The Influence of Innovation and Imitation on Economic Performance

Sylvie Geisendorf[1]

ABSTRACT

The importance of innovation and imitation for the economy is discussed in different branches of economic theory. Some study the macro, others the micro level. Macroeconomic theories, concerned with technological progress do not explicitly distinguish between innovation and imitation. Microeconomic case studies, examine the advantage of one strategy over the other for individual firms, but do not study the macroeconomic effects. The present paper attempts to close this gap by proposing a model capturing the innovative and imitative activity on the micro level and the resulting performance on the macro level. This is done on the basis of a multi-agent simulation. The model gives a comprehensive picture of an evolving economy over time, first because it depicts the interplay of innovation and imitation and second because the agents are placed in a changing economic landscape, forcing them to discover new products. Apart from detecting a predominant strategy, the model shows to what extent the strategies depend on each other. A main result is that the significance of innovation is overemphasised in some parts of the literature. Imitation is the more important strategy, but it is actually the right mixture with a large proportion of imitation that is advancing an economy.

1. INTRODUCTION

THERE IS AN ONGOING DEBATE about the determinants of technological progress — the main source of economic growth. Standard economic growth theory, as in the Solow Model, uses an exogenously given rate at which technology advances, whereas the newer endogenous growth theories try to explain the reasons for this advance. Progress is attributed to local spillover effects (Romer, 1994), historical differences of the technological background (Barro and Sala i Martin, 1992) or human capital (Mankiw, 1992). On closer inspection, some of these aspects can be identified as imitation and some of them rather as innovation. However, endogenous growth theory does not explicitly distinguish between innovation and imitation, or discuss the extent to which one is based on the other or more profitable alternative. This debate is conducted apart from mathematical models of macroeconomics, in a mostly empirical literature. In a geographical economics approach, Florida (2002) argues that creativity — i.e. innovations of a particularly creative labour force - is the main factor of success. On the micro level, case studies examine the advantage of being a pioneer or imitator. The results are ambiguous: a lot of studies affirm that innovation is the prevalent strategy, but as Schnaars (1994) illustrates, they have a strong 'survivor bias' in that they are based on data of successful innovations. Schnaars himself sustains the view that imitation is the far more profitable strategy, if the high costs of unsuccessful inventive attempts are considered. These studies however, are concerned with individual firms and do not discuss the effects of the two strategies on macroeconomic performance.

Often situated in between micro and macro approaches are evolutionary models of economic change, considering innovation and imitation as driving forces of economic evolution — particularly those which are based on learning algorithms, comprising these two strategies. But they usually focus on questions other than a comparison of the advantages of one strategy over the other. They are, for example, interested in returns to investments in R&D (Nelson and Winter, 1982) or in a distinction between situations in which firms are likely to undertake one or the other strategy. Silverberg and Verspagen (1998) for example, assume imitation is more likely the more unsatisfactory a firm's performance was. A lot of studies are concerned with the diffusion of innovations and therefore do not distinguish between innovation and imitation, but between innovation and different mechanisms, rates or conditions of its diffusion (Metcalfe, 1988 or Silverberg, Dosi and Orsenigo, 1988).

The present paper attempts to compare the effects of innovation and imitation and to close the gap between micro and macro approaches by integrating both. It proposes a model capturing the innovative and imitative activity on the individual level and the resulting performance on the macro level, and their mutual influence upon each other. The individual behaviours on the micro level generate the system behaviour on the macro level, i.e. the summed performance of the model economy and its structure in terms of concentration or diversity of products. Because, in some scenarios individual profits depend on the number of firms producing the same good, this performance and the resulting structure depend directly on the extent to which competition reduces individual profits. Macro performance and the knowledge of products existing thus far determine, in turn, the development of next term's products, because they constitute the information base for the micro decisions of the next time period. Further micro development is thus linked to former macro results and vice versa. This direct link is a quality missing in solely micro and solely macro models.[2]

It seems more fruitful to study the effects of innovation and imitation from such an integrated perspective for several reasons. First, no innovative effort of firms is lost. Failures are included in the overall results of this model economy, as well as successful innovations. Thus the advantages of a leading firm are balanced against the drawback of others and the net effect becomes visible. Second the model, although quite simple, gives a more comprehensive picture of an evolving economy over time, in that it depicts the interplay of innovation and imitation. It does so even more, as the agents are placed in a changing economic landscape, where products formerly in demand disappear and new production opportunities have to be discovered.

Apart from detecting a predominant strategy, the model shows the extent to which strategies depend on each other, if the economy should develop as a whole. A key result is that the significance of innovation is overemphasised in some parts of the literature. The possible advantage of being first mover comes with a high price, because most innovative effort does not lead to profitable products. Firms or countries with the opportunity to imitate others are at a clear advantage, which confirms Schnaar's results, not only for single firms but for national economies. By attempting to discover profitable products exclusively by own innovations, without a parallel effort to take up high-quality background of others, an economy is performing on a much lower level than one that is able to profit from spillover effects, even if there are some leading firms in the former. On the other hand, the model demonstrates how important a sound innovation base is for overall growth, especially in a changing environment where products only sell well for some periods before being outdated by newly emerging requirements. Studies concentrating on the advantages of imitation should not forget to mention that an economy comprised solely of imitating firms would evolve nowhere. Finally the importance - but also the difficulties — of innovations are also illustrated by a comparison between economies starting with some or at least one good example to imitate and economies that have to invent everything from scratch.

The paper will proceed in the following way. Section two explains how we define innovation for the purposes of this paper and gives an overview over the discussion of innovation and imitation in empirical approaches on the micro or meso level and macro economic growth models. Section three introduces the model with which we will study the relation of innovation and imitation and the feedback between them and the macro performance of the model economy. It first explains how potential benefits are modelled by a product landscape and how this landscape changes over time; and then describes how the economic agents are behaving in this landscape. The model details are subsumed in Appendix 1. Section four discusses and illustrates the model results. Section five concludes the paper.

1. Innovation and imitation

Before we discuss the importance of innovation and imitation we should clarify what we understand by innovation. Innovations in the Schumpeterian sense start where entrepreneurs take up existing inventions and transform them into marketable products. Innovation therefore is understood as the creation of a product and its launch on the market, not as the creation or discovery of something virtually new (Schumpeter, 1961). Psychological innovation theories go a step further in the direction of diffusion, and only call a novelty an innovation if it manages to be accepted by its relevant community (Csikszentmihalyi, 1997). The most profound distinction is one between invention, innovation and diffusion (Beckenbach, 2005), where invention is the actual discovery of something new,[3] innovation is its transformation into something marketable and the diffusion process depicts whether (or how) an innovation is actually taken up by society.

Although the last distinction is quite useful, and certainly the most profound one, it is somewhat too subtle for our purposes. A distinction between invention and innovation is important, when a model is designed to explain how novelty is generated, as has been done elsewhere by the author (Geisendorf, 2004). However, the present paper concentrates on the difference between own innovative activity of a firm and the imitation of products. For this purpose we choose a simple distinction between innovation and imitation, where innovation comprises the invention and the development of a marketable product.[4] This use of the term largely corresponds to the common language use of the term innovation. Imitation means that firms are copying products of these innovative firms. The innovators are thus the ones who introduce novelty into the system.[5]

In economic growth theory, what at first glance should probably be the main theory concerned with different ways to introduce new products, innovation and imitation are not clearly distinguished. The main discussion is taking place around the question of whether the actual reasons for new products (or technological progress, as it is called there) should be part of the theoretical framework at all. Standard economic growth theory, as in the Solow Model (1956), uses an exogenously given rate at which technology advances, whereas the newer endogenous growth theories try to explain the reasons for this advance. On closer inspection, some of these reasons can be identified as imitation and others as an increase of the innovative capabilities of an economy or its agents.

The theory of local knowledge spillovers, for example, is clearly an imitative one (Romer, 1987). It does not actually explain how the imitation is performed, but it assumes capital investments in regions with a high technological level increase the level of technology more than in backward regions. The inclusion of investments in human capital, on the other hand, seems to be more of an innovation-based explanation for technological progress (Mankiw et al, 1992). To some extent, the two factors have been intermingled in the discussion, because it has been rightly stated, that technological spillover depends on a trained labour force, able to use and construct the copied technology and adapt it to local conditions; since, on the other hand, an educated population alone does not help if the country has no access to international best practice (Pack, 1994).

None of the new growth theories has generally substituted neoclassical growth theory so far, although of course, as Romer (1994, p.12) put it: "No economist [...] has ever been willing to make a serious defense of the position that technological change is literally a function of elapsed calendar time." It is certain that technological change, based on innovation and imitation, is crucial for economic development. But the critics of endogenous growth theory state that empirical tests have failed to prove a specific alternative theory for all circumstances so far (Pack, 1994).

An explicit debate about the importance of innovation over imitation or vice versa is conducted apart from neoclassical growth theory, in a more empirically based literature. Florida (2002), for example, refers to the emphasis of endogenous growth theory on the importance of human capital, but leaves the solely macroeconomic perspective. He is a clear advocate of the prevalent importance of creativity, i.e. innovative activity performed by particularly creative workers and tries to prove his assertions by comparing some creativity indices with economic performance. His research units are large and medium US cities, where he counts the numbers of well-educated employees, nightlife clubs and homosexuals, reflected in 'Talent', 'Coolness' or 'Diversity' indices; and compares them with income per capita. His theory is that growth is brought about by highly creative people and that they are attracted by the 'cool' ambiance of a city. He states that being attractive for such people is more important for a city than the usual economic incentives like low income taxes or house prices that attract 'conservative' firms. A main shortcoming of his theory might be that his data are disputable. Malanga (2004) alleges that a lot of Florida's leading cities have not done as well as Florida states and that his theory is based to a large extent on the period of the rapidly emerging internet enterprises with their stock exchange success, that subsequently proved to be exaggerated in many cases.

Thoroughly on the micro level are case studies in which the advantage of being a pioneer or imitator in newly emerging markets has been examined. A lot of them are cited and commented upon in Schnaars (1994). The problem of these studies however, is their solely individual perspective. They compare advantages of innovation or imitation for sometimes very specific markets, but are not exemplary for the whole economy, such as the highly protected pharmaceutical market (Schnaars, 1994). Most studies, moreover, that talk about the advantages of pioneering a new market have a strong 'survivor bias', in that they are based on databases of successful innovations (ibid, p.25). Schnaars himself sustains the view that imitation is the far more profitable strategy, if all aspects are considered, especially the high costs of unsuccessful innovative attempts. Such analysis might give interesting insights into the conditions under which particular firms can gain advantages by either innovating or imitating; and following Schnaars, with his more profound consideration of macroeconomic facts, a lot seem to speak for the lead of imitation as a strategy for the individual firm. The overall importance of these mechanisms for the growth of the whole economy, however, remains unclear.

This is where the present paper steps in. It attempts to capture the amount of innovative and imitative activity at the individual level, the resulting performance on the macro level and their interdependencies. The immediate relation between micro behaviour and macro performance is most straightforward. The income of the model economy is the sum of individual benefits. These however usually depend on the number of competitors for the sales of a given product and might even depend on the sales of other competing or complementary products. We will not include the latter effect but consider the former one. In different scenarios it will be tested how varying degrees of profit reductions in relation to the number of competitors offering the same product affect overall performance, the structure of the market and the performance of the strategies we are interested in. It can be expected, for example, that the more profits drop with the number of competitors, the less attractive an imitative strategy becomes — a further effect that is usually not investigated in the innovation/imitation case studies. Another advantage of the closed model economy is the fact that we omit the success bias that Schnaars (1994) suspects in a lot of innovation studies. The model will include failed as well as successful innovation and overall profits will reflect the net effect of both.

Macro performance and the structure of the economy in terms of product varieties and qualities than feed back to the micro behaviour of the next time period. They do so in several ways; first, because it is assumed that new products can only be developed on the basis of given knowledge. The formerly sold products thus constitute the knowledge base from which further developments have to be derived. This corresponds to the observation that new artefacts have to be built out of known materials and represent new combinations or variations of existing materials or ideas (Witt, 1997); second, because performance differences serve as a selection criterion to decide which products seem to be most profitable and thus in what direction innovations or imitation should be directed. As the firms have no perfect foresight their perception of their economic environment is thus restricted or determined in two ways by the current macro state.[6] Further development depends on current performance and on current products. The best performing products so far are most likely to be copied or modified in order to create own best-sellers.

But the link between the micro and macro levels goes further than that. When comparing the strategies of innovation and imitation, individual case studies neglect the question of where the basis for imitation should come from. In a closed economy the strategies are complements rather than substitutes. Our model should reveal to what extent one depends upon the other. Someone has to invent something new in order to enable others to copy it. The imitation of well performing products then raises overall income but also might reduce individual incomes, because first-mover advantages are reduced as followers invade the market. It is this process of Schumpeterian creative destruction (1961) that is to a large extent responsible for a prevailing incentive to develop new innovations even in stable environments. In the changing environment we will examine in the model, such a need still arises when profits do not depend on the number of producers selling a particular good, because the firms constantly have to adapt to new market requirements. This also corresponds with Hayek's idea of competition as a discovery process. Hayek argued that consumer preferences and production technologies have to be discovered in a competitive trial and error process which has certain similarities with the structure of the model we will propose here (Hayek, 1969). But his emphasis was on arguing against perfect information and optimisation: it was not on the relationship between innovation and imitation; as neither was Schumpeter's.

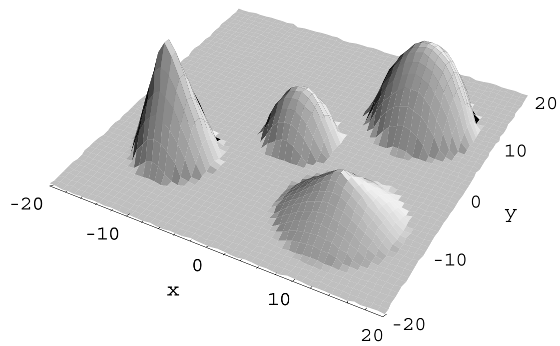
The paper investigates these interdependencies between innovation and imitation by a computer simulation model of a simple closed economy evolving over time. A number of heterogeneous economic agents or firms which are producing different goods of different qualities are placed in the same economic landscape, which is shaped by exogenously given demand. They produce and sell goods and can observe their own success and the success of their competitors. The model economy runs over several periods and the success of the current period determines how an agent will attempt to improve its product for the next period. As the model is designed to compare the effects of innovation and imitation, these strategies are not chosen by the agents but exogenously varied in different scenarios. This will allow us to compare the performances of economies whose firms are highly imitative with ones where only some agents imitate others, or everybody is inventing everything himself. [7]Macroeconomic success will thus be compared for different mixtures of the intensity of innovation and imitation, and for different initial settings, to test for the importance of parameter variation and random starting conditions. As real economic environments are not stable over time — demand changes and requires new products — our model economy changes too. The agents are placed in a changing economic landscape, where products formerly in demand disappear and new production opportunities have to be discovered thus, creating a constant need for adaptation even when the assumption of declining profits due to too many suppliers is dropped.

2. Modelling the process of innovation and imitation

2.1. A complex product landscape and its representation of attainable profits

The individual firms are placed in a common product landscape, depicted in Figure 1. It is their economic environment. The hills in the landscape are profitable products. Each point on these product hills can be produced by a certain combination of two production inputs. Optimal product quality in terms of benefits is reached on top of the hills. Nothing is to be gained on the plain between the hills. Firms located on this plain have attempted an unsuccessful innovation.

Figure 1: Initial product landscape



The smaller product hills in front and in the middle of the landscape both have a maximum of 50, corresponding to the maximum benefit attainable on them. The rightmost cone has a maximum of 80 and the global maximum of the landscape is the cylinder with an altitude of 120. Although the cylinder has a maximum 1/3 higher than the cone, it is far more difficult to detect as the most profitable product hill, because of its steeper slope and smaller diameter.

While the depicted landscape remains the same throughout the following simulations, actual profits in the scenarios that have been run can vary with the number of firms selling the same product. In the reference scenario NO RED, profits do not depend on competitors. In two further scenarios profits drop with the number of firms on a product hill. In RED 0.5 the entire potential profit is only realised if just one firm sits on a product hill. When there are several firms profits drop continuously, to reach 0.5 of the potential profit, if everybody is selling the same product. Such a moderate drop of profits might seem too modest an effect of competition, but we have to take into account that populating the same product hill does not necessarily mean selling the exact same product. Different positions on a hill correspond to different variants or qualities of a product (e.g. different types of cars) which compete but also might have their respective groups of buyers. The modest drop of profits also might reflect the fact that new products often create rising markets with increasing sales as the product becomes widely accessible and prices drop. However, to test how a complete division of the potential profits influences the development of our model economy a third scenario, RED 0.1, has been run. Here, individual profits are always divided by the number of firms on a given product hill. For example, if all ten firms are producing the same good, each only earns 1/10th of the potential benefit.

2.2. Change of the economic environment over time

The economic landscape changes over time. It remains stable for some periods (1/3 of the observed time steps), then changes into a different economic environment, in which some of the product hills disappear and others emerge; and remains stable for the last 1/3 of the observation time. Altogether the economy is observed for 20 time steps. The change in the landscape is to be interpreted as a shift in demand or production possibilities.[8] Two kinds of change from the same initial landscape (Fig. 1) are studied in the simulations. In both landscapes the product represented by the middle hill disappears and the small front product hill is stable.

Landscape one (Fig. 2) makes performance for the economic agents easier for two reasons. First, during the periods of change, the leftmost cylinder transforms into a lower cone, but the profit of the corresponding production opportunity never drops to really low levels. Second, a cylinder (the new global maximum) emerges at the back. This product, however, does not differ in all respects from former products. In one input factor it is similar to the former cone and in the other to the former cylinder. Adaptation and even a switch from the former second best product to the new optimum are more likely than for an entirely novel product.

Figure 2: Landscape one after change

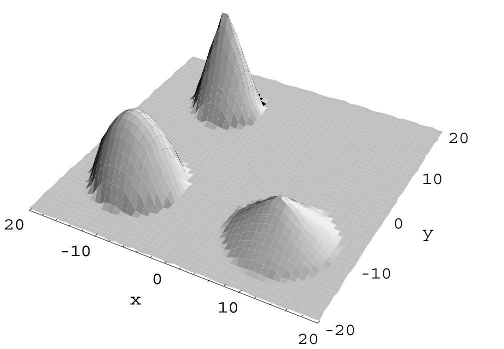
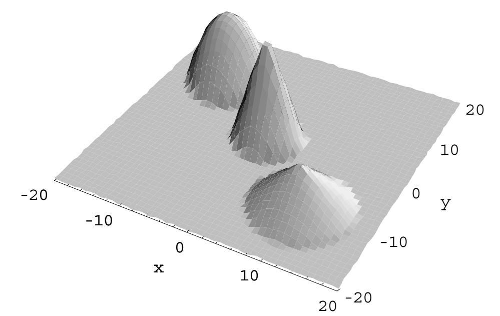
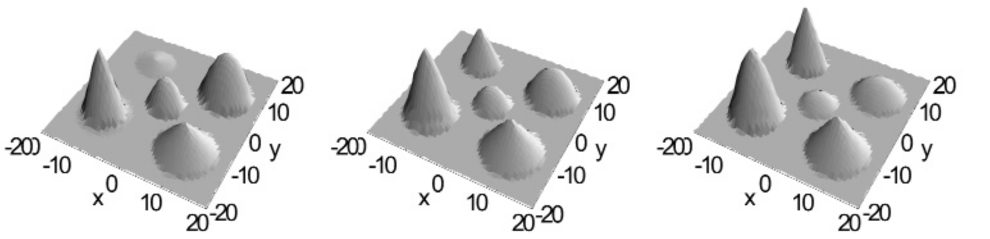


Figure 3: Landscape two after change



In the changed landscape two the optimum is harder to discern. To start with, the initial optimum is less likely to be found than the second best product. The change then is also in favour of the second best alternative. The new second best can be found by varying only one of the two production inputs, whereas the new optimum requires almost complete innovation, because it is only based on a formerly minor production function. During the periods of change, the economic landscape looks like something in between the two states. Figure 4 shows this for landscape one.

Figure 4: Change of landscape one over time/ time steps eight, ten and 11



2.3. The economic agents and their strategies

There are ten individual firms searching for profitable products in the economy. Each of them produces one good.[9] In the model they are represented by their production function for this good.[10] The production is a function of two inputs that are combined to form either a sellable product or something no one would buy. Benefit depends on how high a firm gets on the product hills and, in some scenarios, additionally on how many agents are selling on this same hill (i.e. selling the same product). Production inputs for each firm are represented by a binary string of 12 bits, where the first part is decoded for the amount of input one and the second part for input two. For details see Appendix 1. Both inputs can be varied by the following strategies:

- Pure Imitation of production functions or parts of them
- Innovation and imitation of whole successful production functions
- Innovation and imitation of parts of successful production functions
- Individual and independent innovation without exchange of ideas with others

An innovation occurs when a firm changes one or several bits of its string. Imitation implies the firm drops its own production function in favour of someone else's. When imitating parts of production functions, the firms keep part of their own former input scheme, but exchange some of it for the method of others. Note that there is no intentional choice of the firms between these strategies. Because the current paper tries to investigate the effect of different levels of innovative versus imitative activity, these levels are model parameters that are varied according to the above four scenarios. If agents copy parts or whole production schemes of others, they do so in proportion to the success of these firms. The bigger the advance of a firm, the more likely it is to be imitated by others. All these activities influence the amount of one or both of the production inputs either slightly or significantly. The inputs can be interpreted as aggregate input factors like capital and labour. Different amounts and combinations therefore not only imply different productivity levels for the same production, but can be interpreted as employment of different kinds of capital and labour. Consequently innovation either leads to another point on the product hill, or the firm ends up producing a different good.

Pure imitation or imitation of parts has only been regarded in exemplary runs for demonstration, because it represents an unrealistic restriction. Depending on initial production performance of the leading agents, the economy quickly converges to a mostly not very sophisticated level and once the economic environment changes it remains stuck — even in the zero-benefit plain — if virtually no one is coming up with something new (i.e. innovations). This possibility has therefore not been included in the below Monte-Carlo Simulations.

Each time period a firm can attempt to create new products or product improvements with a certain probability. This assumption is disputable as well as defendable. In evolutionary models like Genetic Algorithms it is argued that successful individuals are more likely to be selected to improve their strategies (or more precisely to be the basis for new strategies by mixing up theirs in their offspring).[11] Simon (1982), on the other hand, argues successful individuals have less incentive to change, because they are satisfied. Change, he states, only occurs when the individual's aspiration level is unfulfilled. Not contributing to this dispute here, the present model excludes neither assumption and lets the successful as well as the unsatisfied firms try to improve. However, as the activities of innovation and imitation are only performed with certain probabilities, not every firm actually develops a new product each time period.

In simulations in which only innovation takes place, every firm changes each part of its string with a certain probability. 2 per cent and 20 per cent are tested. That amounts to a total innovation propensity by changing at least one bit of the string of 24 per cent and 240 per cent if multiplied by the 12 bits. The second innovation probability is unrealistically high, but serves to examine whether the possibility to invent 'for free' might be favourable for the economy under some conditions. Note that for the first probability the product remains unchanged with a probability of 76 per cent, i.e. for ¾ of the firms.

In simulations where innovation and imitation are allowed, a mix of both activities as well as just one, is possible. An agent either only changes each part of its string with the given innovation probability (pmutate = 0.2 or 0.02); or it copies parts or whole production functions of others and additionally performs its own innovations by changing some elements. The former case occurs with a probability of 25 per cent, the latter with 75 per cent probability ($p = 0.75$). For given settings of pmutate the model is quite robust over a wide range of p. Results are therefore only given for this example. When only parts of other production functions are copied, it is randomly decided whether the imitation concerns both inputs or only one of them, and whether they are only altered or completely imitated from the example. In the purely innovative scenario p and pimutate are set to zero.

After the changes have been performed the new — as well as the unchanged — products are launched on the market and receive their corresponding benefits. This assumption again is again disputable and defendable. A lot of research and development activities lead to nothing marketable and it is plausible to assume that the innovative firms in particular try to assess the success of their possible products before actually putting them on the market. Although this seems to be a reasonable assumption, its inclusion into the model is not straightforward. The agents are placed in a landscape unknown to themselves, except for the few product performances they and their competitors have achieved. If they develop a new product, there is probably nothing in the known economic data to indicate whether it might be accepted by the market or not.[12] This is especially the case in a changing market environment. As Beckenbach (2005, p.10) writes: 'Novelty creating processes can be interpreted as processes solving ill-defined problems. Normally, there is no possibility for an unambiguous testing before really selecting and practicing an option.' However, as a reference scenario for the above setting, where all new products are launched on the market — called NEXT — a scenario BEST has been calculated. In this setting old products are only substituted for the new ones if they would have performed better under the former economic conditions.[13] Such a test can be imagined for the firms if we assume that they are able to determine a product's potential by performing market studies. Such an assessment would still not imply perfect information — which would lead to direct optimisation — but would nevertheless yield a more complete knowledge of the economic landscape than the agents possibly have.[14]

Besides, the better such a test would be, the more it would cost. Costs however, are not explicitly included in the model for several reasons. First, the model should be kept as simple as possible. Usually it is agreed upon that innovation is the more cost-intensive strategy (Schnaars, 1994). As the model will find that imitation is the prevalent strategy, cost inclusion would only emphasise this fact. Second, cost effects and the inclusion of other monetary effects like capital stock, starting capital, payments for patent rights, insolvency or a variation of costs according to the complexity of the action (incremental innovations would have to be less expensive than fundamental ones etc.) might superpose the basic comparison of the two strategies and blur the findings. However, after having established this basic relationship, it might be interesting to start testing their influence. We will come back to this point after the discussion of the results. The BEST scenario is certainly overoptimistic, because it does not account for the costs of such a sophisticated product placement, whereas NEXT — although it does not consider costs either — does reflect the larger costs of innovations implicitly. A key reason for the higher development costs of innovative firms is the large amount of unsuccessful innovative attempts. In the scenario NEXT, the higher costs of failure are included in the form of their economic counterpart in terms of forgone benefits that are present in the overall performance of this economy. As every innovation is put on the market, failures do not generate income.

3. Results — The relation of innovation and imitation

The performance of the model economy has been observed under different conditions, each of which have undergone a Monte Carlo simulation over 1.000 runs to get a statistical average. The economy has been started with four different initial conditions in terms of initial production functions: two randomly generated ones and two in which the first or the first two production functions of one of the random initialisations have been substituted for the optimal input mix. We observe the same initial landscape, changing over time in two different final landscapes. The performance is tested for two innovation intensities, one of which is rather high. Performance was observed for the first three of the four abovementioned product development strategies or strategy mixes in all these settings, whereas pure imitation has only been tested for reference and not been included in the Monte Carlo simulations, because its performance is quite straightforward. In three different scenarios it has been compared how innovation and imitation contribute to macroeconomic results if individual profits do or do not drop when several firms are producing the same good. They reach, from a profit that is independent of the number of competitors (NO RED), over a moderate reduction of 50 per cent of the theoretical profit, if all are selling the same product (RED 0.5); to a complete division of potential profits among all suppliers (RED 0.1).[15] Results for these three scenarios and the corresponding outcomes for product launching schemes NEXT and BEST are given in Tables 1 to 6 in Appendix 2. As NO RED will be our reference case in which the observed effects become most visible, the figures in the following section will be taken from this case. The outcome of the cases in which profits drop moderately or considerably under competition will be compared with the former in order to examine how robust its results are against such assumptions.

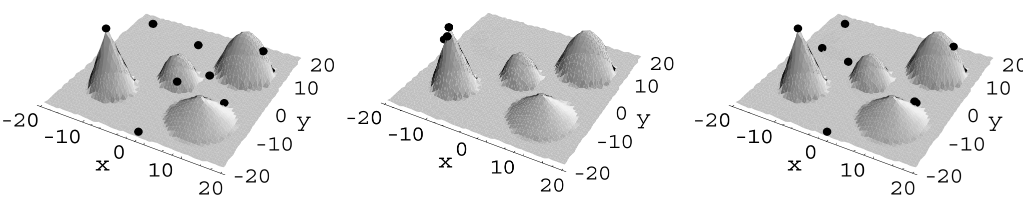
The performance indicator for the model economy is total benefit over time. For reference: if all the firms would spend all the time on the topmost product hill, total benefit over time would be 24,000 without profit division. All the results are considerably lower,[16] which is an interesting finding in comparison to standard economic theory, where optimisation is assumed. Even a privileged economy under scenario BEST, that only launches tested products and gets innovations and their tests for free, remains far from a long term optimum. It is able to locate profitable and even optimal solutions quite quickly, but still, innovations take time and the changing environment requires a continuous adaptation.[17]

The second interesting observation and the main focus of the paper is the effect of innovation and imitation on macroeconomic performance. As all individual attempts to place new products are comprised in the overall success of the model economy in terms of the benefit they generate — or fail to generate — the odds of developing new product opportunities become visible.[18] The disadvantage of economies with too many fruitless innovations or an unsuitable mixture of innovation and imitation thus becomes visible without considering costs explicitly.

3.1. Imitation pays

The prevalent result of the model is that whatever else the agents do it most profitable, if there is a large amount of imitation in the market. The economy as a whole generates the highest income when new ideas are propagated. This does not imply that some first movers might not be at a clear advantage over followers, but as Schnaars (1994) recognises, studies emphasising this advantage often sweep the huge amount of innovative activity necessary until a sellable product is found under the rug.[19] Figure 5 shows how an economy that allows for complete product imitation performs after five time steps[20] and how firms with the same initial conditions, including two optimal solutions, perform if no imitation is allowed.

Figure: 5: Initial conditions and time step five with and without imitation (NO RED, L1, Inv.int. 0.02, 2/4, NEXT)[21]

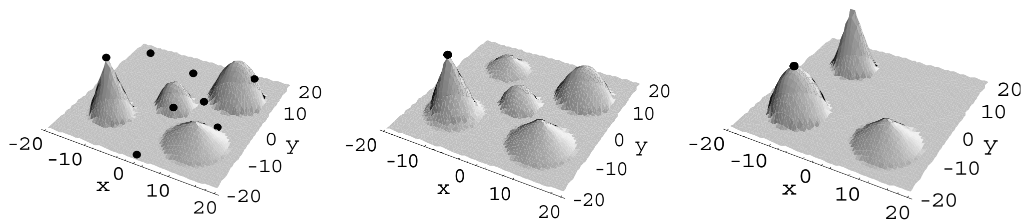


These results prevail to a large extent even if profits have to be shared among direct competitors. For the RED 0.5 scenario a large amount of complete product imitation is still providing the best results in most cases. It always does if it is accompanied by a large quantity of incremental innovations generating, in turn, new well-adapted variants quickly to copy. Indeed, it still does in the majority of cases with lower innovative activity (see Tables 3 and 4 in Appendix 2). Surprisingly, even for a complete split of profits among all suppliers of a given product, imitation remains the prevalent strategy for the more realistic setting NEXT, in which the agents do not have access to prelaunch performance tests for their new products. In over 56 per cent of the cases profits are highest with imitation. Thus even if profits have to be shared completely when competitors are on the same product hill — which is quite a strong assumption — a large extent of imitation advances an economy best. Only for BEST the economy performs better with partial imitation, in 88 per cent of the cases (see Tables 5 and 6 in Appendix 2). It should be obvious that complete imitation cannot lead to very high overall profits, if these are always split between all providers of identical and even similar goods. But because, on the other hand, a random search produces so many failures, it is no alternative. The overall performance in this scenario is not very high, but it is still to a huge extent maximised by a base level of innovations and high imitative activity, spreading its findings.

3.2. Success makes lazy

Although contributing largely to economic performance, imitation has its dangers. It takes heterogeneity out of the market. This does not matter if quick adaptation to given conditions is attempted, but becomes a problem in a changing environment. As Fig. 6 shows, economic agents can get quite resistant to change if they already are in a good position, especially if new products only are launched, when presumably performing better than accomplished ones. In the long run, this can pose a problem for an economy, because often new products do not sell better than established ones right from the start, although they have the potential to overtake the established products when given the chance to be ameliorated in use.[22]

Figure 6: Production schemes in time steps one, eight and 20 with imitation (NO RED, L1, Inv.int. 0.02, 2/4, BEST)



It is an interesting observation that an economy that has not yet converged to the global optimum at the beginning is better positioned to reach the optimum after change. This effect also becomes obvious when comparing the two landscapes. Landscape two undergoes more fundamental changes over time than landscape one. One result is that the global maximum after and during change is harder to find than in landscape one. The importance of this difficulty becomes observable when comparing results for simulations started with one or two pioneering firms with optimal product qualities, that others are allowed to imitate (imitation rows in 1/4 and 2/4 columns of the tables in the Appendix). Benefits of this economy get quite high in a first time period, where laggards are catching up with the market leaders. After the transformation of marketable product qualities however, it gets much harder to adapt to the new requirements, when fundamental innovations are necessary.[23]

Greater difficulties in detecting the global maximum after its shift are not always reflected in the sum of benefits over time, however. But the seeming indifference of the economy towards this complication under some conditions is deceptive. These findings are a result of the fact that, in many cases, agents do not detect the global maximum at all in the first stable time period. When settling on a local maximum, or still roaming search space, they are more likely to discover a newly-emerging opportunity than formerly optimising agents. Obviously — as probably in all evolving systems — there exists a trade-off between good adaptability and openness to further change.

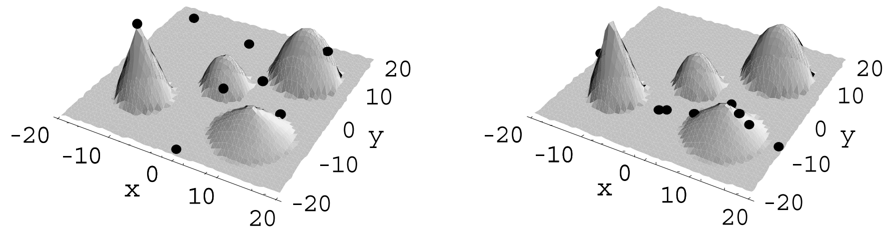
This adaptability is maintained best in the most competitive scenario. Although reducing overall profits, this Schumpeterian creative destruction also constitutes insurance against too homogenous a product landscape. As imitation of best practice lets individual profits drop, it becomes necessary to search for new innovations - and even minor products can provide larger benefits as long as one is the only one to produce them. It is interesting however, that this effect only occurs in RED 0.1, where profits drop considerably when innovators are imitated. In the other cases creative destruction is not strong enough to superpose the generally beneficial effect of imitation, although it comes with a risk of getting stuck. Therefore strong competition can even be an advantage, in that it forces innovations, although devaluing them quickly. If we transfer our scenario into the real economy, it might also generate higher incomes than in the model because the latter does not consider a production driven market, where the speed of new innovations also accelerates the speed with which they are accepted by the market.

3.3.Better imitate entirely than mix up parts

There is a considerable difference in performance between the strategy of partial and complete imitation.[24] This does not need to be so under all circumstances, but it certainly is so in a complex environment, where the inclusion of parts of others production functions often does not lead to a clear innovative mixture but to a strange muddle instead. The more complex the environment, the less obvious this might be for the imitating firm in advance. Recombination of successful elements is a strong procedure compared to pure trial and error, but on average profitability hills are climbed faster, if there is a possibility to directly follow leading firms. Figure 7 gives an example of what can happen, if a firm incorporates just some aspects of a successful production function, for example just the technological production process, without considering the importance of an effectively trained workforce or adequate materials.

The only exemption from this rule is the scenario with complete profit distribution among competitors and the possibility to assess product success in advance (NO RED, BEST). As complete imitation lets profits drop quickly, it is particularly the risk depicted in Figure 7 that is beneficial for this economy. Partial imitation enables the agents to innovate along only one product characteristic, and thus potentially invent something that is far enough away from former best sellers to create a new product (i.e. to detect a product hill that has not been occupied by others and will be protected longer from them, because complete imitation is not possible). This agrees with findings from empirical patent research, showing that the risk of being imitated is smaller when the strategy of innovation is less discernible (Flemming and Sorenson, 2003).

Figure 7: Initial conditions and time step 6 with partial imitation (NO RED, L2, Inv. int. 0.02, 2/4, NEXT)

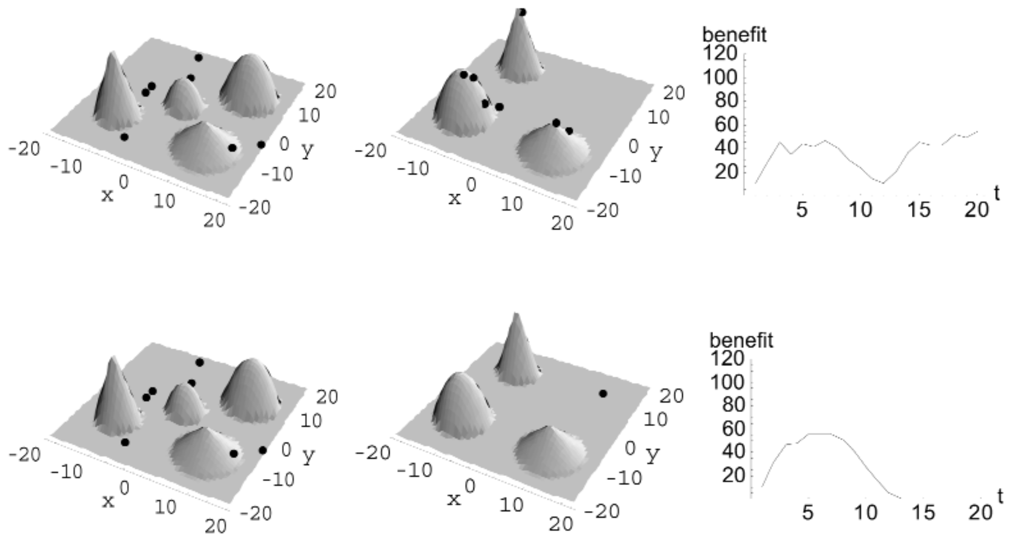


3.4. Imitation needs innovation

As strong as imitation is in advancing an economy, it needs a sound base of innovation. This must not be forgotten when long term economic development — such as for a country - is considered and when facing changing economic environments like real markets. Firms or countries relying utterly on imitation will find themselves at a point where no first mover has breached way anymore — perhaps because the imitator already took over all markets by being able to sell copied products at a lower price. If they have not contributed to the common knowledge pool so far, their labour force probably does not have the intellectual capacity to start suddenly being creative on their own. We do not go into detail here, but psychology tells us that creativity needs certain character traits (Guilford, 1976 or Csikszentmihalyi, 1997), that are possibly not easy to acquire on demand, if not trained.[25]

The necessity for ongoing innovations becomes all the more obvious when profits drop because of an invasion of a new market by imitators (RED 0.1 and 0.5). If we observe the development of our model economy over time in these scenarios, imitation is raising profits in a few periods after a new breakthrough has been invented. But when its market has been broadly discovered the benefits from further innovations increase again, because they allow the agents to switch to an unshared profit region. So what happens to some extent in the real economy is not a constant mixture of the strategies, but a succession of an innovative period that is replaced by an imitative one, once a noticeable breakthrough has been discovered, and will return when the higher profits of the time of the new products market launch are exhausted by competition. We have to keep in mind however, that a switch between these modes is not straightforward for the individual firm, because of the above mentioned argument that followers first have to learn about a new technology before they are able to perform their own innovation upon it. Instead of a constant switch between innovation and imitation activity in each firm, it is more the distribution of these activities that changes over time. But there are still leading firms and leading countries from which most innovations stem and imitating ones that disseminate them on a larger scale.

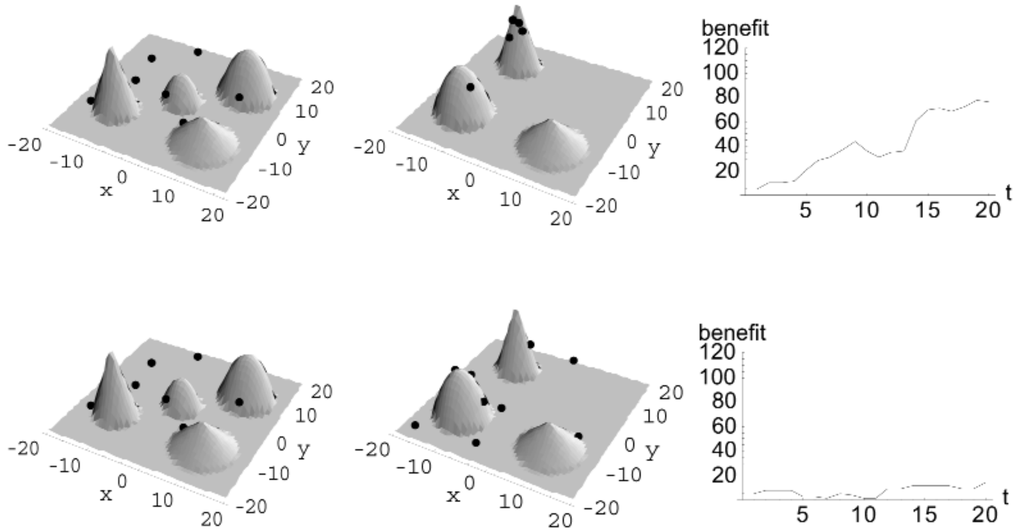
Figure 8: Initial conditions, production schemes at time step 20 and average benefit over time with imitation, but with and without innovation (NO RED, L1, Inv. int. 0.02, 1, NEXT)



3.5. Innovation needs imitation

Innovations are the base on which an economy can grow, but under most conditions it is not favourable to experiment as much as possible. The performance of a solely inventive economy is very low. This holds even if search and development cost are not explicitly regarded, as in this model. They are, however, included in the form of forgone benefits in scenario NEXT, where innovations often substitute products that have performed better than the newcomer. Benefits in this case are very low (see Figure 9 and the invention rows of table 1).

Figure 9: Initial conditions, production schemes at time step 20 and average benefit over time with innovation, but with and without imitation (NO RED, L1, Inv. int. 0.02, 4, NEXT)



In this context it is quite interesting to have a closer look at the economy where new innovations are only launched when superior to former practice. Somewhat surprisingly, even there exceedingly high creative activity for free is only favourable under very restrictive conditions. In a purely innovative economy such activity leads to considerably higher results than for fewer experiments, but as soon as imitation is allowed to some extent, the results become ambiguous, depending on initial conditions. And when successful products can be imitated entirely, it gets safer to stop experimenting this exuberantly (compare the rows for an invention intensity of 0.2 and 0.02 for the different strategies in table 2 in Appendix 2). The overall result is that inventing from scratch takes too long and reduces performance considerably. Inventions are a crucial base of a sound economic development but they have to be adjusted adequately.

4. Conclusions

The importance of innovation and imitation on economic performance and their interrelations have thus far not been studied thoroughly by the economic literature. Macroeconomic growth models do not distinguish clearly between them. Microeconomic empirical studies do not consider the macro effect of an individually preferable strategy and give ambiguous results, some arguing for the prevalence of innovation and some for imitation. This paper has tried to fill this gap by proposing a simulation model, linking the micro to the macro level and investigating the importance of both strategies and their interdependencies. The relevance of both thus becomes obvious in the macro results. The macro level in turn feeds back as a restriction on the micro level, because new products can only be developed out of or copied from existing ones; and their relative performance is the indicator of possible future success.

The model economy is designed as a multi-agent system with an economic landscape, indicating possible profits from several products and different product qualities. This landscape is exogenously given, but changes over time into two different final landscapes, in order to model changing market requirements. A number of heterogeneous agents have been placed in this landscape, each producing one good per time period. The model runs over a number of time periods in which the agents can try to develop new products by imitating others, copying parts of other agents' products and/or making their own innovations. In order to be able to compare the effect of these strategies, different scenarios have been run in which the proportion of the strategies has been fixed, ranging from pure imitation to pure innovation. The results reveal with which mixture the economy develops best over time. In three different scenarios it has been tested how these result depend on the extent to which profits drop when several suppliers are offering the same good (thus reducing the advantage of imitation). Results have been confirmed for several initial conditions and have been run in a Monte Carlo simulation to get reliable averages.

The integrated perspective of the model was able to show which strategy is preferable but, as well, how much it relies on the other strategy. Imitation is a very profitable strategy, not only for the imitator but for the economy in general, because it shifts technological know-how of the whole society towards a higher level, thereby making it easier — even for the already advanced firms — to develop further innovations. Innovation is thus a less important aspect for economic performance than assumed in some parts of the literature. On the other hand, the model also displays the key role innovation plays for overall development for several reasons. First and quite obviously, imitation needs a base on which to imitate, which is neglected in individual case studies arguing for imitation. Second, a mostly imitative strategy takes variety out of the economic system, making it inflexible to changes and even to the detection of preferable products under static conditions. It would only be advisable in an ideal world with an optimal example to copy from and not helpful in changing environments. Economic performance is best with a well balanced mixture of rather small inputs of novelty generating innovations and their diffusion by extended imitation activity. This result is robust over a wide range of tested scenarios. It only shifts towards on advantage of partial imitation for the case where profits are completely divided among all suppliers selling the same or similar products; and are able to check potential benefits of new products in advance.[26]

Although already displaying some effects quite agreeably, the model is still very basic and offers potential for further research and amelioration. One alteration to be tested might be the explicit inclusion of innovation costs. However it is not a priori clear whether this would actually be an improvement or would only complicate the model unduly. Schnaars (1994, p.28f) cites studies that found imitation costs were only 65 per cent of innovation costs, or that it only takes 70 per cent of innovation time to copy the product; and those figures are still rather cautious. This would mean the effect, already found, of a superiority of imitation would only be reinforced by making innovation even less attractive, without possibly gaining further insights. However, the inclusion of costs might cure another problem of the model. So far it sometimes displays unrealistically high leaps up or down, which can be attributed to the fact that innovations can be attempted at all times and for free. An inclusion of costs and a dependency of product development activities on capital might settle the model economy at reasonable growth rates.

Another interesting extension could be the inclusion of patent rights, imitation mistakes, for example depending on the technological complexity of a product or different costs for production inputs in different firms. The latter obviously leads to another interesting extension: the explicit distinction between different countries, one example being the technological leader and the other one trying to catch up by different strategies. Finally the demand side of the model could be endogenised more explicitly than by making benefits dependent on the total market supply of a product, by including demand curves.[27]

APPENDIX 1: MODEL DETAILS

The model has been written in Mathematica. In the following it will be explained to non-programmers in conventional language.

Initialisation

The model starts with a number n = ten of agents, which are initialised with starting values for their production functions. The production functions are binary strings of length m = 12. E.g.: {1,1,1,0,1,0,0,1,0,0,1,0}

Economic landscape

The agents are placed in an initial landscape (fig. 1). It contains two hills of maximum 50, one of maximum 80 and one of maximum 120. The plain in between the hills is of value zero. The functions and starting values for the cones and hills are defined as follows:

$$cones = \frac{-h_i}{r_i}\sqrt{(v_{i1}+x)^2+(v_{i2}+y)^2}+h$$

with radii ri = {5, 7}, hill centres vi{1,2} ={{-11, -9}, {10, -10}} and height hi = {120, 50}

$$hills = \frac{-h_i}{r_i^2}(v_{i1}+x)^2 + (v_{i2}+y)^2 + h$$

with radii *ri* = {6.32, 4.47}, hill centres *vi*{1,2} ={{11, 9}, {0, 0}} and height *hi* = {80, 50}

The initial landscape changes in two different scenarios (L1 and L2) into two different final landscapes, both containing equal theoretical profit opportunities (i.e. three hills of maximum 50, 80 and 120 respectively). Centres *vi*{1,2} for the changed landscapes are:

L1: *vi*{1,2} ={{-11, 9}, {-11, -9},{10, -10}} and L2: *vi*{1,2} ={{0, 0}, {-11, 9}, {10, -10}}

The change happens in the middle 1/3rd of the model running time and is performed by the following function:

$$For \;\; i < \tfrac{1}{3}, \; a = 0$$

$$For \;\; \tfrac{1}{3}I \;\le i \ge \tfrac{2}{3}I, \; a = -0.5\cos\left[\frac{i-\tfrac{1}{3}I}{\tfrac{2}{3}I-\tfrac{1}{3}I}\pi\right]+0.5$$

$$For \;\; i > \tfrac{2}{3}, \; a = 1$$

with I = running time of the model (here I = 20), i = current time step and a = morph parameter, changing the initial landscape into the final one by multiplying the first with (1-a) and the second with a.

Performance evaluation

The economic landscape constitutes a fitness landscape for the agents. Each point on it represents profits from a certain product and product quality. To evaluate profits, the binary strings are decoded into the two production inputs represented by the axes of the landscape. The first five bits of each string are decoded into input x, the last five bits into input y. The strings are first decoded into their corresponding decimal values which are then renormalised to the range of the landscape (reaching from -20 to 20, but note that the scaling of these figures is irrelevant):

decodeLabor = [string, 6]] / 63×40.-20
decodeCapital = [string,-6]] / 63×40-20

The resulting x and y values indicate the agents' position on the economic landscape, which attributes the corresponding benefit. Total performance is the sum of individual performances.

Influence of competition on profits

In NO RED every agents gets the full profit of the corresponding point in the landscape. RED 0.5 reduces benefits by multiplying potential benefit by $\frac{0,5}{n-1}(pn-1)+1$ and RED 0.1 by (n + 1 - pn), with pn = number of producers selling on the same product hill.

Product innovation and imitation/ Selection criterion
In each time period all agents can theoretically change their production function. Whether they actually do so depends on the probability to innovate inv.int. and the probability p to imitate at all, where pimi = 1 denotes complete imitation and pimi = 0 partial imitation. If they undertake a change which involves copying parts or whole strings of others, they select them by a roulette tournament, where each agent gets a slot size in relation to its benefit. According to the scenario studied, the agents innovate using one of the following algorithms:

Pure imitation:	inv.int. = 0, p = 0.75, pimi = 1
Innovation and imitation:	inv.int. = {0.02, 0.2}, p = 0.75, pimi = 1
Innovation and partial imitation:	inv.int. = {0.02, 0.2}, p = 0.75, pimi = 0
Pure innovation:	inv.int. = {0.02, 0.2}, p = 0, pimi = 0

Selection of next period's products
NEXT: all products are substituted by the new one, if one has been developed.
BEST: the new product only substitutes for the old one if performing better under current conditions. Note that this is not a full assessment of actual profits during the change of the landscape.

APPENDIX 2: TABLES

The numbers over the benefit columns in all the tables indicate the reproducible starting values, with which the runs have been initialised. All runs of a column have the same starting conditions in terms of product quality and choice. One and four are different starting values. 1/4 and 2/4 are almost the same as 4. Only the first (1/4) or the first two (2/4) products have been substituted by a production input mix corresponding to the global optimum.

No profit division

Table 1: NO RED, Average benefit over time of 1.000 runs for different strategies/ setting NEXT (all innovation are launched)

Innovation	*Strategy*	*1*	*4*	*1/4*	*2/4*
0.02	Innovation + imitation	6.945	5.175	13.994	14.425
	Innovation + imitation of parts	4.373	4.116	4.981	6.248
	Innovation	1.382	1.431	1.923	2.720
0.2	Innovation + imitation	2.227	2.649	3.042	3.177
	Innovation + imitation of parts	1.794	1.758	1.919	2.069
	Innovation	1.420	1.378	1.523	1.638
0.02	Innovation + imitation	6.896	5.856	9.269	9.693
	Innovation + imitation of parts	3.179	2.670	3.732	4.503
	Innovation	1.539	1.332	1.886	2.528
0.2	Innovation + imitation	2.386	2.292	2.650	2.764
	Innovation + imitation of parts	1.648	1.609	1.778	1.928
	Innovation	1.424	1.370	1.531	1.639

Table 2: NO RED, Average benefit over time of 1.000 runs for different strategies/ setting BEST (innovations are launched if performing better than old practice)

Product	*Innovation*	*Strategy*	*1*	*4*	*1/4*	*2/4*
	0.02	Innovation + imitation	9.016	6.206	17.563	17.925
		Innovation + imitation of parts	7.460	7.219	8.774	10.403
		Innovation	2.305	2.833	3.846	5.173
	0.2	Innovation + imitation	8.534	9.095	13.062	14.196
		Innovation + imitation of parts	7.079	7.661	8.603	10.171
		Innovation	5.921	6.816	7.056	8.404
	0.02	Innovation + imitation	8.100	7.831	11.443	11.807
		Innovation + imitation of parts	6.784	5.185	7.129	7.728
		Innovation	3.318	2.746	3.523	4.503
	0.2	Innovation + imitation	8.090	7.338	8.645	9.308
		Innovation + imitation of parts	6.647	6.264	7.109	7.804
		Innovation	6.257	5.860	6.627	7.331

Profit division RED 0.5

Table 3: RED 0.5, Average benefit over time of 1.000 runs for different strategies/ setting NEXT (all innovations are launched)

Product	*Innovation*	*Strategy*	*1*	*4*	*1/4*	*2/4*
	0.02	Innovation + imitation	1.011	1.556	3.730	4.594
		Innovation + imitation of parts	1.545	1.502	2.458	3.254
		Innovation	1.356	1.380	1.896	2.604
	0.2	Innovation + imitation	1.350	1.336	1.558	1.677
		Innovation + imitation of parts	1.188	1.326	1.501	1.632
		Innovation	1.378	1.326	1.472	1.574
	0.02	Innovation + imitation	1.332	1.349	3.132	3.759
		Innovation + imitation of parts	1.304	1.205	2.029	2.627
		Innovation	1.407	1.223	1.793	2.390
	0.2	Innovation + imitation	1.319	1.301	1.531	1.656
		Innovation + imitation of parts	1.227	1.273	1.442	1.560
		Innovation	1.311	1.257	1.420	1.516

Table 4: RED 0.5, Average benefit over time of 1.000 runs for different strategies/ setting BEST (innovations are launched if performing better than old practice)

Product	*Innovation*	*Strategy*	*1*	*4*	*1/4*	*2/4*
	0.02	Innovation + imitation	4.447	3.614	9.052	9.249
		Innovation + imitation of parts	5.645	5.201	7.176	8.289
		Innovation	2.059	2.397	3.279	4.742
	0.2	Innovation + imitation	6.358	6.236	8.353	8.807
		Innovation + imitation of parts	5.537	5.899	7.148	8.202
		Innovation	5.002	5.370	6.050	7.099
	0.02	Innovation + imitation	4.466	3.315	6.009	6.149
		Innovation + imitation of parts	5.619	3.738	5.693	6.441
		Innovation	2.794	2.353	3.124	3.952
	0.2	Innovation + imitation	5.571	5.285	6.536	6.896
		Innovation + imitation of parts	4.929	5.098	6.027	6.741
		Innovation	5.257	4.927	5.755	6.404

Profit division RED 0.1

Table 5: RED 0.1, Average benefit over time of 1.000 runs for different strategies/ setting NEXT (all innovation are launched)

Product	*Innovation*	*Strategy*	*1*	*4*	*1/4*	*2/4*
	0.02	Innovation + imitation	770	1.101	2.672	3.133
		Innovation + imitation of parts	1.452	1.388	2.273	2.931
		Innovation	1.327	1.336	1.870	2.530
	0.2	Innovation + imitation	1.288	1.272	1.493	1.605
		Innovation + imitation of parts	1.163	1.284	1.455	1.569
		Innovation	1.339	1.289	1.434	1.527
	0.02	Innovation + imitation	740	907	2.202	2.540
		Innovation + imitation of parts	1.163	1.049	1.840	2.365
		Innovation	1.301	1.146	1.706	2.258
	0.2	Innovation + imitation	1.191	1.180	1.390	1.512
		Innovation + imitation of parts	1.254	1.178	1.346	1.455
		Innovation	1.225	1.174	1.333	1.421

Table 6: RED 0.1, Average benefit over time of 1.000 runs for different strategies/ setting BEST (innovations are launched if performing better than old practice)

Product	*Innovation*	*Strategy*	*1*	*4*	*1/4*	*2/4*
	0.02	Innovation + imitation	2.934	1.970	2.823	2.684
		Innovation + imitation of parts	5.085	4.217	6.234	6.996
		Innovation	2.042	2.253	3.235	4.535
	0.2	Innovation + imitation	5.143	4.772	5.299	5.108
		Innovation + imitation of parts	4.795	5.036	6.220	6.904
		Innovation	4.526	4.753	5.487	6.335
	0.02	Innovation + imitation	2.647	1.820	2.756	2.582
		Innovation + imitation of parts	4.950	3.282	5.044	5.682
		Innovation	2.428	2.185	2.910	3.647
	0.2	Innovation + imitation	4.559	4.302	4.239	5.263
		Innovation + imitation of parts	4.398	4.436	5.368	5.923
		Innovation	4.596	4.363	5.158	5.750

Endnotes

1. Department of Environmental and Behavioural Economics, University of Kassel, Nora-Platiel-Str. 4, D-34109 Kassel. E-mail: s.geisendorf@wirtschaft.uni-kassel.de. I gratefully acknowledge valuable comments on earlier versions of the paper from Frank Beckenbach, Ramón Briegel and two anonymous referees.

2. For those familiar with synergetic models, it has to be said that the model is not a synergetic one, although comprising some of its characteristics.

3. As already defined by Usher (1959), an invention brings novelty into the system.

4. As some of them are profitable and others fail in the market, Csikszentmihalyi´s (1997) distinction is excluded.

5. Note, however, that in the following a product is called 'new' for an individual firm if it is has not been produced before by this particular firm, regardless of whether it was self-developed or copied.

6. Otherwise they would be able to produce the optimal product right away, or would be restricted solely by possibly missing resources for investments in human or physical capital required.

7. In reality the choice between both strategies is of course a complex problem itself. It depends on various aspects and is not something a firm can chose freely and constantly at will. Imitation, for example, is typically only possible when paying patent fees or being able to copy illegally as is often reproached regarding China (Webb 2002). On the other hand firms or countries catching up will often be forced to imitate existing technologies in order to learn enough about them to be able to improve them later on. Finally the possibilities to imitate might depend on firm or country interrelations or geographical closeness, as is discussed in the economics cluster literature (Guarino/ Tedeschi 2006).

8. The economy is thus basically driven by an exogenously-given change in demand but, as has been explained above, benefits can drop with the number of firms selling the same product, which creates an endogenous effect of economic structure on its benefits and further development.

9. Of course, firms producing a single good are not very sophisticated entities. But whole countries doing the same thing – as common in macroeconomic growth models – are even less so. So it might be justifiable to make this simplification. It is not a necessary one in terms of computability, but makes the interesting effects more discernible.

10. With the present paper, I do not want to contribute to the discussion about the justification of firms, their production schemes or products as entities of selection in an evolutionary model. This is done elsewhere (Geisendorf 2004) and by others in abundance (e.g. Mokyr 2003).

11. For those familiar with Genetic Algorithms, it can be said that the model has similarities with these models, but also deviates in some crucial aspects, the most important one probably being this deviation from natural selection in several respects.

12. No one knew in advance if monoskies or snowboards would succeed, the former being a sort of variant of skies, the latter a mixture of skies and skateboards or surfboards. Both propagated at first. Only after some years did snowboards prevail and even outnumber traditional skies for the next generation of customers.

13. See Nelson and Winter (1982) for this kind of internal selection, or Arifovic (1994), who used something similar as an 'election operator' in a Genetic Algorithm.

14. If they can find out how some products would perform, why not just look at the whole landscape to find out the global optimum straight away? Of course we could further assume that the landscape is so large an assessment of all possibilities is too time consuming and expensive, or that one is only capable of assessing the potential of products the characteristics of which are already known.

15. If, for example, all firms are selling the same product, each can only gain 1/10th of the profit one would gain if they were the only supplier.

16. The highest one, without profit division, being close to 18,000 with a large advance on most other results (Table 2 in Appendix 2).

17. This is an interesting result in itself, speaking for a more widespread use of evolutionary models to verify the results of general equilibrium models in more realistic settings, taking adaptation time into account.

18. This advantage is lost to some extent in scenario BEST. As mentioned above, this scenario is therefore only used for comparison. Most examples are taken from scenario NEXT.

19. This becomes clear when comparing simulations with and without at least one ideal initial product. Discovering possible new bestsellers takes a lot of time, and when the market changes before someone detects an opportunity is lost.

20. Remember that this is just before the landscape starts to change.

21. The information in parentheses gives details about the scenario from which the results are taken. The first indicates if individual profits are reduced if competitors offer the same product. The second value denotes whether dynamic landscape one or two has been used. The third specifies the innovation intensity of 0.2 or 0.02. The fourth indicates which initial production functions have been used, one and four being two randomly generated initialisations, whereas 1/4 and 2/4 designate the first or first two strings of random initialisation four have been substituted by the optimal production function.

22. The model incorporates this fact by making the global maximum hard to discover, because the region for which the product does better than the second best is rather small.

23. For example, for NO RED total benefits under a reasonable amount of innovation of 0.02, initially two optimal performing firms and an allowance to imitate is 14,425 in landscape one compared to 9,693 in landscape two (see Table 1 in Appendix 2).

24. In only one of the simulated 32 cases did partial imitation perform better than pure imitation.

25. This problem was, for example, realised by China. The Chinese economy is based on catching up by imitation to a large extent and it works tremendously well. The Chinese are very motivated to commit themselves to economic growth and the labour force is comparatively cheap. The Chinese mentality, however, does not have a strong critical tradition – an important prerequisite for creative thinking – a problem that is starting to be realised by the educational system (Hirn 2005).

26. The scenario thus being very restrictive in one respect and much idealised in another one.

27. In Geisendorf and Weise (2001) this has been done for a simpler economic landscape, in which agents search for an optimal production function for just one product and the demand side is modelled by a demand curve.

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