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## Firms' differential innovative success and market dynamics

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by

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## **Firms' Differential Innovative Success and Market Dynamics**

### **On the feedbacks between innovative activities and market competition**

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**Abstract:** This paper deals with innovative activities of firms, the resulting market success as well as the interdependencies between both. In a first theoretical part, different cases of those interdependencies are investigated by the way of a simple model based on replicator dynamics. It is shown that the resulting differential success (in those activities) of firms in a market leads to specific characteristic pattern of industry dynamics. The second empirical part of the paper is used to get an account of the working of replicator dynamics mechanism within German manufacturing. Doing so changes in firms' market shares and the relation to their respective relative technological performance and to their or innovative performance are investigated with productivity levels as a proxy for technological performance and productivity changes as proxy for innovative performance.

**Keywords:** Innovation, market competition, replicator dynamics, productivity decomposition

**JEL-classification:** O3, L1, D24

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## 1. Introduction

Joseph Alois Schumpeter made prominent the notion of competition in innovation by highlighting that entrepreneurs introduce new combinations into the economic system (Schumpeter 1912) and thereby destroy old structures – the notion of *creative destruction* (Schumpeter 1942) quite nicely describes this relationship of competition between the new and the old. With this approach in mind market competition can be seen as a mechanism which drives just this competition. Herein markets can be interpreted as a mechanism which continuously evaluates different, competing solution to a problem (new products, new way of production and consumption, etc.) and where this comparative evaluation leads to differential rewards (in the sense of profits, market shares, etc.). Thus, if the market process works sufficiently well, firms with above-average performance levels (high productivity growth rates) are expected to grow, firms with below-average performance levels (low productivity growth rates) are expected to shrink and better performing entering firms replace less performing exiting firms. Exactly this has been described as the process of creative destruction by Schumpeter (1942).

This relationship between innovations, their market success and the resulting structural development is at the core of an evolutionary interpretation of economic development as it has being introduced to the literature by Schumpeter and as it has been developed further during the last about six decades. Those endeavors comprise also formal modeling, initiated prominently the work by Nelson and Winter in the 1970s and 1980s, which applies quiet regularly the concept of replicator dynamics which has been in the literature of mathematical biology since the work of Fisher (1930). This dynamics applies a formal approach for understanding in the easiest way the relationship how differential performances of actors (maybe due to their differential abilities to apply or generate different technologies) translate into differential market success – even possibly leading to market exit. Quiet easily this approach can be enhanced by an endogenous dynamics for innovative success leading to the rather simple model relating innovative success and market selection. This kind of modeling has been very prominent in various simulation models of an evolutionary type. These aspects are also present in the more recent evolutionary models of Metcalfe (1994, 1998) and Winter et al. (2000, 2003).

This paper relies on those approaches and shows by the way of a simple model based on replicator dynamics how endogenous innovative activities and market success interact.

Dependent on the nature of those feedback effects, the resulting differential success (in those activities) of firms in a market leads to characteristic pattern of industry dynamics.

Besides these formal approaches, empirical analyses just focus on the question whether this market selection operates in the way suggested by theory. Such an endeavor has been shown to be rather difficult and a direct test in setting up a regression equation has as yet not lead to a confirmation of replicator dynamics to work. As an exception the paper by Metcalfe and Calderini (1998) is to be mentioned where the selection parameter (measuring the speed of selection) is tested for constancy over time and thus for the constancy of the selection to work. The literature on industry life cycle quite nicely shows – not only but also empirically – how market exit of firms can be related to a relatively weak technological or innovative performance (Klepper and Simmons 2005). It also shows for firms entering a market, that a subsequent high probability to survive is the higher the more innovative such an entrant is (Cantner et al. 2007, 2006, Cantner et al. 2005).

In addition to this literature empirical work developed exploring the patterns of plant entry, growth and exit in four-digit US manufacturing industries (see Dunne et al. 1988, 1989) and also among UK manufacturing establishments (Disney et al. 2003a). Other work such as Nickell (1996) and Nickell et al. (1997) concentrates on the generation of firm level evidence on the positive relation of product market competition and total factor productivity growth. These results are thoroughly surveyed by Caves (1998) and by Bartelsman and Doms (2000) with special focus on the relation to productivity. For the investigation of the relation of market turbulence and technological (i.e. productivity) change, decompositions of productivity measures into several components that shed light on the sources of aggregate productivity change at the micro-level and therefore provide an explanation for aggregate productivity change have been developed. These decomposition formulae allow in particular for the separation of the contributions of structural change and firm entry and exit to aggregate productivity development from the contribution of within-firm productivity growth. Since the beginning of the 1990s those decomposition formulae have been proposed by Baily et al. (1992, 1996) and Foster et al. (1998) together with applications to productivity change of US manufacturing establishments. Disney et al. (2003b) provide related results for UK manufacturing establishments. A notable and to date unnoticed precursor for the development of productivity decompositions is Salter (1960).<sup>1</sup>

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<sup>1</sup> See Salter (1960, pp. 184ff.) for the derivation of his decomposition and his chapters XI and XIII for the application to UK and US industry data, respectively.

This paper extends these analyses to Germany. The decomposition of productivity changes is here used to get an account of the working of replicator dynamics mechanism. Doing so changes in firms' market shares and the relation to their respective relative technological performance and to their or innovative performance are investigated with productivity levels as a proxy for technological performance and productivity changes as proxy for innovative performance.

The paper proceeds as follows. The theoretical section 2 introduces replicator dynamics as a mechanism able to cope with the relationship between innovativeness, market selection and structural change. The empirically oriented section 3 attempts to investigate whether the mechanism of replicator dynamics – as discussed in section 2 – holds for selected industrial sectors in German between 1981 and 1998. Section 4 concludes.

## **2. The Relationship between Innovativeness and Competition — A Formal Evolutionary Approach**

Within the evolutionary approach the relationship between innovativeness and competition is a central one for the explanation of structure, structural development and structural change. In order to provide a formal analysis for this, we refer to the so-called *replicator dynamics*. This principle goes back to Fisher (1930) and allows the formal representation of the Darwinian principle of *survival of the fittest*. The dynamic competition among heterogeneous agents can be dealt with here.

In a number of models replicator dynamics are applied to explain the dynamic development of certain sectors or whole economies. In general the high complexity of these models does not enable analytical solutions and therefore it is necessary to run simulation experiments (see for example, Kwasnicki and Kwasnicka, 1992; Kwasnicki, 1996; Saviotti and Mani, 1995). This holds especially when innovative activities are modeled as a search and experimental behavior (see for example, Nelson and Winter, 1982; Silverberg and Lehnert, 1994, 1996; Silverberg and Verspagen, 1994; Kwasnicki and Kwasnicka, 1992; Metcalfe 1994, 1998; Winter et al. 2000, 2003) and stochastic effects are taken into account. In the following we want to present the basic mechanisms within a quite simple deterministic model of an industry.

Replicator dynamics is formally given as follows: we consider  $N$  constant magnitudes or replicators  $i, i \in N$ , the relative frequency of which (share within total population  $N$ )  $s_i$

changes during time. This change is dependent on the fitness  $f_i$  with respect to the average weighted fitness  $\bar{f}$  of the whole population. Fitness in general is dependent on a vector  $\mathbf{s}$ , which contains the relative frequency of all replicators.<sup>2</sup> The respective dynamics is given by the following differential equation, where is  $\beta$  a parameter governing the speed of the selection dynamics:

$$\dot{s}_i = \beta \cdot s_i \cdot (f_i(\mathbf{s}) - \bar{f}(\mathbf{s})), \quad \bar{f}(\mathbf{s}) = \sum_N s_i \cdot f_i(\mathbf{s}). \quad (1)$$

For the analysis of industry evolution this dynamics is interpreted as follows: replicators  $i$  are considered as different firms within a sector which have a respective market share of  $s_i$ . Fitness  $f_i$  can be measured looking at the level of unit costs, productivity or in some other measures (see, for example, Metcalfe, 1994,1998; Mazzucato and Semmler, 1998; Cantner, 2002). The replicator dynamics now states for a constant fitness function  $f_i$  that a firm  $i$  will enhance (reduce) its market share whenever her fitness is above (below) the average weighted fitness within the sector. Then, by competitive selection, those firms with comparatively low fitness are driven out of the market. In the end, the firm with the highest fitness gains a monopoly position.<sup>3</sup>

At this point it has to be stated critically that in formulation (1) single firms have no impact on the selection dynamics. Hence, the routine of producing with fitness  $f_i$  will not be changed. At least for real actors with a selection disadvantage ( $f_i < \bar{f}$ ) a reaction is to be expected.

Let us assume that the only kind of reaction to be expected is that firms attempt to innovate. How can this be introduced into this formal model? Our discussion of empirical studies has shown that there are different feedback effects from the economic to the technological—innovative sphere. Quite generally, this can be taken into account by a dependence of fitness  $f_i$  from economic success  $e_i$  and within the context of innovative activities by the way of *dynamic scale effects*. These imply that the *change of fitness*<sup>4</sup> depends on the success of the firm. In principle, the following formulation holds:

<sup>2</sup> This broad formulation already contains the possibility of frequency-dependent fitness.

<sup>3</sup> It can be shown that average fitness, here unit costs, decrease proportionally to the variance of unit costs:  $\frac{\partial \bar{f}}{\partial t} = \text{var}(f_i) \leq 0$ , Fisher's fundamental theorem (Fisher 1930).

<sup>4</sup> When the level of fitness is affected, static economies of scale are at work (Metcalfe, 1994, 1998).

$$\dot{s}_i = \beta \cdot s_i \cdot (f_i(e_i) - \bar{f}), \quad \bar{f} = \sum_N s_i \cdot f_i(e_i). \quad (2)$$

$$\dot{f}_i = g(e_i). \quad (3)$$

Translating this into a sectoral model it can be asked how the economic success of a firm might be represented there. In quite a simple formulation it could be assumed that the market share  $s_i$  accounts for economic success. This market share can then represent economic as well as technological aspects relevant for further innovative success. With respect to the former, (relative) firm size is related to the ability of appropriating profits and of financing R&D projects. With respect to technological abilities and know-how a large market share and, thus, a large firm size implies that know-how can be accumulated quite easily, and a broad range of technological possibilities and directions can be covered. This case implies a model formulated with *positive dynamic scale effects* and oriented along the principle of *success breeds success*. Then the formulation fits along the regime of *Schumpeter II*, where relatively large firms are innovatively more successful.

However, contrary to this it could also be argued that small firms are more flexible and therefore more innovative. This flexibility economically refers to the effect that small firms do not have large R&D laboratories which can only be directed with high product costs; and in a technological context, large R&D laboratories apply very standardized routines in order to be innovative and these routines are not easily changeable. This problem should not be too difficult for small firms to solve. Therefore, an interpretation along the regime of *Schumpeter I* seems appropriate here, and the model formulation contains *negative dynamic scale effects* (see Malerba and Orsenigo, 1993, 1997).

Both alternatives are discussed in Mazzucatto and Semmler (1998) and in Cantner (2002). For the competition among firms, and for the innovations which improve the production process and therefore imply higher fitness, the following model holds:

$$\dot{s}_i = \beta \cdot s_i \cdot (f_i - \bar{f}), \quad \bar{f} = \sum_N s_i \cdot f_i. \quad (4)$$

$$\dot{f}_i = v \cdot g(s_i). \quad (5)$$

The function  $g(s_i)$  represents the relationship between technological improvement  $\dot{f}_i$  and market success: as stated, we can distinguish positive and negative dynamic scale effects



where the rate and not the direction of technological improvement is influenced; the latter will always be increased. We assume that there is an upper level of technological fitness ( $f_{\max}$ ) which cannot be exceeded representing the maximum technological opportunities that can be exploited.  $v$  is a parameter which represents the intensity of the economic feedback.

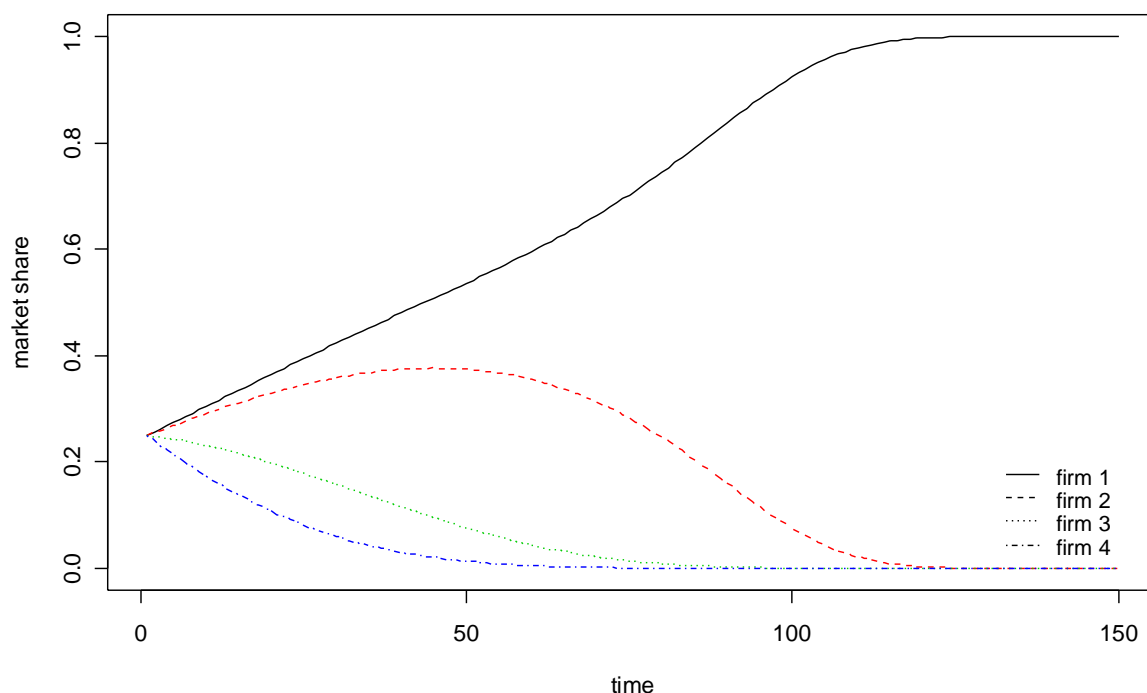


Figure 1: Development of market shares with increasing dynamic returns to scale

Analyzing first the case of *Schumpeter II*, the process of *success breeds success* is modeled. Comparative selection as well as scale and size-dependent innovative success lead to increasing economic and technological dominance of the technology leaders and, consequently, to monopolization (see Mazzucato and Semmler, 1998; Cantner, 2002). Simulations show this result, as is seen in the example of Figure 1, where four technologically different firms 1—4 compete, where the ranking in technological fitness in  $t=0$  is  $f_1 > f_2 > f_3 > f_4$ .

In period 0 all firms have an equal market share,  $s_1 = s_2 = s_3 = s_4 = 0.25$ . The technological leader 1 then increases its market share  $s_1$  due to a selective advantage and, based on this, on *scale advantages*. The other firms will, one after the other, be driven out of the market; firm 2 with the lowest initial technological fitness first, then firm 3 and finally firm 4. Innovation  $\dot{f}_i$  and competition dynamics  $\dot{s}_i$  act here in the same direction of monopolizing the market.

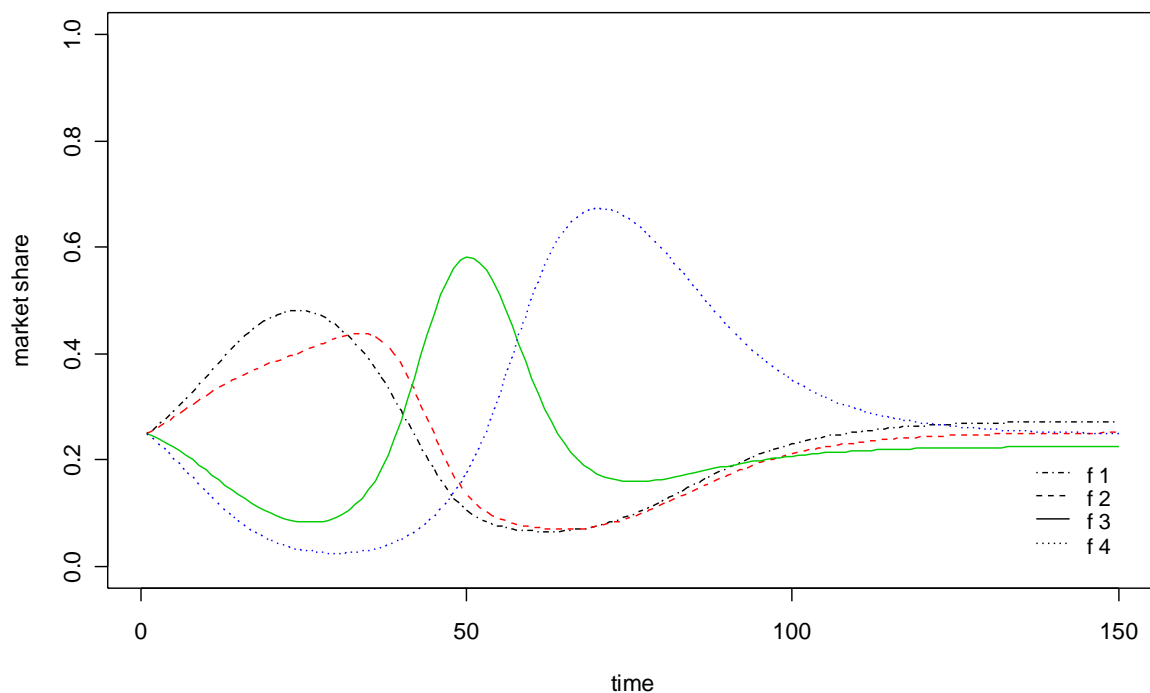


Figure 2: Development of market shares with decreasing dynamic returns to scale

Let us contrast this result with the constellation of *Schumpeter I*, which is characterized by decreasing returns to scale in innovative activities. Consequently, driven by selection dynamics the market share of the firms with the lowest technological fitness will increase because the innovation dynamics of firms with a small market share is quite intensive. Thus, competitive selection  $\dot{s}_i$  and innovation dynamics  $\dot{f}_i$  are counteracting forces. There are a lot of cases where one or the other force dominates and a smooth development to coexistence<sup>5</sup> or monopoly<sup>6</sup> is observed. For appropriate parameters it can be shown that both forces are in a changing balance and the development of market shares is characterized by turbulences. Figure 2 shows and exemplifies this case again for the four firms.

In period 0 the technologically different firms again share the market equally. Innovation and competitive selection dynamics start and the technological leader 1 gains market shares. However, by this its innovation dynamics slows down and the backward firms 2—4 are able to catch up and finally even to take over firm 1. This applies to the technological level as well as to the economic success measured in market shares. With reversed signs this process can be repeated over and over again.<sup>7</sup> By the degree, however, to which technological

<sup>5</sup> The rate of exploiting technological opportunities is fast compared to the rate of competitive selection.

<sup>6</sup> Here, compared to innovation dynamics selection dynamics is fast.

<sup>7</sup> The number of takeovers depends on the chosen parameters for innovation and selection dynamics.

opportunities become exploited ( $f_{\max}$ ) and further technological advances diminish these turbulences will slow down, the intensity of innovation  $\dot{f}_i$  and selection dynamics  $\dot{s}_i$  will decrease and, finally, a technologically homogeneous structure, that is, identical technological levels with different market shares, will come about.<sup>8</sup>

### 3. Innovation Competition and Replicator Dynamics: An Empirical Analysis using the Decomposition of Productivity Change<sup>9</sup>

Having outlined the model of competition in innovation this section is devoted to test whether the mechanism described holds empirically. In more general terms a test of the mechanism of replicator dynamics is to be accomplished.

In this paper the following route is taken. First, it is assumed that technological fitness of a firm can be expressed by her total factor productivity  $a_i$ .<sup>10</sup> Second, we consider certain sectors and assume that firms assigned to this sector (with their main activity) compete in the same market. Third we consider the development of total sector productivity of each sector over time and look by the decomposing the respective productivity changes at the role of market competition and innovation for the productivity development of the sector. This implies, as we will see, an investigation to what degree replicator or selection dynamics holds.

#### 3.1 Decomposition of Productivity Change

Productivity change is here decomposed using the formula proposed in Foster et al. (1998) which is a modification of the formula of Baily et al. (1992) that also accounts for the contributions of entering and exiting firms. This formula is here preferred to the alternative decomposition formula of Griliches and Regev (1995), which is deemed to be more robust to measurement errors but is straightforward to interpret. Denote the share-weighted aggregate productivity levels of periods  $t$  and  $t-k$  ( $k > 0$ ) by  $\bar{a}_t^s = \sum_{i=1}^n s_{it} a_{it}$  and  $\bar{a}_{t-k}^s = \sum_{i=1}^n s_{it-k} a_{it-k}$ , respectively. Then the average change of share-weighted aggregate productivity can be denoted by

$$\Delta \bar{a}_t^s = \bar{a}_t^s - \bar{a}_{t-k}^s = \sum_{i \in C \cup N} s_{it} a_{it} - \sum_{i \in C \cup X} s_{it-k} a_{it-k} \quad (6)$$

<sup>8</sup> For a further discussion of this issue see Mazzucato (1998), Mazzucato/Semmler (1998) and Cantner (2002).

<sup>9</sup> This section draws on Cantner/Krüger (2008).

<sup>10</sup> See Cantner/Hanusch (2006) for a discussion of this issue.

where  $C$  denotes the set of continuing firms,  $N$  denotes the set of entering firms and  $X$  denotes the set of exiting firms. Clearly, these sets are disjoint and  $C \cup N \cup X = \{1, \dots, n\}$ , taking account of the fact that  $s_{it-k} = 0$  (and  $a_{it-k} = 0$ ) in the case of the entering and  $s_{it} = 0$  (and  $a_{it} = 0$ ) in the case of the exiting firms.

With this notation the annual percentage average growth rate of the share-weighted aggregate productivity over the period  $t$  to  $t-k$  can be written as  $\frac{100}{k} \cdot \Delta \bar{a}_t^s / \bar{a}_{t-k}^s$ . The part  $\Delta \bar{a}_t^s$  of this expression can be decomposed into

$$\begin{aligned} \Delta \bar{a}_t^s = & \sum_{i \in C} s_{it-k} \Delta a_{it} + \sum_{i \in C} \Delta s_{it} (a_{it-k} - \bar{a}_{t-k}^s) + \sum_{i \in C} \Delta s_{it} \Delta a_{it} + \\ & \sum_{i \in N} s_{it} (a_{it} - \bar{a}_{t-k}^s) - \sum_{i \in X} s_{it-k} (a_{it-k} - \bar{a}_{t-k}^s) \end{aligned} \quad (7)$$

where  $\Delta a_{it}$  and  $\Delta s_{it}$  are understood to denote  $a_{it} - a_{it-k}$  and  $s_{it} - s_{it-k}$ , respectively.

The interpretation of this formula is straightforward: for the continuing firms, the growth rate of share-weighted average industry productivity is expressed as the sum of the share-weighted productivity change within industries (the within component), the share cross term which is positive if firms with above-average productivity increase their shares (the between component) and a covariance-type term which is positive if firms with increasing productivity tend to gain in terms of their shares (the covariance component). The latter two terms summarize the effect of the structural change on aggregate productivity growth among the continuing firms of the industry under consideration.

In the final two terms of the formula the contributions of the entering and the exiting firms to aggregate productivity growth are stated. They are called the entry and exit components in the following. The contribution of an entering firm to aggregate productivity change is positive if it has a productivity level above the initial average and the contribution of an exiting firm to aggregate productivity growth is positive if its productivity level is below the initial average. The entry and exit effects summarize these contributions, weighted by  $s_{it}$  in the case of the entry component and by  $s_{it-1}$  in the case of the exit component.

Particularly appealing from an evolutionary point of view is that the between component is positive if the share development follows a discrete-time version of the familiar replicator dynamics mechanism. In that case above-average productivity levels in period  $t-k$  tend to be associated with positive share growth between periods  $t$  and  $t-k$  and below-average productivity levels tend to be associated with negative share growth. On the other hand, if

below-average productivity firms tend to grow in terms of shares and above-average productivity firms tend to shrink in terms of shares the between component will be negative, thereby contradicting the replicator mechanism. Admittedly, in a heterogeneous sample of firms this mechanism will be confirmed by a certain part of the sample and contradicted by another part of the sample and positive and negative contributions may cancel out to some extent. Thus one has to bear in mind in the interpretation of the between component that a positive between component may just be the result of an overweight of the firms with positive contributions over the firms with negative contributions.

Related to that a positive covariance component indicates that selection is faster than predicted by the replicator dynamics mechanism alone, while a negative covariance component is associated with a slower selection compared to the replicator dynamics mechanism. Thus, the covariance effect can be interpreted as indicating the kind of feedback that exists between innovation as measured by productivity change and market success as measured by the change of market share. If for a particular firm we observe a positive covariance component a positive feedback seems to prevail (increasing dynamics returns to scale); contrariwise a negative covariance component indicates the working of a negative feedback effect (decreasing dynamic returns to scale).

Both between and covariance components can be added resulting in the combined component  $\sum_{i \in C} \Delta s_{it} (a_{it} - \bar{a}_{t-k}^s)$ , which is distinguished from the discrete-time replicator dynamics mechanism by the fact that the productivity levels of period  $t$  are compared with the average productivity level of period  $t - k$ .

### 3.2 Empirical results for the German manufacturing sector 1981-98

Turning to the results in table 1 the average percentage growth rate of the aggregate productivity levels during 1981-98, again with employment shares used as weighting factors, is reported together with the five terms of the decomposition formula. It should be stressed that only in the long-run the components other than the within component show up with considerable magnitude, so that time spans of several years are necessary to achieve meaningful results. Note that each single term of the above stated decomposition formula for  $\Delta \bar{a}_t^s$  appears in the table as divided by  $\bar{a}_{t-k}^s$  and multiplied by  $\frac{100}{k}$ .

First of all, the results show a positive aggregate productivity development for the total sample as well as for most industries considered (the sole exception being construction). A

certain part of this outcome can be attributed to productivity growth within the industries as is evident from the positive within component. Concerning the effects of entry we observe that entering firms are more productive than the average of the starting period with the exception of food and rubber. Exiting firms tend to have below-average productivity levels in the total sample and in five individual industries, thus contributing positively to aggregate productivity growth. In the remaining six industries, exiting firms contribute negatively to aggregate productivity growth. Generally, net entry provides a positive contribution, except for rubber. Thus, on average more productive entering firms replace less productive exiting firms.

Table 1  
Foster-Haltiwanger-Krizan Decomposition 1981-98 (employment shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	0.7428	0.2654	0.0563	0.2066	0.1731	-0.0413
Construction	-0.1469	-0.0712	0.0298	-0.1902	0.0961	0.0114
Food and Beverages	0.1491	0.1195	-0.0344	0.1458	-0.0846	-0.0027
Textiles and Apparel	0.9975	0.5734	0.1571	-0.1970	0.3290	-0.1349
Paper and Printing	1.9066	0.3195	0.0649	-0.1263	1.7800	0.1314
Chemicals and Petroleum	0.9614	0.0705	0.2525	0.1770	0.3967	-0.0646
Rubber and Plastics	0.7528	0.5179	0.0099	0.3536	-0.0599	0.0688
Metal Products	0.2751	0.2112	0.0621	-0.0165	0.0717	0.0534
Machinery and Equipment	2.1975	0.5637	0.0790	0.9111	0.4631	-0.1805
Electronics	0.1253	-0.0322	0.2898	-0.1971	0.0190	-0.0458
Transportation Equipment	1.1350	0.5667	0.3450	0.0331	0.2198	0.0296
Instruments	0.9027	0.3495	0.0428	0.2455	0.2981	0.0333

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1998–1981).

Structural change takes place not only in form of entry and exit of firms, but is also important within the group of continuing firms. This shows up in the between and covariance components that relate employment share changes either to the deviations from the average productivity level or to productivity changes. Supposing a positive relation of the number of employees of a firm to its size, these two effects reflect the intensity of competition within an industry driven by micro-heterogeneity in productivity levels and growth. For the between component we generally observe positive effects (except for food). This indicates a

development pattern as can be expected to be generated by the replicator dynamics mechanism which postulates that firms with above-average productivity levels tend to grow in terms of shares and vice versa. The actual strength can be seen from the relative contribution of the between component to aggregate productivity change. This contribution is rather low in most industries except chemicals, electronics and transportation.

This between component can be enforced or weakened by the covariance component. For the total sample the positive but small between component is reinforced by a covariance component that is positive and of a considerable magnitude. Thus, productivity growth (or decline) of the individuals firms in the total sample tends to be associated with share growth (or decline). The selection represented by a positive between effect is accelerated in a similar fashion by a positive covariance component in case of chemicals, rubber, machinery, transportation and instruments. In most of these cases the covariance component represents a quantitatively important contribution to aggregate productivity growth (except for transportation). In construction, textiles, paper, metal and electronics the covariance component is negative and therefore reduces or even outweighs the positive between components. As shown in table 5 in the appendix, the between components becomes negative in a larger number of industries if sales shares are used for the aggregation instead of employment shares. The other results are analogous to those discussed here.

The combined effect of the between component and the covariance component are characteristic for the structural development of an industry. If both components are positive, the heterogeneity of firms with respect to both productivity differentials and size differentials is increasing. Eventually, a bimodal structure emerges as a result of the working of replicator dynamics and reinforcement effects between market share changes and productivity changes (as a kind of positive dynamic economies of scale). In the case of a positive between component, a negative covariance component and a positive combined effect represents a replicator dynamics effect which, however, is damped by a negative feedback between changes in productivity and employment shares. If the combination of the between and the covariance term is negative, replicator dynamics effects do not show up as expected but are superimposed by a tendency towards a more homogeneous structure of firms as a kind of negative dynamic economies of scale. Relating these results to results found in previous work of Cantner and Krüger (2004a,b,c) for example for the chemicals and rubber show that not only a rather simple success-breeds-success dynamics with respect to productivity leadership shows up. In addition a coupled success-breeds-success process is detected where economic and technological success reinforces each other (see esp. Cantner and Krüger 2004c).

The just discussed results for the total sample of German manufacturing firms are quite similar to that of studies for US manufacturing establishments which are succinctly surveyed by Bartelsman and Doms (2000) and Haltiwanger (2000). In most of these studies establishments are sampled together irrespective of the industry of origin. Although the results vary considerably across time periods, data frequency, the specification of the shares in terms of labor or output, and the choice of labor productivity or total factor productivity, the within component usually represents the largest contribution to aggregate productivity growth. The between component is sometimes found to be quite small in absolute magnitude, while the covariance component is frequently positive and of considerable magnitude. Net entry contributes positively to aggregate productivity growth. An analogous investigation of UK manufacturing establishments by Disney et al. (2003b) reaches qualitatively the same results.

Table 2  
Foster-Haltiwanger-Krizan Decomposition 1981-89 (employment shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	0.3399	0.4745	0.0837	-0.2614	0.0389	-0.0042
Construction	-0.9622	-1.0047	0.0038	-0.0892	0.0884	-0.0396
Food and Beverages	-0.3507	-0.4331	-0.0314	0.4809	-0.3675	-0.0005
Textiles and Apparel	0.4587	0.5780	-0.0423	-0.1390	0.0863	0.0243
Paper and Printing	1.5269	0.8984	0.0715	-0.4199	1.0445	0.0675
Chemicals and Petroleum	1.0408	0.8358	0.0824	-0.1219	0.2440	-0.0006
Rubber and Plastics	1.4102	1.4566	-0.0635	0.0423	0.0000	0.0251
Metal Products	0.2985	0.1567	0.1022	-0.0007	0.0407	0.0005
Machinery and Equipment	1.5150	1.8655	0.2125	-0.9474	0.4121	0.0277
Electronics	-1.1056	-0.8829	0.1673	-0.3105	-0.0930	-0.0136
Transportation Equipment	1.7890	2.0476	0.1417	-0.3848	-0.0154	0.0000
Instruments	-0.0068	-0.0209	0.0564	-0.0570	0.1156	0.1008

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1989–1981).

Dividing the sample period into two parts, one before the German reunification (1981-89) and the other after the German reunification (1990-98), reveals some interesting developments. Comparison of tables 2 and 3 reveals that aggregate productivity growth is



much stronger for the total sample and in most industries in the period since the reunification compared to the period before (with the sole exception of the transportation equipment industry).

Table 3  
Foster-Haltiwanger-Krizan Decomposition 1990-98 (employment shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	1.9661	0.5198	0.2942	0.6775	0.2447	-0.2299
Construction	0.8701	0.7424	-0.0108	-0.1390	0.3904	0.1129
Food and Beverages	0.5767	0.4619	-0.1770	-0.0008	0.3883	0.0955
Textiles and Apparel	1.6705	0.8385	0.6945	-0.3214	0.0245	-0.4344
Paper and Printing	2.3926	1.2999	0.0289	0.3472	0.5759	-0.1408
Chemicals and Petroleum	4.7091	0.2012	2.1206	0.6732	1.1409	-0.5731
Rubber and Plastics	2.2103	0.5495	0.7244	0.1984	-0.0502	-0.7882
Metal Products	0.7526	0.1877	0.4008	0.0521	0.0512	-0.0608
Machinery and Equipment	2.9296	1.4835	-0.0259	1.2685	0.2299	0.0264
Electronics	1.6838	0.3520	0.3743	0.6113	0.2648	-0.0815
Transportation Equipment	1.1477	0.5257	0.1340	0.4416	-0.0206	-0.0671
Instruments	1.9845	0.5559	0.0738	0.8190	0.4861	-0.0497

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1998–1990).

To a large extent these productivity improvements since 1990 can be explained by the components of the productivity decomposition that are related to structural change either in the form of selection among continuing firms (the between and covariance components) or in the form of entry and exit (the entry and exit components). These components play a much larger role after the German reunification than they did before. Only in the case of construction and of food is the within component dominating. The covariance component is positive in all industries but construction and textiles, and often large in magnitude. In all other industries the within components deviate substantially from aggregate productivity change. Hence, a large role for the productivity improving forces of structural change is left over. The same holds for the total sample. Thus, the widespread acceleration of productivity since 1990 is mainly driven by the exceptional growth of firms with above-average productivity levels which are also growing in terms of productivity and by the entry of firms

with above-average productivity levels combined with the exit of firms with below-average productivity levels. Again, the same pattern can be discerned from the results in the appendix when the sales shares are used.

In sum, the results reported in this section show that the contributions structural change and net entry can explain an important part of aggregate productivity growth. This outcome appears to be much weaker before the German reunification and appear to be particularly pronounced in the period since that event. The general pattern of results holds for the whole sample in which all firms are sampled together irrespective of their industry of origin. It also holds in most cases if the firms are assigned to industries at the two-digit (SIC) level. By that, support for the replicator dynamics mechanism can be given, although we have to be cautious at the present stage of our analysis. Importantly, the overall pattern of results is rather robust to the specification of the shares in terms of employment or sales.<sup>11</sup>

#### **4. Conclusion**

The analysis performed in this paper is concerned with the heterogeneous micro-dynamics at the intra-sectoral, firm level and the aggregate development of sectors. As theoretical basis of the analysis serve first replicator dynamics which governs the selective competition and second specific innovation dynamics which are modeled as endogenously driven. This simple model is tested for industrial sectors in Germany from 1981 to 1998. For that firm level total factor productivity is used as a proxy for technological performance of a firm whereas the change in total factor productivity serves as proxy for innovative performance. The main results can be summarized as follows:

First, we find that within firm productivity growth accounts for much of the performance at the aggregate level, especially in the period before the German reunification. Second, we also find that entering firms tend to have productivity levels above the average, whereas exiting firms are mainly characterized by productivity levels below the average. Both results confirm the results of other studies for US and UK manufacturing establishments. Third and most important, in the period since the German reunification we can identify the impact of success-breeds-success dynamics coupling economic and technological improvements for the majority of sectors. The accompanying structural change can explain a non-negligible part of the aggregate productivity performance and can be interpreted in terms of the replicator dynamics mechanism, where well performing firms (in terms of productivity) are selected in favor of

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<sup>11</sup> See appendix.

badly performing firms. Our results give an indication of the forces of structural change that together with entry-exit dynamics seem to shape a substantial part of aggregate productivity development and are much more difficult to uncover by an investigation of short-run (year-by-year) changes.

Our findings additionally support the rather general and stylized observation of rather smooth developments at the aggregate level as the result of quite turbulent micro-dynamics that is discussed in Dosi et al. (1997): "In general, what is particularly intriguing is the *coexistence* of turbulence and change on the one hand, with persistence and regularities at different levels of observation – from individual firms' characteristics to industrial aggregates – on the other. Industrial dynamics and evolution appear neither to be simply characterized by random disorder nor by perfectly self-regulating, equilibrium oriented processes that quickly wipe away differences across firms. Rather, the evidence accumulated so far seems to suggest a subtle and intricate blend of these two elements".

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**Appendix: Results for sales shares**

Table 4: Foster-Haltiwanger-Krizan Decomposition 1981-98 (sales shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	0.4242	0.0077	-0.3624	0.3762	0.1861	-0.2166
Construction	-0.1459	-0.2087	-0.0710	0.0523	0.0729	-0.0086
Food and Beverages	0.5543	0.1402	-0.0358	0.1314	0.2990	-0.0195
Textiles and Apparel	0.9827	0.4469	0.0418	-0.2321	0.7212	-0.0049
Paper and Printing	1.9786	0.2573	0.0460	-0.0613	1.8754	0.1389
Chemicals and Petroleum	0.1002	-0.4441	-0.0909	0.0858	-0.1431	-0.6925
Rubber and Plastics	0.9707	0.5868	-0.1430	0.6738	-0.0287	0.1183
Metal Products	0.2273	0.1226	-0.1138	0.1622	0.1382	0.0819
Machinery and Equipment	2.7359	0.5971	0.0248	0.2745	1.7324	-0.1071
Electronics	0.2049	-0.0593	0.2367	-0.1950	0.1573	-0.0653
Transportation Equipment	1.2799	0.4476	0.0915	0.5019	0.2504	0.0114
Instruments	0.8944	0.3198	-0.0157	0.3652	0.2640	0.0390

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1998–1981).

Table 5: Foster-Haltiwanger-Krizan Decomposition 1981-89 (sales shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	-0.3524	-0.1722	-0.7090	0.4598	0.0596	-0.0095
Construction	-0.9907	-1.1952	-0.1816	0.1691	0.1535	-0.0636
Food and Beverages	0.3231	-0.1439	-0.0367	0.3701	0.1327	-0.0009
Textiles and Apparel	0.4043	0.1898	-0.1823	0.0330	0.3651	0.0013
Paper and Printing	1.3043	0.9606	0.0154	-0.4476	0.8827	0.1068
Chemicals and Petroleum	-1.3370	-0.8422	-1.3092	0.8636	-0.0507	-0.0016
Rubber and Plastics	1.4493	1.4322	-0.0728	0.1099	0.0000	0.0200
Metal Products	0.3049	-0.1722	0.0863	0.4486	-0.0575	0.0003
Machinery and Equipment	1.9471	1.0750	-0.1859	0.0014	1.0589	0.0023
Electronics	-1.0775	-1.0322	0.1056	-0.1609	-0.0047	-0.0147
Transportation Equipment	1.8481	1.7794	-0.0274	-0.0306	0.1267	0.0000
Instruments	0.2041	-0.0366	-0.0227	0.0456	0.3222	0.1044

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1989–1981).

Table 6: Foster-Haltiwanger-Krizan Decomposition 1990-98 (sales shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	1.3977	0.2994	-0.0942	0.7369	0.2199	-0.2356
Construction	0.6105	0.6953	-0.1101	-0.0371	0.2770	0.2146
Food and Beverages	0.0540	-0.6667	-0.9268	1.1724	0.1160	-0.3592
Textiles and Apparel	1.9147	0.6646	0.6663	0.0612	0.0266	-0.4960
Paper and Printing	2.5929	1.1534	0.0439	0.3914	0.8807	-0.1235
Chemicals and Petroleum	1.8318	0.1583	0.6406	0.5621	-0.0167	-0.4875
Rubber and Plastics	3.2429	0.3816	0.4454	1.2233	0.1020	-1.0906
Metal Products	0.6771	0.1198	0.1177	0.4305	-0.0375	-0.0466
Machinery and Equipment	3.3852	1.2552	0.2219	0.8625	1.0118	-0.0337
Electronics	1.7989	0.2900	0.1425	0.6435	0.5843	-0.1386
Transportation Equipment	0.9123	0.2653	-0.2884	0.6808	-0.0302	-0.2847
Instruments	1.8058	0.5639	-0.0924	0.9052	0.4478	0.0187

Note: reported are average percentage growth rate of the aggregate productivity levels in the column change and the terms of the decomposition formula in the subsequent columns, each divided by the initial share-weighted average productivity level and multiplied by 100/(1998–1990).