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REGULAR ARTICLE

Micro-heterogeneity and aggregate productivity development in the German manufacturing sector

Results from a decomposition exercise

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Abstract A decomposition of aggregate productivity growth of German manufacturing firms that pertain to 11 different industries at a roughly two-digit level observed over the period 1981–1998 is performed. Productivity is measured by a nonparametric frontier function approach. The decompositions of productivity allow for an explanation of the aggregate outcomes by the quantification of the effect of structural change and the contributions of entering and exiting firms. Our results show that these forces drive aggregate productivity to a considerable extent. Remarkably, the large productivity improvements after the German reunification are mainly driven by structural change.

Keywords Productivity · Structural change · Manufacturing

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1 Introduction

The aggregate productivity development of industries or sectors is an artificial construct that is driven by the productivity developments of the individual firms that

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constitute these industries or sectors. The productivity of the individual firms develops not in a uniform way, but is characterized by a great degree of turbulence. This turbulence leads to differential rates of growth and decline of productivity as a cause of differential rates of technological progress, of employment growth or sales growth. Moreover, turbulence is also associated with the extent of entry into and exit from a particular industry or sector. All these factors affect the rate of change of aggregate productivity.

The fact that industry evolution is indeed a very turbulent process is well documented in the empirical research, summarized in the survey articles of Bartelsman and Doms (2000), Caves (1998), Dosi et al. (1997) and Haltiwanger (2000). In that work it is recognized that the relation of turbulence at the firm-level and the rather smooth aggregate (industry-level) outcomes are nontrivial. In the words of Dosi et al. (1997, p. 12): "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 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." Moreover, in related research with a data base similar to that used in this paper, we investigate the dynamic properties of productivity and market shares of firms and find that these dynamics are quite different and rather unrelated to each other (see Cantner and Krüger (2004a, b)).

Notwithstanding that, if the market forces work sufficiently well, firms with above-average productivity levels or high productivity growth rates are expected to grow, firms with below-average productivity levels or low productivity growth rates are expected to shrink, and more productive entering firms are expected to replace less productive exiting firms. It is just this pattern which Schumpeter (1942) described as the process of creative destruction. In this paper, we take an integrative approach to explain aggregate productivity changes by combining productivity data at the firm level with information about the shares of the individual firms in the total aggregate to quantify the contributions of different aspects of these heterogeneous dynamics at the firm level. The decomposition of productivity change allows us to quantify the contributions of structural change, entry and exit to aggregate productivity growth, in addition to productivity growth within individual firms. Our results show that the contributions of structural change and net entry can explain an important part of aggregate productivity growth, especially since the German reunification. This result holds if all firms are sampled together irrespective of their industry of origin, as well as if the firms are assigned to industries at the two-digit Standard Industrial Classification (SIC) level. In addition, it can be demonstrated that the components of the productivity decomposition representing structural change have an illuminative interpretation in terms of the replicator dynamics mechanism.

The paper proceeds as follows. Following a brief literature review in the next section, the nonparametric method to compute total factor productivity is explained and descriptive statistics are discussed in Section 3. Section 4 first introduces the decomposition formula for the productivity change and then turns to a discussion of the corresponding results. Section 5 concludes. An Appendix contains the results with sales shares used for the aggregation instead of the employment shares used in the main text.

2 Related literature

The results reported in this paper relate to three different strands of literature: the theoretical literature on industry dynamics, the empirical literature on market turbulence, and the methodological literature on productivity decompositions. The theoretical literature on industry dynamics comprises a multitude of models of competition within industries in which firms are also subject to entry and exit. In neoclassical tradition, the models of Jovanovic (1982), Lambson (1991) and Ericson and Pakes (1995), together with the empirical validation of Pakes and Ericson (1998), are exemplary. These models rely on profit maximizing firms that either are endowed with differing time-invariant efficiency levels or are able to improve their productivity levels by investment in research and development. Firms are subject to random shocks which may force them to exit. In evolutionary tradition, starting with Nelson and Winter (1982), industry dynamics are imagined as being driven by firms that experiment with different technologies and grow or shrink depending on their success relative to their competitors, thus creating a highly uncertain and turbulent environment. These aspects are also present in the more recent evolutionary models of Metcalfe (1994, 1998) and Winter et al. (2000, 2003).

Simultaneously with the theoretical literature, empirical work developed exploring the pattern of plant entry, growth and exit in US manufacturing industries (see Dunne et al. (1988, 1989)) and also among UK (Disney et al. (2003a)) and Canadian (Baldwin and Gu (2006)) manufacturing establishments. Other work, such as Nickell (1996) and Nickell et al. (1997), concentrates on the generation of firm level evidence on the positive relation between 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, decomposition formulae of productivity measures into several components have been developed that shed light on the sources of aggregate productivity change at the micro-level and in this sense provide an explanation for aggregate productivity change. 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, 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 largely unnoticed precursor for the development of productivity decompositions is Salter (1960).[1] Besides the decompositions of productivity change, a special decomposition formula for productivity levels has been proposed by Olley and

[1] 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.

Pakes (1996). The entire literature on these decompositions of aggregate productivity growth is summarized by Haltiwanger (2000).

3 Productivity measurement

To quantify total factor productivity, the nonparametric frontier function approach is used. The specific method used here is the Andersen and Petersen variant of data envelopment analysis (Andersen and Petersen (1993)). This nonparametric method calculates an index of total factor productivity by the distance of the input–output combinations of a sample of n firms towards a piece-wise linear frontier production function that is determined from quantity data alone without having to rely on assumptions about the functional form of the production relationship and without requiring price data. The output-oriented version of the Andersen–Petersen model calculates productivity by computing an index indicating to what extent the output of a firm has to be increased in order to reach a point on the frontier production function. This function is determined by the observations of the other n-1 firms that pertain to the same industry, excluding the firm for which productivity is actually computed.

The productivity computations are performed for each industry and time period t separately. Letting y_{it} denote the output of the ith out of n_t firms in the industry under consideration at t and x_{it} the vector of the three input factors (labor, capital, material) of the same firm. Then the productivity score of firm i in period t is computed as the solution of the following linear program

$$\max_{\theta,\lambda_{-i}} \left\{ \theta : \theta y_{it} \leq \sum_{h \in \{1,\ldots,n_t\}/i} \lambda_h y_{ht}, \sum_{h \in \{1,\ldots,n_t\}/i} \lambda_h x_{ht} \leq x_{it}, \lambda_{-i} \geq 0 \right\},$$

where λ_{-i} denotes the vector of weights omitting the ith component. Note that the sums in the formula are over all but the ith observation, which in effect excludes the ith firm from the technology set. The solution of this linear program is denoted by θ_{it} and quantifies the percentage level to which the output of the ith firm in period t has to be increased (θ_{it}>1) or could be decreased (0<θ_{it}<1) in order to reach a facet of the frontier function spanned by the best-practice observations of the other firms in period t.

In the case of the all-time-best frontier function used here, this procedure has to be modified so that θ_{it} is computed by comparing the observation of firm i in period t with all firms within the same industry in all periods, excluding only firm i in period t. Larger values of θ_{it} imply lower productivity levels and therefore the inverse is used as the productivity measure, denoted by $a_{it}=1/\theta_{it}$. These productivity measures are always to be interpreted as relative towards the all-time-best frontier function.

The sample used to compute the productivity levels in this paper is composed of German manufacturing firms with observations for the years 1981 to 1998 (or a part of that time span, in the case of entering and exiting firms). Overall, 874 firms are in this sample at some time. These firms can be assigned to 11 industries at roughly two-digit (SIC) level of aggregation. Table 1 gives an overview over the data coverage by a listing of industries, their two-digit SIC codes and the minimum and maximum number of firms in the respective industry.

Table 1 Industry composition of the sample

Industry	SIC2	Shortcut	Min. # firms	Max. # firms
Construction	15, 16, 17	Construction	22	49
Food and beverages	20, 21	Food	53	87
Textiles and apparel	22, 23	Textiles	26	48
Paper and printing	26, 27	Paper	13	32
Chemicals and petroleum	28, 29	Chemicals	50	107
Rubber and plastics	30	Rubber	12	23
Metal products	33, 34	Metal	45	91
Machinery and equipment	35	Machinery	75	150
Electronics	36	Electronics	31	66
Transportation equipment	37	Transportation	18	50
Instruments	38	Instruments	14	23

The data are all obtained from the balance sheets and the annual reports of the firms, compiled from the Hoppenstedt firm data base. For the determination of the productivity scores, we use a specification with a single output variable and the inputs labor, capital and material. Labor is measured by the number of employees, capital input is measured by the book value of firms' assets from the balance sheets, and materials are taken from the position raw materials and supply in the profit and loss accounts. For output, the sum of total sales is taken, corrected for inventory changes and internally used firm services, from the profit and loss accounts. The data for total sales and the number of employees are also used to compute firms' employment or sales shares. The productivity computations are based on real data for output as well as the capital and material inputs. Industry specific price deflators from the 60-Industry Database of the Groningen Growth & Development Centre (see http://www.ggdc.net) are used to deflate the output as well as the capital and material input data.

Table 2 reports descriptive statistics related to firm size, where firm size is measured by the number of employees. Reported are the mean, skewness and kurtosis as well as the quartiles of the firm size distribution for each industry, with the data of all periods pooled together. Substantial differences in the mean firm size across industries can be observed. The largest mean (and median) firm size is found

Table 2 Firm size distribution with respect to employment

Industry	Mean	Skewness	Kurtosis	Q0.25	Q0.50	Q0.75
Construction	1,521.49	4.14	23.11	192.75	565.50	1,358.00
Food	3,081.10	5.40	33.96	206.00	578.00	1,692.50
Textiles	1,905.21	7.22	70.70	224.00	553.00	1,764.00
Paper	5,179.54	5.38	37.95	323.00	878.00	2,853.00
Chemicals	2,241.21	11.30	183.46	274.00	597.00	1,571.00
Rubber	1,132.13	3.59	19.07	236.00	469.00	1,333.00
Metal	3,504.68	9.84	107.50	196.00	557.00	1,880.00
Machinery	3,293.75	11.10	142.70	221.00	549.00	1,691.00
Electronics	2,567.01	5.97	44.46	292.75	790.00	2,283.25
Transportation	3,356.03	8.75	99.61	228.00	756.00	2,751.25
Instruments	2,404.61	5.76	41.39	227.00	541.00	1,904.00

in the paper industry, the smallest in the rubber industry. The firm size distribution shows the typical right-skewed shape for all industries as can be inferred either from the positive skewness measure, from the fact that the mean is consistently larger than the median (Q0.50), or from the fact that the first quartile (Q0.25) is closer to the median than the third quartile (Q0.75). This skewness is largest in chemicals, metals and machinery.

The Appendix contains analogous results for real sales as another indicator of firm size in Table 6. From there, similar conclusions regarding the differences in mean firm size across industries and the prevalence of a right-skewed firm size distribution arise. We now turn to the discussion of the results for the decomposition of aggregate productivity change in the next section.

4 Decomposition of productivity change

4.1 Decomposition formula

The aggregate productivity change of a group of firms (such as an industry) is here decomposed using the formula proposed in Foster et al. (1998), which is an extension of the formula of Baily et al. (1992) that also accounts for the contributions of entering and exiting firms. This formula is preferred to the alternative decomposition formula of Griliches and Regev (1995), which is deemed to be more robust to measurement errors but is less straightforward to interpret.

To introduce the formula, let $\overline{a}_t^s = \sum_{i\in C\cup N} s_{it} a_{it}$ and $\overline{a}_{t-k}^s = \sum_{i\in C\cup X} s_{it-k} a_{it-k}$ denote the share-weighted aggregate productivity levels of periods t and $t-k$ ($k>0$), respectively. Then the change of share-weighted aggregate productivity can be stated as $\Delta\overline{a}_t^s = \overline{a}_t^s - \overline{a}_{t-k}^s = \sum_{i\in C\cup N} s_{it} a_{it} - \sum_{i\in C\cup X} s_{it-k} a_{it-k}$, where C represents the set of continuing firms, N the set of entering firms and X the set of exiting firms. Clearly, these sets are disjoint and $C\cup N\cup X=\{1,...,n\}$. The summations take account of the fact that $s_{it-k}=0$ in the case of the entering and $s_{it}=0$ in the case of the exiting firms.

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

$$\Delta\overline{a}_t^s = \sum_{i\in C} s_{it-k}\,\Delta a_{it} + \sum_{i\in C} \Delta s_{it}\left(a_{it-k} - \overline{a}_{t-k}^s\right) + \sum_{i\in C} \Delta s_{it}\,\Delta a_{it} + \sum_{i\in N} s_{it}\left(a_{it} - \overline{a}_{t-k}^s\right) - \sum_{i\in X} s_{it-k}\left(a_{it-k} - \overline{a}_{t-k}^s\right),$$

where Δa_{it} and Δs_{it} denote $a_{it}-a_{i-k}$ 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 firms (the within component), the share cross term which is positive if firms with above-average productivity also tend to increase their shares (the between component), and a covariance-type term which is positive if firms with increasing (decreasing) productivity tend to gain (lose) in terms of their shares (the covariance component). The latter two terms summarize the effect of structural change on aggregate productivity growth among the continuing firms of the industry under consideration.

The final two terms of the formula contain the contributions of the entering and the exiting firms to aggregate productivity growth. These are the entry and exit components. 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 components summarize these contributions, weighted by s_{it} in the case of the entry component and by s_{it-k} in the case of the exit component.

Particularly appealing from an evolutionary point of view is the close correspondence of the between component to a discrete-time version of the familiar replicator dynamics mechanism. This mechanism relates firm productivity levels above (below) the share-weighted average in the industry to growing (shrinking) shares. It can be formally stated as

$$\Delta s_{it} = \lambda s_{it-k}\left(a_{it-k} - a^{s}_{t-k}\right),$$

where $\lambda > 0$ is a parameter controlling the speed of selection (see Metcalfe (1994, 1998) for a deeper discussion of replicator dynamics). If above-average productivity levels in period $t-k$ tend to be associated with positive share growth from $t-k$ to t and below-average productivity levels tend to be associated with negative share growth on average, then the between component will be positive. This pattern is exactly the outcome if the replicator dynamics mechanism is a valid description of competition within an industry. Conversely, 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 is likely to 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. Thus, one has to keep in mind for the interpretation of the between component that a positive between component may just be the result of the firms with positive contributions outweighing 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 slower selection compared to the replicator dynamics mechanism. Both between and covariance components can be added, resulting in the combined component $\sum_{i\in C}\Delta s_{it}\left(a_{it} - \overline{a}^{s}_{t-k}\right)$, which is distinguished from the discrete-time replicator dynamics mechanism by the fact that firm productivity levels of period t are compared with the aggregate productivity level of period $t-k$.

4.2 Results for the entire sample period

Turning to the results, in Table 3 the average percentage growth rate of the aggregate productivity levels during 1981–1998 (with employment shares used as weighting

Table 3 Decomposition 1981–1998 (employment shares)

	Change	Within	Between	Cov.	Entry	Exit
Total Sample	0.9547	0.2969	0.0656	0.2657	0.2467	−0.0797
Construction	−0.3141	−0.2241	0.0293	−0.1702	0.0621	0.0112
Food and beverages	−0.1057	−0.0634	−0.0311	0.2131	−0.2486	−0.0244
Textiles and apparel	1.1665	0.6671	0.1599	−0.1644	0.3611	−0.1429
Paper and printing	1.6701	0.2551	0.0648	−0.0990	1.5800	0.1308
Chemicals and petroleum	1.6831	0.1412	0.2670	0.4102	0.7925	−0.0722
Rubber and plastics	0.9645	0.6108	0.0126	0.4441	−0.0360	0.0671
Metal products	0.4902	0.2684	0.0750	0.0367	0.1493	0.0393
Machinery and equipment	1.8997	0.4641	0.0876	0.8154	0.3570	−0.1757
Electronics	0.6926	0.0965	0.2658	0.1244	0.1455	−0.0604
Transportation equipment	1.1430	0.6103	0.2518	0.1273	0.2232	0.0696
Instruments	0.9508	0.3648	0.0359	0.2719	0.3158	0.0377

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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).

factors) is reported, together with the five terms of the decomposition formula.[2] It should be stressed that the components other than the within component generally have a considerable magnitude only in the long-run, so that time spans of several years are necessary to achieve meaningful results. Also note that each single term of the above stated decomposition formula for $\Delta\overline{a}_t^s$ appears in the table as divided by $\overline{a}_{t-k}^s$ 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 of the industries considered. Part of this outcome can be attributed to productivity growth within the industries, as is evident from the positive values of the within component (except for construction and food, using the industry shortcuts defined in Table 1 above). 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 industries, thus contributing positively to aggregate productivity growth. (Note that the figures in the exit column of the table represent the last sum in the decomposition formula without the minus sign.) In the remaining six industries, exiting firms contribute negatively to aggregate productivity growth. Generally, net entry (computed by the difference of the entry and exit columns) provides a positive contribution, except for food and rubber. Thus, on average more productive entering firms replace less productive exiting firms.

Structural change takes place not only in the form of entry and exit of firms, but also 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

[2] Here, employment shares are used as aggregation weights, since they have the advantage of being more robust to short-run fluctuations than sales shares. In the literature on Gibrat's law, employment is also frequently used to measure firm size (see Evans (1987a, b) and Hall (1987) for leading examples). Employment shares, however, obviously have the disadvantage of being affected by the tendency towards mechanization to the extent that this is uneven across the firms in an industry.

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 the micro-heterogeneity in productivity levels and growth. For the between component, we generally observe positive effects (except for food). This indicates a development pattern consistent with the replicator dynamics mechanism, suggesting that firms with above-average productivity levels tend to grow in terms of shares and vice versa. The actual strength of this effect can be judged from the relative contribution of the between component to aggregate productivity change. This contribution is rather low in most industries, except textiles, chemicals, electronics and transportation.

This between component can be either 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 individual firms in the total sample tends to be associated with share growth (or decline), on average. The combined effect is similar in magnitude to the within component here. Similarly, the selection that is represented by a positive between effect is accelerated by a positive covariance component in all industries except construction, food, textiles and paper. In most of these cases, the covariance component represents a quantitatively important contribution to aggregate productivity growth. As shown in Table 7 in the Appendix, the between component becomes negative in a larger number of industries if sales shares are used for the aggregation instead of employment shares. The other results are largely analogous to those discussed here.

The combined effect of the between and covariance components is 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 force 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 attenuated by a negative feedback between changes in productivity and employment shares. If the combination of the between and the covariance terms is negative, replicator dynamics effects do not show up, but are outweighed by a tendency towards a more homogeneous structure of firms as a kind of negative dynamic economies of scale. Relating these results to previous work of Cantner and Krüger (2004a, b) for chemicals and rubber shows that not just a rather simple success-breeds-success dynamics with respect to productivity leadership works. Overall, this evidence points to a kind of coupled success-breeds-success process, where economic success and technological success are mutually reinforcing.

The 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 their 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. Qualitatively similar conclusions are reached from analogous investigations of UK and Canadian manufacturing establishments by Disney et al. (2003b) and Baldwin and Gu (2006), respectively. Using a completely different methodological approach and calibration of parameters to the US economy, Luttmer (2007) finds about half of aggregate growth resulting from selection among firms. Selection there is associated with an excess of productivity growth of entrants over productivity growth of the incumbents.

4.3 Effect of the German reunification

Dividing the sample period into two parts, one before the German reunification (1981–1989) and the other after (1990–1998), reveals some interesting developments. Comparing Tables 4 and 5 below reveals that aggregate productivity growth is much stronger for the total sample and most industries in the period after the reunification, compared to the period before (with the sole exception of the transportation equipment industry). Particularly striking is the case of electronics, with negative aggregate productivity change before and substantial positive aggregate productivity change since the German reunification.

To a large extent, these productivity improvements since 1990 are 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 cases of construction and food is the within component really dominating after 1990. In all other industries, the within component is substantially lower than aggregate productivity growth, thus attributing a large role to the productivity improving force of structural change.

Table 4 Decomposition 1981–1989 (employment shares)

	Change	Within	Between	Covariance	Entry	Exit
Total sample	0.1986	0.4025	0.0327	−0.2576	0.0204	−0.0005
Construction	−0.7257	−0.7405	0.0013	−0.1064	0.0825	−0.0373
Food and beverages	−0.4659	−0.5785	−0.0119	0.5135	−0.3894	−0.0004
Textiles and apparel	0.5249	0.6411	−0.0495	−0.1435	0.0963	0.0195
Paper and printing	1.4171	0.8172	0.0719	−0.3800	0.9715	0.0635
Chemicals and petroleum	0.9438	0.7085	0.0832	−0.1141	0.2656	−0.0004
Rubber and plastics	1.4920	1.5361	−0.0618	0.0417	0.0000	0.0240
Metal products	0.0799	−0.0146	0.1118	0.0535	−0.0705	0.0005
Machinery and equipment	1.1597	1.4811	0.2219	−0.8541	0.3347	0.0239
Electronics	−1.1957	−0.8192	0.0801	−0.3582	−0.1133	−0.0149
Transportation equipment	1.5055	1.7615	0.1414	−0.3573	−0.0402	0.0000
Instruments	0.1524	0.1179	0.0576	−0.0568	0.1313	0.0977

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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 5 Decomposition 1990–1998 (employment shares)

	Change	Within	Between	Covariance	Entry	Exit
Total sample	2.4136	0.6183	0.3635	0.8146	0.3342	−0.2830
Construction	0.4701	0.4064	0.0078	−0.1253	0.3138	0.1327
Food and beverages	0.3180	0.3045	−0.1765	−0.0628	0.3478	0.0949
Textiles and apparel	1.9779	1.0257	0.6861	−0.1947	0.0299	−0.4309
Paper and printing	2.1759	1.2071	0.0237	0.3381	0.4795	−0.1275
Chemicals and petroleum	6.3679	0.4028	2.2333	1.4250	1.7004	−0.6065
Rubber and plastics	2.6362	0.7579	0.7255	0.3677	−0.0027	−0.7878
Metal products	1.3281	0.3220	0.4126	0.3148	0.1858	−0.0928
Machinery and equipment	2.8420	1.4452	−0.0193	1.2354	0.2073	0.0267
Electronics	2.8428	0.6746	0.4139	1.2144	0.4422	−0.0977
Transportation equipment	1.1878	0.5990	0.0542	0.5411	−0.0174	−0.0109
Instruments	2.0071	0.5707	0.0541	0.8534	0.4908	−0.0381

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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).

The covariance component is positive in all industries except construction, food and textiles, and often quite large in magnitude. The same holds for the total sample. Thus, the widespread acceleration of productivity since 1990 is, to a large extent driven by the exceptional growth of firms with above-average productivity levels, which are also growing in terms of productivity together with the entry of firms with above-average productivity levels and the exit of firms with below-average productivity levels. Productivity growth within individual firms is less dominating in that period than before. Again, a similar pattern can be discerned from the results in the Appendix when sales shares are used.

In sum, the results reported in this section show that the contributions of structural change and net entry are able to explain an important part of aggregate productivity growth. This contribution appears to be much weaker before the German reunification and appears to be particularly pronounced in the period following that event. The general pattern of results likewise holds for the whole sample in which all firms are pooled together irrespective of their industry of origin, as well as in the majority of cases where the firms are assigned to industries at the two-digit (SIC) level. Thus, support for the force of 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. In a previous version of this paper, we used the gross domestic product deflator as price index and a special investment deflator for the capital input common to all industries, finding the results also robust to these changes.

5 Conclusion

The analysis performed in this paper is concerned with the aggregate productivity development of sectors and the underlying heterogeneous micro-dynamics at the firm level. Our findings support the stylized observation of rather smooth developments at the aggregate level as the result of the quite turbulent micro-dynamics discussed in Dosi et al. (1997) and quoted in the introduction. With our approach of decomposing aggregate productivity development into several meaningful components we are able to detect some interesting regularities for the German manufacturing sector during the period 1981–1998.

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 findings from other studies for US and UK manufacturing establishments. Third, and most important, in the period after the German reunification we can identify a larger impact of success-breeds-success dynamics, coupling economic and technological developments for the majority of sectors. The associated structural change among the continuing firms explains a non-negligible part of the aggregate productivity performance and can be interpreted in terms of the replicator dynamics mechanism, where above-average productivity firms are selected in favor of below-average productivity firms.

Thus, the results reported in this paper give an idea of the force of structural change that, together with the entry and exit dynamics, seems to explain a substantial part of aggregate productivity development. These forces are much more difficult to uncover by an investigation of short-run (e.g. year-by-year) changes. Thereby, we extend our previous work in Cantner and Krüger (2004a, b) by providing evidence for a link of the technological development of firms (represented by productivity change) to their economic success in the form of increasing shares in industry employment or sales. Future work will expand the findings reported in this paper in at least three directions. First, testing significance can help to disentangle small but insignificant effects from the really statistically confirmed findings. This could be implemented in a nonparametric way by bootstrapping. Second, many additional insights might be gained by looking at the heterogeneity of the contributions of the individual firms to the five components of the decomposition. Third, broader data sets comprising a larger number of small firms and therefore more entry and exit activity could be exploited to validate and expand the present findings.

Appendix

Results for sales shares

Table 6 Firm size distribution with respect to real sales

Industry	Mean	Skewness	Kurtosis	Q0.25	Q0.50	Q0.75
Construction	60,1563.23	3.36	15.86	75,431.06	196,068.00	540,147.09
Food	1,099,783.28	4.58	25.96	63,178.29	205,794.75	554,283.76
Textiles	672,811.76	9.02	102.30	76,410.08	193,703.31	593,386.78
Paper	2,115,807.29	5.22	35.23	96,308.75	408,010.00	1,309,443.88

Table 6 (continued)

Industry	Mean	Skewness	Kurtosis	Q0.25	Q0.50	Q0.75
Chemicals	787,157.33	10.39	158.50	78,304.82	175,711.50	659,991.09
Rubber	472,389.11	2.78	10.10	61,190.38	137,631.65	374,540.44
Metal	1,003,813.15	9.16	95.78	56,464.56	205,226.58	575,812.36
Machinery	1,234,884.02	9.01	94.39	70,592.25	177,706.07	695,666.34
Electronics	971,689.33	7.64	67.16	88,579.65	295,616.82	754,392.12
Transportation	1,162,838.23	7.36	66.57	65,925.15	239,234.91	991,142.07
Instruments	789,826.54	7.75	66.48	68,465.09	189,628.70	575,707.16

Table 7 Decomposition 1981–1998 (sales shares)

	Change	Within	Between	Covariance	Entry	Exit
Total sample	0.6480	0.0620	−0.3506	0.4264	0.2661	−0.2441
Construction	−0.3134	−0.3501	−0.0677	0.0586	0.0385	−0.0073
Food and beverages	0.2411	−0.0849	−0.0406	0.2381	0.0831	−0.0453
Textiles and apparel	1.1439	0.5321	0.0434	−0.2315	0.7896	−0.0102
Paper and printing	1.7408	0.2078	0.0461	−0.0478	1.6718	0.1372
Chemicals and petroleum	0.5512	−0.3522	−0.1158	0.2541	0.0207	−0.7444
Rubber and plastics	1.1981	0.6969	−0.1386	0.7584	−0.0029	0.1157
Metal products	0.4932	0.1732	−0.1025	0.2323	0.2677	0.0776
Machinery and equipment	2.3906	0.4946	0.0357	0.2189	1.5372	−0.1042
Electronics	0.8071	0.0838	0.2317	0.1074	0.3110	−0.0732
Transportation equipment	1.2809	0.4875	0.0133	0.5792	0.2521	0.0512
Instruments	0.9402	0.3337	−0.0207	0.3918	0.2776	0.0422

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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 8 Decomposition 1981–1989 (sales shares)

	Change	Within	Between	Covariance	Entry	Exit
Total sample	−0.4688	−0.2917	−0.7154	0.4842	0.0473	−0.0068
Construction	−0.7402	−0.9524	−0.1734	0.1817	0.1438	−0.0600
Food and beverages	0.1810	−0.3355	−0.0208	0.4648	0.0718	−0.0008
Textiles and apparel	0.4872	0.2635	−0.1859	0.0214	0.3851	−0.0031
Paper and printing	1.2127	0.8853	0.0204	−0.4148	0.8218	0.0999
Chemicals and petroleum	−1.6312	−1.1050	−1.4415	0.9770	−0.0632	−0.0016
Rubber and plastics	1.5477	1.5276	−0.0644	0.1035	0.0000	0.0190
Metal products	0.0885	−0.3169	0.1061	0.4580	−0.1584	0.0003
Machinery and equipment	1.5882	0.7200	−0.1776	0.0755	0.9696	−0.0008
Electronics	−1.1245	−0.9318	0.0539	−0.2373	−0.0246	−0.0154
Transportation equipment	1.5670	1.4980	−0.0282	−0.0098	0.1071	0.0000
Instruments	0.3893	0.1021	−0.0224	0.0379	0.3726	0.1009

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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 9 Decomposition 1990–1998 (sales shares)

	Change	Within	Between	Covariance	Entry	Exit
Total sample	1.8184	0.4016	−0.0330	0.8683	0.3044	−0.2771
Construction	0.1713	0.3237	−0.1183	−0.0049	0.1923	0.2215
Food and beverages	−0.2056	−0.8123	−0.9229	1.1050	0.0664	−0.3582
Textiles and apparel	2.1839	0.8240	0.6619	0.1711	0.0363	−0.4906
Paper and printing	2.3542	1.0541	0.0391	0.3680	0.7854	−0.1077
Chemicals and petroleum	2.9960	0.3944	0.7206	1.0916	0.2352	−0.5542
Rubber and plastics	3.6990	0.5940	0.4426	1.4207	0.1523	−1.0893
Metal products	1.3691	0.2835	0.1375	0.8146	0.0710	−0.0626
Machinery and equipment	3.2330	1.1730	0.2404	0.7788	0.9975	−0.0434
Electronics	2.9493	0.6359	0.1844	1.1440	0.8257	−0.1592
Transportation equipment	0.9108	0.2987	−0.3865	0.7773	−0.0292	−0.2506
Instruments	1.8428	0.5767	−0.1009	0.9350	0.4554	0.0233

Reported are average percentage growth rates of the aggregate productivity levels in the column change and the five 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).

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