WORKING PAPER

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von
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University of Lüneburg
Working Paper Series in Economics

No. 49

May 2007

www.uni-lueneburg.de/vwl/papers

ISSN 1860 - 5508

Exports and Productivity Growth – First Evidence from a Continuous Treatment Approach*

by

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Abstract: A recent survey of 54 micro-econometric studies reveals that exporting firms are more productive than non-exporters. On the other hand, previous empirical studies show that exporting does not necessarily improve productivity. One possible reason for this result is that most previous studies are restricted to analysing the relationship between a firm's export *status* and the growth of its labour productivity, using the firms' export status as a binary treatment variable and comparing the performance of exporting and non-exporting firms. In this paper, we apply the newly developed generalised propensity score (GPS) methodology that allows for continuous treatment, that is, different levels of the firms' export activities. Using the GPS method and a large panel data set for German manufacturing firms, we estimate the relationship between a firm's export-sales ratio and its labour productivity growth rate. We find that there is a causal effect of firms' export activities on labour productivity growth. However, exporting improves labour productivity growth only within a sub-interval of the range of firms' export-sales ratios.

Keywords: *Export-sales ratio, labour productivity, continuous treatment, dose-response function*

JEL Classification: *F14, F23, L60*

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* Special thanks go to the Statistical Office of Lower Saxony, and especially to Uwe Rode, for providing us the access to the confidential micro level data and running our Stata do-files. Earlier versions of the paper were presented at workshops on *The Microeconometrics of International Firm Activities* at Lüneburg University in September 2006 and on *Exports and Productivity – An International Comparison* at the University of Nottingham in March 2007; comments from participants are gratefully acknowledged.

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1 Motivation

A recent survey of 54 micro-econometric studies, which include data for firms from 34 countries and were published between 1995 and 2006, shows that exporting firms are more productive than non-exporters (cf. Wagner 2007). Germany is a case in point; productivity differentials are found in favour of exporting firms compared to firms that sell their products on the national market only. These differentials are statistically significant and economically important even when observed and unobserved firm characteristics are controlled for.

There are two alternative but not mutually exclusive hypotheses as to why exporters can be expected to be more productive than non-exporting firms (see Bernard and Jensen 1999; Bernard and Wagner 1997). The first hypothesis points to self-selection of the more productive firms into export markets. The reason for this is that selling goods in foreign countries involves additional costs. The range of extra costs includes transportation costs, distribution or marketing costs, the cost of personnel with skill to manage foreign networks, or production costs from modifying domestic products for foreign consumption. These costs provide an entry barrier that less successful firms cannot overcome. Based on the Ricardian theory of comparative advantage, Bernard et al. (2003) derived a theoretical trade model that traces back the self-selection of firms with higher productivity into the export market to firm-specific differences in efficiency. Export activities constitute a higher "efficiency hurdle" (Bernard et al. 2003: 15) than domestic sales.[1] Thus, firms with higher efficiency are more likely both to export and to have higher measured productivity. Similarly to Bernard et al., Melitz (2003) developed a monopolistically competitive model of trade with firm heterogeneity. According to his model, only more productive firms export while firms with low productivity may not survive, or survive but only serve the domestic market.

The second hypothesis points to the role of learning-by-exporting. Knowledge flows from international buyers and competitors help to improve the post-entry performance of export starters. According to this hypothesis, the productivity-increasing effect of international sales results from knowledge and expertise related to the foreign market that non-exporters do not have (Aw et al. 2000). Criscuolo et al. (2005) examined the differences in knowledge between internationally engaged firms and domestic firms using the *knowledge production function* framework (see Griliches 1979; 1990) that links output of new knowledge to two types of input, namely

[1] In the model, among all potential producers of any good only the most efficient ones serve the (domestic) market.

investment in discovering new knowledge (e.g., spending on research and development) and flows of ideas from existing stock of knowledge. The authors show that globally engaged firms generate more innovative outputs due to, among other things, more learning from sources like suppliers and customers, universities, and the intra-firm worldwide pool of information. Wagner (2006) reports similar findings in a replication study using German plant level data. In addition to the learning-by-exporting hypothesis, it is argued that firms participating in international markets are exposed to more intense competition and must improve faster than firms who sell their products domestically only.[2] Thus, exporting makes firms more productive.

The two hypotheses (self-selection of the more productive firms and the learning-by-exporting hypothesis) have been tested empirically since the mid-1990s. Wagner's (2007) survey reviews the findings of studies that use micro data at the level of firms (i.e. plants, establishments, local production units)[3] to investigate the causal relationship between export activities and productivity empirically. Wagner concludes that "details aside the big picture that emerges after ten years of microeconometric research in the relationship between exporting and productivity is that exporters are more productive than non-exporters, and that the more productive firms self-select into export markets, while exporting does not necessarily improve productivity" (Wagner 2007: 67).

This finding, however, does not answer the question in which way a firm actually benefits from its export activities. Arguing that more productive firms become exporters is only a necessary condition for exporting. But this argumentation does not constitute a sufficient condition. All of the theoretical models of individual firms' foreign market participation – for example, the dynamic model formulated by Roberts and Tybout (1997) – state that a firm will export if the (expected) benefits of such an engagement are positive. There might be various reasons why the hitherto existing literature has not found an impact of a firm's export activities on its labour productivity. Firstly, Roberts and Tybout's model assumes a profit-maximising firm. A firm will export if the profits the firm makes by selling its products abroad are non-negative. Thus, a firm may benefit from its export activities by increasing profits rather than by achieving higher labour productivity. Unfortunately, in most cases micro data at the level of firms do not contain information on firms' profits. This is particularly true for those data sets that originate from voluntary surveys.

2 In open economies like Germany, domestic firms also face competition from foreign companies because of imports to the domestic market ("imported" competition; see Bernard and Wagner 1997). Thus, it is questionable whether the argument of the exposure to more intense competition in foreign markets is applicable to German firms. In fact, this argument is often stated in the literature concerning development economics. In developing countries, foreign firms are often confronted with barriers to entry into the domestic market, implying less fierce competition for domestic firms (see Aw and Hwang [1995] for further details).

Secondly, the behaviour of firms might be forward-looking in the sense that the desire to export tomorrow leads a firm to improve performance today to be competitive on the foreign market, too. Cross-sectional differences between exporters and non-exporters, therefore, may in part be explained by ex ante differences between firms. In this case, we observe that the more productive firms become exporters. Thirdly, most of the papers reviewed by Wagner only examine direct effects of firms' export activities on labour productivity. Under circumstances involving regional spillover effects, non-exporting firms might also profit from other firms' exporting activities such that international business activities have a productivity-increasing effect on both exporting and non-exporting companies.[4]

Finally, most studies that empirically investigate the learning-by-exporting hypothesis only distinguish between exporting and non-exporting companies. The firms' export status is used as a binary treatment variable and the labour productivity of exporting and non-exporting firms is compared applying different econometric methods. Whether or not exporting has a positive effect on firm performance might, however, not simply depend on a firm's export status, but might be a function of the *extent* of the firm's export activities. On the one hand, there are firms that only occasionally receive some unsolicited orders from abroad, whereas, on the other hand, some firms pro-actively exploit the potential of the foreign market, generating a high percentage of their total sales in the foreign market (denoted as export-sales ratio or export intensity). In this paper, we will work on the basis of the latter argument and analyse the effect of exporting on firms' labour productivity growth at each export-sales ratio in the interval from zero to one. If we can show that exporting improves labour productivity only within a sub-interval of the range of firms' export-sales ratios whereas it has no or even a negative effect within another sub-interval, this can at least partly explain why those studies that confine themselves to firms' export status do not find any impact of firms' export activities on productivity growth.

Considering those firms that generate a relatively small share of their total sales in the foreign market, for instance due to some unsolicited orders from abroad, it can be postulated that learning-by-exporting is less relevant for them. Firms with a small export-sales ratio may have only infrequent contacts with a limited number of foreign customers, leading to a very limited flow of ideas from foreign knowledge sources to the domestic firm. Thus, it can be hypothesised that an exporter must exceed a minimum export-sales ratio before it can benefit from learning-by-

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[3] In this paper, we will use the terms *firm*, *establishment*, and *plant* interchangeably to describe the (local production) unit of analysis.

[4] For a discussion of spillover effects of export activities see Aitken et al. (1997).

exporting. Beyond this minimum export-sales ratio labour productivity growth is expected to increase with the firms' export intensity. However, when a firm increases its foreign engagement the costs of coordination and control also rise and sometimes begin to escalate when a critical value of the export-sales ratio is exceeded. Firms that extend their export activities often enter more distant markets. The increasing geographic distance, differences in culture and peculiarities of the individual foreign markets raise the costs of exporting and necessitate additional sales personnel (cf. Gomes and Ramaswamy 1999). In this case, an increasing international expansion has a negative impact on a firm's labour productivity growth (at least if labour productivity is measured by sales per employees; see section 2) which may exceed the benefits an exporter can gain due to learning-by-exporting. Thus, there might be an optimal value of the export-sales ratio, leading to an inverted *U*-shaped relationship between a firm's export intensity and its labour productivity growth. This optimal level of a firm's international engagement is also called the "threshold of internationalisation" (Sullivan 1994a).

In the economic literature, only few studies investigate empirically the influence of varying export-sales ratios on performance, among them the study by Castellani (2002) who finds a positive linear effect of the share of exports in total sales on firms' productivity growth and the paper by Liu et al. (1999) where the export-sales ratio negatively influences firms' productivity growth. The impact of varying degrees of a firm's international business activities on its performance has been discussed more frequently in the international business literature since the 1980s. Early studies hypothesise and empirically confirm a (in most cases positive) linear relationship between the degree of internationalisation and performance (e.g., Bühner 1987 and Grant 1987). More recently published studies find a curvilinear relationship. Geringer et al. (1989) and Gomes and Ramaswamy (1999) support an inverted *U*-shaped relationship, whereas some empirical studies even argue in favour of multiple waves in the relationship between firms' levels of foreign involvement and their performance (cf. Hitt et al. 1994, Sullivan 1994a, and Riahi-Belkaoui 1998).

It must be noted, however, that the cited studies from the international business literature are not exclusively restricted to analysing the relationship between firms' export-sales ratios and their labour productivity growth rates. Instead, they examine the relationship of different measures of the extent of firms' international business activities (number of foreign destination countries, ratio of foreign assets to total assets; see for instance Sullivan 1994b) and firm performance (employment and sales growth, wages, return on assets). Thus, our paper is embedded in the more general literature on the export-performance relationship. In this context, however, the relationship between a firm's export-sales ratio and its (labour) productivity growth rate is the most frequently discussed research question, in particular in the economic literature, and will therefore be analysed in this paper too.

This paper contributes to the literature in two important ways. Firstly, it determines the relationship between performance (measured by the growth of labour productivity) and firms' export-sales ratios at each value of firms' export intensity in the interval from zero to one and, secondly, we show how the causal effect of firms' export activities on labour productivity growth varies along the domain of the export-sales ratio. Earlier studies estimate linear equations explaining (the growth of) labour productivity by a set of firm-specific variables that includes a firm's export-sales ratio and, in some specifications, its squared value (e.g. Castellani 2002, Gomes and Ramaswamy 1999). These studies only make it possible to determine whether the export-sales ratio and labour productivity are positively or negatively correlated and whether this relationship is linear or non-linear (*U*-shaped). Other studies classify firms into different internationalisation categories, with each category representing a predefined subinterval of firms' export-sales ratios in the range from zero to one (e.g. Geringer et al. 1989). The disadvantage of this approach is that it only approximates the relationship between productivity and firms' export intensity. The exact value of the export-sales ratio where productivity is maximised (or minimised) or "turning points" of the relationship examined, cannot be identified.

In this paper, we apply the generalised propensity score (GPS) methodology recently developed by Imbens (2000) and Hirano and Imbens (2004). The GPS method allows for continuous treatment, that is, in our case, different levels of the firms' export intensity. Imbens (2000) shows that, similarly to the case of binary treatment, adjusting for the GPS removes all the bias associated with differences in pre-treatment variables between treated (exporting in our case) and non-treated (non-exporting) firms. Based on the GPS, Hirano and Imbens (2004) further estimated a dose-response function that depicts the conditional expectation of outcome (growth of labour productivity in our case) given the continuous treatment (export-sales ratio) and the GPS, evaluated at any level of the continuous treatment variable. The GPS methodology was introduced to the literature examining the export-performance relationship by Fryges (2006a), who estimates the relationship between the firms' export-sales ratios and their subsequent sales growth rates (as a measure of firm performance) using a data set of young technology-oriented firms in Germany and the UK. Applying the GPS methodology, this paper analyses the causal relationship between the growth of labour productivity and the export intensity using a data set of plants from mining and manufacturing industries in Lower Saxony, one of the federal states of Germany.

The rest of the paper is organised as follows: Section 2 describes the data set used for the empirical analysis and shows some descriptive statistics. The empirical methodology is explained in section 3. Section 4 discusses the empirical results and section 5 concludes.

2 Data and Descriptive Analysis

The empirical investigation uses data from an unbalanced panel of establishments (local production units, plants) built from cross sectional data collected in regular surveys by the Statistical Office of Lower Saxony. The surveys cover all establishments from mining[5] and manufacturing industries that employ at least twenty persons in the local production unit or in the company that owns the unit. Therefore, single or multiple establishment enterprises with less than 20 employees in total do not report to the surveys. Participation of firms in the survey is mandated in official statistics law, and the firms have to report the true figures. In this paper annual data for 1995 (when the new WZ93 classification scheme and the new definition of the population of establishments to be surveyed was introduced) to 2005 are used. Note that the micro level data are strictly confidential and for use inside the Statistical Office only, but not exclusive. Further information on the content of the data set and how to access it is given in Wagner (2000).

It should be noted that in this data set *export* means the amount of sales to a customer in a foreign country plus sales to a German export trading company; indirect exports (for example, tires produced in a plant in Lower Saxony that are delivered to a German manufacturer of cars that exports some of its products) are not covered by this definition.

5 Given that there are only a few establishments from mining industries we will use the term manufacturing industries to describe our sample in this paper.

Productivity is measured as total sales (at 1995 prices) per employee, i.e. labour productivity. More appropriate measures of productivity like value added per employee (or per hour worked), or total factor productivity, cannot be computed because of a lack of information on hours worked,

Table 1: Export activities of manufacturing firms in Lower Saxony

	Share of exporting firms	Mean export intensity	
		all firms	exporters only
1995	47,07	10,76	21,59
1997	43,81	10,27	22,42
1999	45,57	11,03	23,25
2001	47,79	12,63	25,27
2003	51,12	14,38	26,79
2005	52,77	16,23	29,54

Note: Export intensity defined as share of foreign sales.
Source: Own calculations using data from the Statistical Office of Lower Saxony.

value added, and the capital stock[6] in the surveys. Controlling for the industry affiliation at the detailed 4-digit-level in the econometric investigations, however, can be expected to absorb much of these differences in the degree of vertical integration and capital intensity.[7]

Table 1 reports the share of exporting firms in all firms and the average share of foreign sales in total sales for the period under consideration. About half of all manufacturing firms were exporters, and the share of exporting firms tends to increase between 1995 and 2005.[8] During these years the average share of foreign sales in total sales increased from 10% to 16% for all firms, and from 22% to 30% for exporting firms. It should be noted, however, that our data set does not contain information on exporters' foreign target markets. This implies that we do not know whether an exporter generates its foreign sales in only one country or whether it sells its products

6 The survey has information about investment that might be used to approximate the capital stock. A close inspection of the investment data, however, reveals that many establishments report no or only a very small amount of investment in many years, while others report huge values in one year. Any attempt to compute a capital stock measure based on these data would result in a proxy that seems to be useless.

7 Note that Bartelsman and Doms (2000: 575) point to the fact that heterogeneity in labour productivity has been found to be accompanied by similar heterogeneity in total factor productivity in the reviewed research where both concepts are measured. Furthermore, Foster et al. (2005) show that productivity measures that use sales (i.e. quantities multiplied by prices) and measures that use quantities only are highly positively correlated.

8 The decrease in the share of exporting firms between 1995 and 1997 is due to a change in the sampling frame used for the survey from which the data are taken. Starting in 1997 a large number of establishments that responded to the craft sector survey in earlier years were included in the survey covering the manufacturing sector. Given that these craft establishments (e.g., butchers or bakers) tend to produce goods for the local market only, the share of exporting firms decreased even though it is possible that the numbers of exporting firms increased.

in numerous foreign destination countries. Nevertheless, our data demonstrate that in the manufacturing sector in Lower Saxony the importance of exporters and exporting is high and increasing.

Exporters and non-exporters differ in several dimensions. Table 2 illustrates this for our sample of firms in two years, 1996 and 2002.[9] On average, exporters are larger (in terms of the number of employees and the volume of total sales), pay higher wages per employee, and have both higher levels and higher growth rates of labour productivity (measured as sales per employee). Most of these differences between exporters and non-exporters are statistically significant at an error level of 5% or better; exceptions are the level of labour productivity in 1996 and the growth of labour productivity between 2002 and 2005.[10] This picture is familiar from earlier studies comparing exporting and non-exporting firms (see Bernard and Wagner [1997] for Lower Saxony, Bernard and Jensen [1995] for the U.S., and several studies for other countries surveyed in Wagner [2007]).

Table 2: Key numbers for exporters and non-exporters in Lower Saxony

	Exporters		Non-exporters	
	Mean	Standard error	Mean	Standard error
1996				
Number of employees	218.60	26.14	62.41	2.48
Sales (in DM 1,000 of 1995)	87,932.22	19,006.00	18,379.44	1,128.79
Labour productivity	296.03	5.54	285.40	6.70
Growth of labour productivity 1996–1999	12.40%	0.71%	9.72%	0.87%
Wage per employee	55.39	0.33	51.88	0.42
2002				
Number of employees	208.76	26.94	53.44	1.66
Sales (in DM 1,000 of 1995)	109,419.9	32,803.19	17,752.07	1,566.69
Labour productivity	331.06	6.08	268.14	6.66
Growth of labour productivity 2002–2005	8.36%	0.75%	6.22%	1.12%
Wage per employee	61.33	0.35	53.35	0.45

Note: Labour productivity defined as sales per employee. All statistics for labour productivity and its growth rate are trimmed by excluding values below the 1st or above the 99th percentiles.
Source: Own calculations using data from the Statistical Office of Lower Saxony.

9 Descriptive statistics are reported for 1996 and 2002 because this is the time span we use for the estimation of our econometric model (due to the way the variables are constructed – see section 4).

10 Note that exporters always have statistically significantly higher values of the number of employees, sales, labour productivity, growth of labour productivity, and wage per employee when log-values are compared.

Table 3: Export intensity and labour productivity

	Labour productivity (in DM 1,000 of 1995)		Growth of labour productivity (t – t+3) (in %)	
Export intensity	Mean	Median	Mean	Median
1996				
0%	285.40	194.45	9.72	3.93
> 0 und ≤ 5%	268.78	200.98	9.78	5.12
> 5 und ≤ 10%	301.73	226.62	7.78	4.89
> 10 und ≤ 20%	280.11	220.02	13.62	8.64
> 20 und ≤ 50%	304.63	229.74	14.72	11.12
> 50%	354.30	280.45	15.08	11.19
2002				
0%	268.14	181.09	6.22	-2.65
> 0 und ≤ 5%	301.30	201.11	5.10	0.77
> 5 und ≤ 10%	329.39	241.20	9.07	4.72
> 10 und ≤ 20%	316.22	225.14	7.73	3.73
> 20 und ≤ 50%	322.31	250.44	9.48	5.00
> 50%	396.33	308.04	10.47	4.46

Note: Labour productivity defined as sales per employee. All statistics for labour productivity and its growth rate are trimmed by excluding values below the 1st or above the 99th percentiles.
Source: Own calculations using data from the Statistical Office of Lower Saxony.

Furthermore, from Table 3 we see that firms with an export share of 20% or more tend to have higher levels and growth rates of labour productivity than firms that export a smaller share of production. However, the relationship between export intensity and labour productivity, and between export intensity and the growth of labour productivity, is not monotonic. The very nature of this relationship between the share of exports in total sales and labour productivity growth is at the core of our econometric investigation.

3 Econometric Methodology

This paper applies the generalised propensity score (GPS) method recently developed by Imbens (2000) and Hirano and Imbens (2004). The GPS method allows for continuous treatment, that is, in our case, different levels of firms' export-sales ratios. Thus, it is a generalisation of the binary treatment propensity score methodology as derived by Rosenbaum and Rubin (1983).

The key assumption of the GPS method is a generalisation of the strong unconfoundedness assumption made by Rosenbaum and Rubin (1983) for binary treatments (cf. Imbens 2000). Let the treatment D take on values in the interval $\mathcal{D} = [d_0, d_1]$. Assignment to treatment D is *weakly unconfounded*, given pre-treatment variables X, if

(1) $$Y(d) \perp D | X \quad \textit{for all} \quad d \in \mathcal{D},$$

with $Y(d)$ as the outcome associated with treatment level d. It is important to note that this assumption does not require joint independence of all potential outcomes $\{Y(d)\}_{d \in \mathcal{D}}$. Instead, weak unconfoundedness only requires pairwise independence of the treatment with each of the potential outcomes. In other words, the random variable D (the treatment) is assumed to be conditionally independent with the random variable Y (the outcome), measured at an arbitrarily chosen treatment level d.

In practice, conditioning on the entire set of pre-treatment variables X may be difficult when the dimension of X is large. In the case of binary treatment, Rosenbaum und Rubin (1983) demonstrate that conditioning on the one-dimensional propensity score (i.e. the conditional probability of receiving the treatment given pre-treatment variables) is sufficient to remove all the bias associated with differences in pre-treatment variables between treated and non-treated individuals or firms. This property of the propensity score is used by numerous studies that apply matching techniques. In order to allow for continuous treatment, this traditional propensity score method must be modified. Let $r(d,x)$ be the conditional density of the treatment given the covariates:

(2) $$r(d,x) = f_{D|X}(d|x).$$

Then the generalised propensity score is defined as $R = r(D, X)$ (Hirano and Imbens 2004: 2). Assuming that the assignment to the treatment is weakly unconfounded, Hirano and Imbens (2004) prove that adjusting for the GPS eliminates any biases associated with differences in the pre-treatment variables. This bias-removing property of the GPS corresponds to that of the binary propensity score. Based on the GPS method, it is possible to estimated a dose-response function that depicts the average potential outcome $E[Y(d)]$ evaluated at any level or dose of the continuous treatment variable.

Hirano and Imbens (2004) suggest a three-stage approach to implementing the GPS method. In the first stage, the conditional distribution of the treatment variable given the covariates is estimated. In our case, the distribution of the treatment variable, i.e. the firms' export-sales ratios, is highly skewed. In particular, it has many limit observations at the value zero, representing firms without any international sales. The latter group of firms decided that their optimal volume of exports was zero. Following Wagner (2001, 2003), we apply the fractional logit model developed by Papke and

Wooldridge (1996) to estimate the export intensity of the firms in our sample.[11] The estimation procedure maximises the Bernoulli log-likelihood function given by

(3) $$l_i(\beta) \equiv D_i \cdot \log\left[\Lambda\left(X_i\beta\right)\right] + \left(1 - D_i\right) \cdot \log\left[1 - \Lambda\left(X_i\beta\right)\right]$$

(with D as the firm's export-sales ratio [the treatment], X as the vector of covariates, and $\Lambda(\cdot)$ as the cumulative distribution function of the logistic distribution) using the generalised linear models (GLM) framework developed by McCullagh and Nelder (1989). The estimated GPS based on the Bernoulli log-likelihood function defined in equation (3) is then given by

(4) $$\hat{R}_i = \left[\Lambda\left(X_i\hat{\beta}\right)\right]^{D_i} \cdot \left[1 - \Lambda\left(X_i\hat{\beta}\right)\right]^{\left(1-D_i\right)}.$$

In the second stage of Hirano and Imbens' GPS methodology the conditional expectation of outcome Y_i (growth of labour productivity in our case) is modelled as a function of the treatment D_i and the (estimated) generalised propensity score $\hat{R}_i$. Following Hirano and Imbens, we use a quadratic approximation for the conditional expectation of Y_i:

(5) $$E\left[Y_i \middle| D_i, R_i\right] = \alpha_0 + \alpha_1 \cdot D_i + \alpha_2 \cdot D_i^2 + \alpha_3 \cdot \hat{R}_i + \alpha_4 \cdot \hat{R}_i^2 + \alpha_5 \cdot D_i \cdot \hat{R}_i .$$

Equation (5) is estimated by OLS. As Hirano and Imbens point out, the estimated regression coefficients $\hat{\alpha}$ do not have any direct meaning and will therefore not be reported in section 4 for reasons of space.

In the last stage of the GPS method, the average expected outcome at treatment level d is estimated, using the regression coefficients $\hat{\alpha}$ from the second stage of the GPS method:

(6) $$\bar{E}\left[Y\left(d\right)\right] = \frac{1}{N}\sum_{i=1}^{N}\left(\hat{\alpha}_0 + \hat{\alpha}_1 \cdot d + \hat{\alpha}_2 \cdot d^2 + \hat{\alpha}_3 \cdot \hat{r}\left(d, X_i\right) + \hat{\alpha}_4 \cdot \hat{r}\left(d, X_i\right)^2 + \hat{\alpha}_5 \cdot d \cdot \hat{r}\left(d, X_i\right)\right),$$

with N as the number of observations in our data set. In order to obtain an estimate of the entire dose-response function, equation (6) is calculated at each level of the treatment, i.e. in our case, at each export intensity in the interval from zero to one, increasing the export intensity successively by one percentage point in each step. Following the same procedure as Hirano and Imbens, the confidence intervals of the dose-response function are determined via bootstrapping.[12]

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11 Hirano and Imbens (2004) use a normal distribution for (the logarithm of) the treatment variable of their model. However, they emphasise that more general models may be considered.

12 Hirano and Imbens state that asymptotic normality for the estimator in equation (6) can be proved.

It should be emphasised that we do not calculate the effect of the treatment per se, that is, we do not compare the potential outcome for non-treated individuals or firms with that for all treated entities simply allowing for different levels or doses of the treatment variable.[13] Instead, the dose-response function we estimate shows the average potential outcome at each dose of the treatment and how average responses vary along the interval $\mathsf{D} = [d_0, d_1]$. From this curve we can calculate pairwise treatment effects of the form (cf. Flores 2004):

(7) $$E\left(\Delta^{d'd''}\right) = E\left[Y\left(d'\right) - Y\left(d''\right)\right] \quad \text{for} \quad d', d'' \in \mathsf{D}.$$

4 Empirical Results

In the following, we estimate three dose-response functions that depict the expected (logarithmic) labour productivity growth rate in the period from year *t* to *t*+3 given the export-sales ratio in *t*. The first dose-response function is based on the pooled data set, using data from 1995 to 2005. The two remaining dose-response functions show the relationship between labour productivity growth and firms' export intensity for the first and the last year of the time span covered by our data set, i.e. 1996 and 2002.[14] In this way, we can test whether the shape of the dose-response function is stable over time or whether the functional form of the dose-response curve has changed over the last decade.

The first step of Hirano and Imbens' GPS method is to estimate the conditional distribution of the treatment variable (export-sales ratio in our case) given the covariates. As already mentioned above, we apply the fractional logit model developed by Papke and Wooldridge (1996) for estimating the export-sales ratio of the firms in our sample. The exogenous covariates of the fractional logit model include the size of the establishment (measured by the logarithmic number of employees) and its squared value, a dummy variable indicating whether or not the establishment is part of a multi-plant enterprise and the (logarithm of the) average wage per employee to proxy human capital intensity. Furthermore, the fractional logit model comprises firms' (logarithmic)

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13 Behrman et al. (2004) examine the effect of a preschool program targeted towards disadvantaged children (the treatment), allowing for different lengths (doses) of exposure to the program. They derive an estimator analogous to the average treatment effect on the treated in the binary case. However, as Flores (2004) pointed out, the methodology of Behrman et al. is based on assumptions that are not related to the assumption of weak unconfoundedness made by Hirano and Imbens (2004).

14 1996 is the first year that allows us to estimate a dose-response function because the regression equation that explains firms' export-sales ratio in the first step of Hirano and Imbens' GPS method includes the absolute value of labour productivity in *t*-1, i.e. 1995 (see below). 2002 is the last suitable year for estimating a dose-response function because the endogenous performance variable is the growth of labour productivity from *t* to *t*+3, i.e. from 2002 to 2005.

labour productivity in *t*-1. The lagged absolute value of labour productivity is used as a covariate because the endogenous performance variable of the third step of the GPS model is the growth of labour productivity in the period from *t* to *t*+3. Including the lagged value of labour productivity guarantees that we control for different levels of labour productivity *prior* to the growth period examined. As explained in section 2, industry dummies at the detailed 4-digit-level are included to absorb differences in the degree of vertical integration and capital intensity. The pooled regression further contains a set of year dummies to control for macroeconomic conditions. Note that limitations of the data prevent the inclusion of further control variables like research and development activities.[15]

The estimation results of the fractional logit models are presented in Table 4.[16] The results of the pooled regression and the two year-specific regressions are very similar. Firm size has a positively significant effect on firms' export-sales ratios, however at a decreasing rate (negative sign of the squared value of firm size). Thus, our results show the familiar picture of an inverted *U*-shaped relationship between the number of employees and the export-sales ratio (see, e.g., Wagner 2001, 2003 and Barrios et al. 2003). Note, however, that the estimated maximum of this inverted *U*-shaped relationship lies at a rather high number of employees; the values are 4.626, 4.791, and

[15] See Fryges (2006b) for a discussion of the impact of R&D activities on firms' export-sales ratios.

[16] The model was estimated using the `glm` command of the software package Stata, version 9.2 SE. For a detailed discussion of estimating generalised linear models with Stata see Hardin and Hilbe (2001).

Table 4: Determinants of the export-sales ratio – results of the fractional logit models

Pooled sample

	Number of observations = 21,856 LL = -5,063.085		
	Coeff.	*robust standard error*	
log (number of employees)	1.114	0.065	***
log (number of employees) ^{2}	-0.066	0.006	***
Multi-plant dummy	-0.080	0.030	***
log (wage per employee)	0.650	0.071	***
log (labour productivity *t*-1)	0.461	0.027	***
Industry dummies			
Year dummies			
Constant	-13.021	0.324	***

1996

	Number of observations = 3,013 LL = -664.804		
	Coeff.	*robust standard error*	
log (number of employees)	1.000	0.169	***
log (number of employees) ^{2}	-0.059	0.016	***
Multi-plant dummy	-0.104	0.084	
log (wage per employee)	0.620	0.185	***
log (labour productivity *t*-1)	0.477	0.075	***
Industry dummies			
Constant	-12.603	0.859	***

2002

	Number of observations = 3,080 LL = -763.598		
	Coeff.	*robust standard error*	
log (number of employees)	1.152	0.167	***
log (number of employees) ^{2}	-0.070	0.016	***
Multi-plant dummy	-0.183	0.075	**
log (wage per employee)	0.753	0.179	***
log (labour productivity *t*-1)	0.487	0.069	***
Industry dummies			
Constant	-9.826	0.768	***

* 10% level of significance; ** 5% level of significance; *** 1% level of significance.
Source: own estimations.

3.746 employees for the pooled sample, for 1996, and for 2002, respectively. Given that only very few plants in Lower Saxony have more employees, the estimated coefficients should be interpreted to indicate that the export-sales ratio tends to increase with plant size, but at a decreasing rate. Furthermore, it should be noted that according to Wagner (2003) it is not firm size *per se* that enables a firm to attain a high export-sales ratio. Rather, the estimated coefficient of the firm-size variable also covers unobserved firm-specific factors that are positively correlated with firm size. The fractional logit models further show that the branch plant dummy is negative and statistically significant in the pooled and the 2002 regression. Plants that belong to a multi-plant enterprise generate a relatively large share of their total sales by supplying their parent companies, leading to an export-sales ratio smaller than that of independent plants. Finally, the export-sales ratio increases with the average wage per employee (i.e. firms' human capital) and with the lagged level of labour productivity. Firms with a high human capital intensity are likely to generate intangible assets (e.g., a technologically superior product) by which they distinguish themselves from their (international) rivals. This leads to a competitive advantage on the (international) market, enabling firms to realise a high export intensity. Similarly, it can be argued that more productive firms have a competitive advantage when compared with their (foreign) counterparts. Thus, more productive firms are more likely to generate a higher share of total sales abroad. The positive impact of lagged labour productivity on firms' export-sales ratios can also be interpreted as a confirmation of the self-selection hypothesis discussed in section 1: More productive firms self-select into export markets because they are able to bear the additional costs of selling goods in foreign countries.

Based on the fractional logit regressions, we calculate the generalised propensity score (GPS) according to equation (4). After estimating the conditional expectation of labour productivity growth in the second step of Hirano and Imbens' GPS methodology (equation (5)), we are able to determine the dose-response functions, i.e. the average expected conditional (logarithmic) labour productivity growth rate in the period from t to t+3 given the export-sales ratio in t and the estimated GPS (equation (6)).[17] [18] The dose-response functions for both the pooled sample and the 1996 and 2002 estimates are depicted in Figure 1.

According to the theoretical considerations in section 1, the estimated dose-response function for the pooled sample shows the expected inverted *U*-shaped relationship between labour productivity growth and firms' export-sales ratios. The maximum value of the labour productivity growth rate

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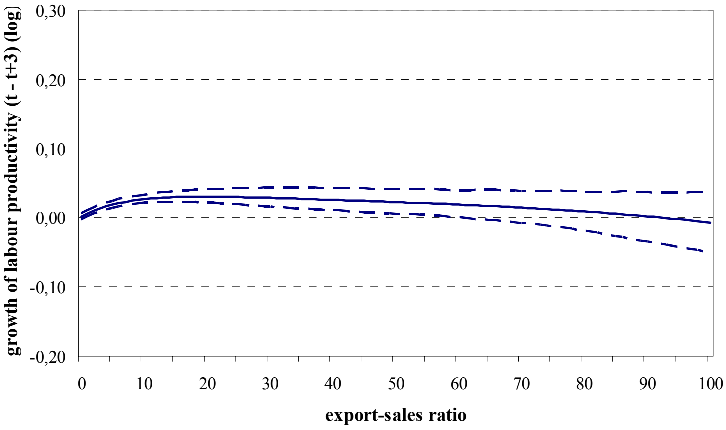
[17] Computations were made using the software package Stata, version 9.2 SE. Details are available from the first author on request.

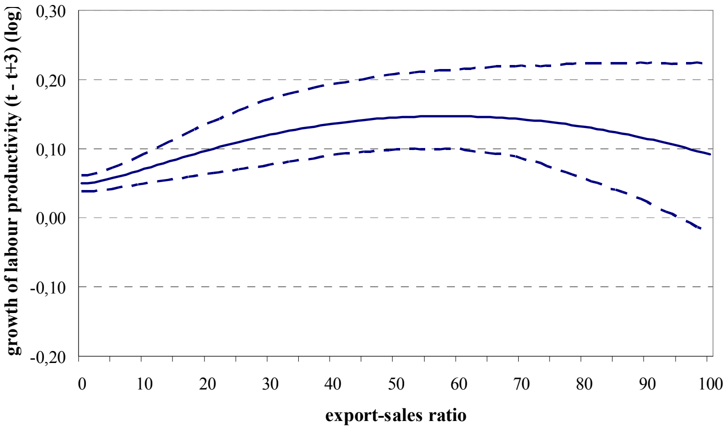
[18] Labour productivity growth is trimmed by excluding values below the 1st or above the 99th percentiles.

Figure 1: Estimated dose-response functions

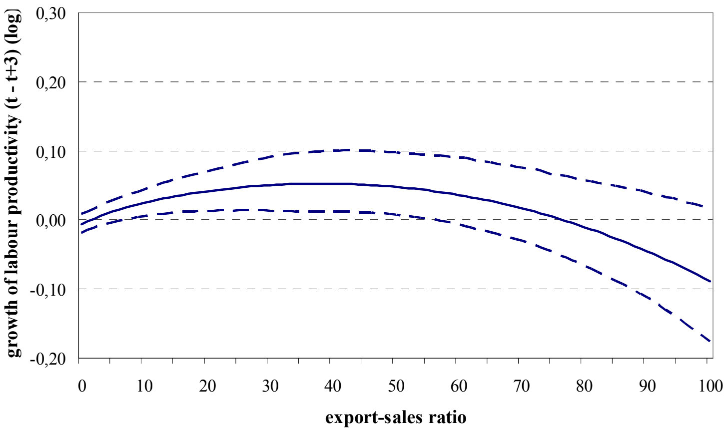
Pooled sample



1996



2002



Solid lines: estimated conditional expectation of firms' logarithmic labour productivity growth rate (*t* – *t*+3) given the export-sales ratio in *t* and the estimated generalised propensity score (GPS).
Dotted lines: simulated 90% confidence interval, using the 5th and 95th percentiles of the bootstrap distribution (pooled sample: 500 replications; 1996 and 2002: 1,000 replications).
Source: own estimations.

is reached at an export-sales ratio of 19%, where the expected value of the labour productivity growth rate amounts to 3.07% (non-logarithmic value). Comparing this maximum value of labour productivity growth with the growth rate of non-exporting firms (non-logarithmic labour productivity growth of non-exporting firms: 0.1%) and calculating the pairwise treatment effect reveals that, at an export-sales ratio of 19%, labour productivity growth is significantly larger than at an export intensity of zero (t-value: 5.61). In other words, if we eliminate firm-specific differences in the pre-treatment variables (as we did by conditioning on the GPS) a hypothetical switch of a firm from non-exporting to exporting 19% of its total sales causes a 3-percentage-point increase in the firm's labour productivity growth rate. Thus, at an export-sales ratio of 19% a firm's export activities have a causal effect on its labour productivity growth rate.

If the export intensity falls below or exceeds this "threshold of internationalisation," a firm will exhibit a lower labour productivity growth rate. Nevertheless, exporting will still have a positive impact on a firm's labour productivity growth rate – provided that the firm's export intensity is less than 52%. For all export-sales ratios that fall below the value of 52%, the difference between the expected labour productivity growth rate at this level of a firm's export activities and labour productivity growth of a comparable non-exporting firm (i.e. the pairwise treatment effect) is significantly greater than zero at the 5% level of significance. Even those firms that export only a relatively small share of their total sales, for example due to some unsolicited orders from abroad, benefit from their export activities, realising a significantly higher labour productivity growth rate. On the other hand, firms that generate 52 or more percent of their total sales in the international market do not profit from their export activities compared with non-exporting firms: The pairwise treatment effect is not significantly different from zero. Thus, we can conclude that exporting improves labour productivity growth only within a sub-interval of firms' export-sales ratios (less than 52% in our case). Studies that analyse the relationship between labour productivity growth and firms' export activities need to recognise that the effect of exporting varies with different levels of firms' export intensity.[19]

In order to test whether the shape of the dose-response function and the causal relationship between labour productivity growth and firms' export-sales ratios is stable over time, we estimated dose-response functions for the first and the last year of the time span covered by our data set, i.e. 1996 and 2002. The two year-specific dose-response functions in Figure 1 first demonstrate that

[19] The dose-response functions displayed in Figure 1 suggests a rather deterministic relationship between a firm's export intensity and its labour productivity growth. From a managerial point of view, however, the more important question is how firm managers react once they have recognised a decrease in performance due to "excessive" internationalisation (Sullivan 1994a). This leads to the question of organisational learning of how to deal with the challenges of a rising export intensity. This question is, however, beyond the scope of this paper.

firms' labour productivity growth rate from 1996 to 1999 is higher than the growth rate in the period from 2002 to 2005. This result corresponds to the descriptive statistics as shown in Table 2 and Table 3. Furthermore, both dose-response functions reveal the inverted *U*-shaped relationship between labour productivity growth and firms' export-sales ratios that was already observed when analysing the pooled data set.

However, the shape of the dose-response function in 1996 differs from that in 2002. In 1996, the dose-response curve reaches its maximum at an export-sales ratio of 58%, whereas in 2002 the highest labour productivity growth rate is attained when firms generate 38% of their total sales abroad. In 1996, the interval in which firms' export activities have a significantly positive impact on labour productivity growth when compared with non-exporting firms ranges from an export-sales ratio of 9% to a ratio of 75% (according to the estimated pairwise treatment effects at the 5% significance level). Thus, the dose-response function for 1996 does indeed show that firms that export only a relatively small share of their total sales do not benefit from their international engagement, as was argued in section 1. This result, however, is not confirmed by the dose-response function for 2002. In the latter case, the interval of the export-sales ratio in which labour productivity growth is causally affected by firms' export activities ranges from 2% to 50%. Thus, in 2002 the causal relationship between labour productivity growth and firms' export intensity is similar to what we found when examining the pooled data set.

The most striking result of year-specific estimations of the dose-response curves is the severe downturn in labour productivity growth in 2002. If firms export more than 76% of their total sales they will even exhibit a negative labour productivity growth rate. Since in our GPS model we control for firm-specific differences, the decrease in the growth of labour productivity from 2002 to 2005 must be caused by firms' extensive export activities in 2002. The labour productivity growth rate at very high levels of the export-sales ratio is even smaller than the growth rate of non-exporting firms, although not significantly so. The dose-response function for 1996 also reveals a fall in the labour productivity growth rate at high levels of firms' export intensity. This decrease, however, is less pronounced than that which we observe when analysing the 2002 subsample. Exporters in 1996 always show a labour productivity growth rate that exceeds that of non-exporting firms, although the difference is not significant for an export-sales ratio larger than 75%.

5 Conclusion

In this paper, we analysed the causal relationship between firms' labour productivity growth rates and their export-sales ratios. We showed that there is a causal effect of firms' export activities on labour productivity growth. However, exporting improves labour productivity growth only within a sub-interval of firms' export-sales ratios. Our results can be regarded as one possible explanation as to why previous studies that are restricted to the analysis of the relationship between a firm's export *status* and its labour productivity growth rate do not necessarily find a positive impact of exporting on labour productivity growth.

Furthermore, we found that the relationship between labour productivity growth and the export-sales ratio is not stable over time. This is a surprising result. If we observed a *shift* of the dose-response function from 1996 to 2002 leaving the *shape* of the dose-response function unchanged, this could be explained by changing macroeconomic conditions, e.g. a slowdown of the economy's technological progress. Our results, however, reveal a time-varying causal relationship between labour productivity growth and the export-sales ratio. In particular, we observe that in 2002 a high export-sales ratio reduces the labour productivity growth rate. One reason for this surprising result might be that in 2002 firms more frequently sell their products in more distant and technologically less advanced countries like India or China. On the one hand, this increases the costs of coordination and control of exporting firms. On the other hand, firms are less likely to benefit from learning-by-exporting if they export to a technologically less advanced country. Since we do not have any information on the target markets of our sample's exporters, we cannot test this hypothesis with our data. Thus, the time-varying relationship between labour productivity growth and the export-sales ratio needs further research.

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[published in: Simon C. Parker (Ed.), The Life Cycle of Entrepreneurial Ventures (International Handbook Series on Entrepreneurship, Volume 3), New York etc.: Springer, 2006, 15-37]

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