally produced hydrogen). Note that the options in the Taanman (2004) model are not exhaustive, because a number of the technological options has been fixed. Besides the choice for micro cogeneration, also a choice has been made to consider only the production of hydrogen from fossil fuels (natural gas). Again, such a choice has implications for the specific outcomes (sustainable hydrogen production is more expensive, certainly in the shorter run), but the general modeling strategy could easily be maintained even if the type of hydrogen production is considered as an additional dimension in the technological domain.

For each of the technological clusters, a number of parameters, such as technologically efficiency, specific infrastructural costs, etc. must be formulated. Obviously, since this is essentially a foresight analysis, the parameter sets must take into account variability of these expectations and investigate the sensitivity of the outcomes for this variability.

A different part of the model for which detailed data must be collected is the (potential) user population. Since Taanman focuses on micro cogeneration, his units of observation on the user side are buildings (and the people who inhabit or use them). He starts from a detailed description of existing buildings in the Netherlands, distinguishing different type of residential buildings (e.g., detached, semi-detached, corner, terraced, apartment), as well as different commercial buildings (e.g., shops, factories, agricultural). He then constructs three different typical 'areas', which consist of a specific mix of these types of buildings. These four types are urban, semi-urban and rural. Each of the types of areas can be existing or newly-built.

Using recent data from Statistics Netherlands, the user population (buildings) is described, and a set of projections is made for how each type of area will grow in the period until 2050. Obviously, projected population growth and planning policies are the main in-
gredients in these projections. Again, variability in the projections is important.

Model elements and some examples of results

The model constructed by Taanman (2004) consists of an aggregated set of adoptions decisions in the population at the level of the three areas (urban, semi-urban, rural). The adoption decisions are assumed to depend only on an economic problem: the costs of using hydrogen and fuel cells are compared to traditional ways of heating and electricity-generation. Hence, each member of the population (i.e., an ‘area’) will compare the costs of using the fuel cell with traditional ways of heating and buying electricity from a supplier in the market. When the costs of using hydrogen fall below those of the traditional system, the area is assumed to adopt the hydrogen system. Obviously, this decision will differ between new entrants in the population (i.e., newly-built areas) and existing areas, because of the differences in costs. Generally, the newly-built areas will adopt earlier than existing areas.

It is obvious that this particular way in which the model is formulated involves an assumption of optimizing behaviour at the micro-level, even if the optimization problem is specified in relatively simple terms (e.g., no aggregating of benefits over longer time horizons, or discounting of future benefits). This goes back to the discussion, in the previous section, about the sources of variety at the population level. As was proposed in the previous section, I am willing to accept this stylized description of consumer behaviour, as long as it is complemented by a sufficient level of variety generated by population characteristics. The Taanman model obviously includes this source of variety, although in a larger scale application one would probably want to elaborate this aspect more.

In this way, diffusion curves can be generated. Table 1 summarizes some of the results for the example of decentralized hydrogen production and electricity-demand-following fuel cells. The table documents the year in which the model produces a take-off of hydrogen use (i.e., the year in which the first user adopts), and the year in which the complete population has adopted. The results are produced for a standard set of parameters, in which two parameters are varied: the price of electricity (which is a competitor for the hydrogen system) and the price of natural gas (which is both a competitor, and an important input into the price of hydrogen itself).

Table 1. Adoption years (take off – complete diffusion) produced by the model for different energy prices
<table>
<thead>
<tr>
<th>Scale factor price of natural gas</th>
<th>$\frac{1}{2}$</th>
<th>1</th>
<th>$1\frac{1}{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{1}{2}$</td>
<td>Hydrogen does not take off before 2050</td>
<td>2021 – 2027</td>
<td>2010 – 2012</td>
</tr>
<tr>
<td>1</td>
<td>2025 – 2034</td>
<td>2011 – 2015</td>
<td></td>
</tr>
<tr>
<td>$1\frac{1}{2}$</td>
<td>2032 - 2045</td>
<td>2013 - 2018</td>
<td></td>
</tr>
</tbody>
</table>

The results, which are given for illustration of the general model outcomes only, clearly show that the two prices have a substantial impact on the results. For low electricity prices, the hydrogen economy does not take off before 2050, but for high electricity prices, the take-off is predicted to take place soon (5 years from now). The price of natural gas has less of an impact, but even here the variation from $\frac{1}{2}$ to $1\frac{1}{2}$ can make a different of 22 years (in terms of the year in which complete diffusion is reached).

In line with the discussion above, we cannot take these results as predictions of what happens in the real-world evolutionary system in which the transition towards a hydrogen economy may (or may not) take place. We should take them as broad indications of the feasibility of a ‘hydrogen-equilibrium’ in the context of the multiple equilibria energy sub-system of the global (Dutch) economy. Rather than the end-result of a modeling analysis, they should be taken as the beginning or a more elaborate process.

**Use of model results**

The Taanman (2004) model is not an extremely realistic description of the actual evolutionary system of energy transitions. I prefer to call it an evolutionary model because it adheres to several major principles in the evolutionary theory of social and economic change, such as the existence of multiple equilibria, the modeling of the user side by means of a population approach in which heterogeneity plays a major role, and close interaction between the model and more qualitative foresight techniques (i.e., the use of detailed information about technological and other forecasts).

Before policy is actually evaluated using the model, I propose that the model results are qualified in a broader analysis of adoption dynamics using some of the principles of evolutionary game theory. This may seem odd, since the context of the model (the adoption, once and for all) of a fuel cell for micro cogeneration, does not resemble the context of multiple and repeated interactions between two players that we see in evolutionary game theory. Despite this, I think that the principles of evolutionary game theory can help us
investigate the robustness of the behavioural patterns that the model predicts.

As was explained above, the model only considers economic decisions, based on user costs. In practice, costs are undoubtedly an important ingredient in adoption decisions, but they are far from the only ingredient. The existing literature on transitions (e.g., Hoogma et al., 2002) has outlined many of these factors, but without being able to provide a precise quantitative interpretation of how the different dimensions of the decision process interact and compare to each other.

Factors that cannot easily be put into a cost-benefit calculation (e.g., perceived safety, related to the explosive nature of hydrogen, or the desire to contribute to a cleaner environment) have been described in this literature, and one of the notions that has emerged is that of niche management. The idea, in a nutshell, is that users are heterogeneous (as they are in the Taanman model), and that some specific users are more willing to adopt than others because they have a specific reason to do so. A group of these users are called a niche. A niche may exist because a specific characteristic of the user group makes their benefits especially high (i.e., a group of ‘heavy users’), or because they have strong inter-group imitation dynamics, or even because they like to use a specific artifact because of different reasons than the actual beneficial impact that policymakers are interested in (e.g., care drivers that are interested in fuel cell-driven cars because of driving characteristics rather than environmental considerations.

Evolutionary game theory may help us model the behaviour of these niche groups in more details, and may be employed to answer the question under which circumstances adoption may actually take place within a niche, and under which circumstances the niche adoption may ‘spill over’ to the broader user population. Although this game, at least in the case of durable goods such as a fuel cell, is not played repeatedly, we may take the existence of a large population as a way of justifying the use of average pay-offs for each strategy that we can define at the individual level. Thus, instead of arguing that each individual player repeatedly plays the same game, and hence has the average pay-off associated with the frequency of strategies by its opponents (see the box on evolutionary game theory above), we can assume that the population pay-off is a weighted average of non-repeated decisions.

What would be needed for the use of evolutionary game theory in this way would be a specification of how behavioural patterns are miti-
gated through a user population. Such a 'game theory plus' approach may be usefully applied to investigate how sensitive the outcomes of the pure economic model above are for a more realistic set of behavioral alternatives.

With this information, of which I cannot here give any specific empirical indication since I have not developed the game theoretic tools to implement it, the model results could be related to various policy options. This would most usefully take the route of identifying policy objectives that would be necessary to achieve a certain goal (e.g., "how much increase in fuel cell efficiency do we need to reasonably achieve a take-off of the hydrogen economy in 2015?") and then to find the policy instruments that can contribute to this goal. As long as the policymaker makes a realistic assessment of the potential of policy instruments, the whole traditional range of instruments can be applied towards this goal. Thus, both policies aimed at users (the selection environment) and at technology (trying to pick winners in the generation of evolutionary variation) are good candidates for an evolutionary policy. I see no reason at all why an evolutionary approach to policy would necessarily be restricted to either selection or variation generation. On the contrary, only a combination of various policy instruments is likely to achieve the necessary effects.

References


Fontana, W. and L. W. Buss (1994). "What would be conserved if "the tape were played twice"?" Proceedings of the National Academy of Sciences of the USA 91: 757-761.


