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Export Performance and Investment in R&D

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Export Performance and Investment in R&D

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Abstract:
This paper analyses the role of R&D in the export behaviour of Danish firms. Export behaviour is defined as the export intensity and the likelihood of a firm being an exporter. In the theoretical part of the paper it is argued that export and R&D behaviour effects are endogenous with respect to each other, and an empirical model is formulated in order to estimate which factors affect the firm's export. It is argued that besides R&D, firm size, wages, capital intensity and a number of other firm-specific factors controlling for risks are highly important for the export performance. In the empirical part of the paper the model is tested on a sample of 3,500 Danish firms. Using censored regression techniques and a FIML estimation form in order to deal with endogeneity problems between the R&D and export decisions of the firms, the computation clearly verifies the theoretical model put forward. Moreover, R&D is an important factor for being an exporting firm.

1. Introduction

From the international trade theory, it is well known that free trade stimulates growth and welfare through the utilization of the comparative advantages of the regions. However, the internationalisation of the firms may also stimulate their investment in research and development as the returns from new innovations are higher when they can be exploited also in a large foreign market. This argument is particularly important for firms in small economies, i.e. the home market is relatively small. Furthermore, investment in research and development may place the firm on the forefront of the technological frontier where it can gain competitive advantages compared to its competitors and further stimulate export and growth. Export and investment in research and development may thus interact and create a benign circle for the firm or the country in question.

Therefore, export performance is a quite important topic to discuss for economic growth and the general performance of firms, especially in small countries. The aim of this study is to analyse the factors determining the export behaviour of Danish firms. Export behaviour is defined in terms of the propensity to export and the likelihood that a firm becomes an exporter. There is some evidence on the export performance of firms, see e.g. Bernard & Jensen (1999), Wakelin (1998), Kumar & Siddharthan (1994) and Sterlacchini (1999). These studies mainly focus on factors determining the capability of a firm to become an exporter and in some cases attention has been paid to the influence from innovation, especially the factors acting as barriers for the incentive to export and innovate in firms. There is, however, only sparse recent evidence on the interaction between the R&D decisions of the firm and its export performance intensity, in most cases probably due to the lack of suitable micro level data.

This paper is based on a rather unique data set combining account information and information on R&D from the official Danish R&D statistics with further information from the official Danish firm register. Thus, the final sample is rather large compared to other micro data set with similar information. In total, the analysis is based on information for 3,500 Danish firms in 1997. Besides the interaction between the firms' R&D decisions and the export performance, this study is concerned with other factors influencing the export and the R&D performance of Danish firms. Thus, attention is paid to the firm's age and size, labour cost, human capital and the firm's financial solvency as determinants for export behaviour. The firm's decisions on R&D are seen explicitly from a strategic point of view. Thus, sales market concentration, minimum efficient scale as well as size and age become important factors in the analysis.

In section 2 the theoretical key arguments in explaining firm export and R&D behaviour are put forward. The outcome of this section is the empirical model to be used in the analysis. Section 3 describes the data used in the analysis, i.e. cross-section of 3,500 Danish firms. Section 4 presents the empirical findings on export. Section 5 deals with the interaction between export and

R&D and presents the estimation results from full information maximum likelihood on factors influencing export and R&D decisions. Finally, section 6 concludes.

2. Theories and earlier empirical findings

Since the end of World War II the internationalisation of firms has increased dramatically. The main explanation is the liberalisation of trade and capital flows across borders. In the 1990s the term 'globalisation' took over, still dealing with the same phenomena: firm behaviour outside its home markets. Note however, that if the degree of internationalisation is measured by the size of the export share in GDP, the internationalisation of countries is back at the same level as in the golden trade period from around 1880 until World War I. However, this paradox is explained by the transformation of the industry structure over time, i.e. societies going from a large agricultural sector via manufacturing as the largest sector to the service society, where the relative size of the two former industries has decreased. Furthermore, the service sectors are for natural reasons more oriented towards domestic markets and because it has grown to above 70% in most of the developed countries, the overall development of the export share of the economies has decreased. The export share of the manufacturing sector has decreased dramatically because of the factors mentioned above and the export shares are two times the levels they were a century ago, see Bordo et al. (1999).

Beside the reductions in trade tariffs and other trade barriers, the development in the export share of the firm depends on its own competitive advantages as well as the comparative advantages of the home country. Generally, following the Hechscher-Ohlin model the labour abundant developing countries have comparative advantages in labour-incentive products whereas the developed countries increase their export of products where the production is based on physical or human capital. Consequently, use of physical and human capital is an important factor behind the export performance of firms in modern economies.

R&D is probably the most human-capital-incentive production activity in a company. As a consequence it is expected that firms with a high R&D intensity have comparative advantages in exporting to the developing countries, as they do not have that kind of products. Furthermore, firms with a relatively large R&D expenditure may move to the forefront of the technology boundary in their market when they invent new products or new production processes. They may then obtain competitive advantages compared to other firms within the same industry also in developed countries. It is therefore expected that the export performance of firms is positively related to their R&D intensity.

On the other hand, investment in R&D may itself be higher in an internationalised firm having a relatively large part of its turnover coming from export. In fact, it might be requisite for R&D activities to have a large market in order to make the investment in R&D pay off. Thus, a sufficiently high return of R&D activities, which is normally considered more risky than other investments, probably demands a market larger than the domestic market.[1] This argument gains weight particularly for firms in small economies like Denmark. Therefore larger investments in R&D improving the export share of the firm will lead to further investment in R&D in the next round and create a benign circle of rising export and R&D shares. Consequently, it is important to take this simultaneous interaction into account when trying to explain firm export from inter alia R&D investment.

Wages are normally considered as a highly important factor for firms' competitiveness in foreign markets. Wakelin (1998) looks at wages from two sides. First, if the firm has large unit labour costs, i.e. total wage costs in percent of turnover, it is likely to have a negative impact on the firm's export performance, especially in cost-intensive markets. Secondly, looking at wages in terms of the average wage, i.e. wage per employee, high average wages might be taken as an indicator of a large amount of human capital accumulated in the firm. In this case, higher wages are expected to result in more competitiveness and consequently in better export performance.

Next, larger firms are expected to have lower costs due to economies of scale over some range of their size. Entering an export market may involve some fixed cost for collecting information on the market and marketing of the product, which probably will require a minimum size of the firm. It is therefore expected that larger firms will have a higher export share, see e.g. Wakelin (1998). However though a certain size of the firm is needed in order to become an exporter beyond some point, size is not expected to have an influence on the export behaviour, see Kumar & Siddharthan (1994). Moreover, Willmore (1992) and Wakelin (1998) find an inverse U-like relationship between export and firm size. They argue, that large firms may have a dominant position at the home market, giving them only little incentive to export.

On the other hand, when focussing at the home market position explicitly, a large home market with critical customers could also develop competitive advantages for a firm which could be exploited in foreign markets as pointed out and documented by Porter (1990). Therefore it can be argued that firms with a large market share on the domestic market will have a higher export share too. The domestic market share should therefore be included in the model as a separate factor explaining export.

[1] This argument can be more formally developed using arguments parallel to the well-known Dorffman Steiner condition as known from the theory of optimal advertisement.

Intensive use of physical capital relative to labour is expected to affect the export share, i.e. a positive relationship between capital-labour ratio and the export intensity is to be expected. Wakelin (1998) includes the capital sales ratio as an explanatory for export performance and argues that the capital variable is an indicator of physical capital, which embodies past innovation, R&D or knowledge in general, thus influencing the marginal cost of output. In general, a high capital-labour ratio may also reflect a high productivity of the firm due to advanced automatic production processes leading to competitive advantages in other developed countries and consequently to a higher export share.

Foreign markets are often unknown to the firm and therefore more risky. In order to explain why some firms do not export, it is necessary to include variables that are expected to indicate the willingness of risk of a firm. First, firms with high financial solvency can afford higher risk and therefore they are expected to have a higher likelihood of becoming exporters and to have a higher export share. Next, firms who are organized as a Ltd. with limited liabilities compared to personal ownership may also be better suited to take the risk in foreign markets and as a result become more internationalised compared to firm with other types of ownership.

Normally very young firms are expected to have less orientation towards foreign markets than older ones. But it is not so clear how the age of the firm is related to its internationalisation in general. On the one hand, it may take time to develop the foreign markets so for this reason older firms may have a higher export share, i.e. the traditional argument. On the other hand, if new firms are founded on the basis of an innovation, young firms may have competitive advantages compared to older firms also on foreign markets, which could give them a higher export share.

As mentioned above the service sector is mainly home-based while the manufacturing sector is expected to have a higher export share. So, the analysis must control for type of industry.

Only a few empirical studies of firms' export behaviour exist, and they are based on survey data with a relatively small sample size. Nevertheless, the main conclusion from these studies is that innovating firms are more oriented to the foreign markets. One of the first studies was Hirsch and Bijaoui (1985) who examined export performance of 111 Israeli firms. They found that innovative firms are more likely to have export activities and that the number of R&D employees has a positive and significant effect on their export growth. Ito and Pucik (1993) studied a sample of 266 Japanese manufacturing firms and they also found that the R&D intensity has a positive impact on the export share of the firms. However, the effect becomes insignificant when they control for firm size. In a study of 640 Indian firms, Kumar and Siddharthan (1994) found a significant effect from the R&D intensity only for firms in low and medium technology industries.

A recent study by Wakelin (1998) examines the export behaviour of 1040 British firms based on a survey of their innovation activities. She finds that innovating firms are less likely to become exporters than non-innovating firms. However, large innovating firms are most likely exporters, and it is argued that the cost of entering export markets is a barrier for small innovating firms.

Sterlacchini (1999) analyses the influence of innovation on export in non-R&D-performing Italian firms. Using a sample of 143 Italian firms, it is found that the probability of being an exporter is affected by the size of the firm in an inverse U-like way. Furthermore, innovative activities affect the export intensity positively.

2.1. R&D behaviour and export performance

The above-mentioned studies all treat R&D and/or innovation as an exogenous variable in their specification of the export equation. However, as argued above the R&D and innovation efforts of the firm itself can be influenced by market factors such as export position of the firm. Consequently, R&D and export performance should be allowed to interact in a simultaneous framework like

(1) R&D = f(export, exogenous variables) + error term
(2) Export = g(R&D, exogenous variables) + error term

The R&D equation will be discussed more in detail in section 5 where the results from simultaneous estimations of (1) and (2) are presented. But a brief discussion of the key arguments follows below. According to Schumpeter (1942), less innovation or R&D is to be expected in competitive industries. Thus market concentration should be included as an important explanatory variable in the R&D equation.[2] On the other hand, Schumpeter also emphasised the idea that large-scale firms were the ideal vehicles for generating technical advances. Large firms have better abilities through scale economies in a monopolized industry but they can also be found in more competitive industries. Therefore, firm size is expected to affect R&D positively.

There are arguments against the Schumpetarian hypothesis. Arrow (1962) e.g. argues that the competitive firms have stronger incentives to invest in cost-reducing innovations than monopolistic firms, because the return from a successful invention will include a monopoly rent, which the monopolistic firm already has. Another theoretical argument against the Schumpeterian hypothesis derives from X-inefficiency under monopolistic conditions, see Leibenstein (1966).

[2] There are numerous studies focussing on the influence from sales market concentration on R&D, most of them reporting a positive correlation, see e.g. Scherer and Ross (1990), Scott (1984), Levin et al. (1985), Wahlroos and Backstr□m (1982), Lunn and Martin (1986), Dilling-Hansen et al (1998), Førre (1997) and Vossen (1998).

Consequently, firms in monopolistic market positions may enjoy higher profits and therefore be lax and fail to pursue the innovation opportunities.

In oligopolistic industries the relationship between market concentration and R&D intensity becomes more blurred. According to Needham (1975), the conditions for optimality of the R&D intensity are analogous to the well-known Dorfman-Steiner condition for advertising. This implies that there will be a higher research intensity in less competitive and more profitable industries. The reason is simple: without a positive price-cost margin it is not profitable for the firm to invest in R&D (or advertising) to promote the demand for its product. This condition also demonstrates that the R&D intensity should be higher in more concentrated industries where firms can internalise the benefits of their research through patent or product differentiation, which is more difficult in industries with a large number of competing firms. Furthermore, the market size becomes crucial because the firm needs to expand in order to utilize the invention coming from R&D. Therefore, the export performance should be included in the R&D equation in order to indicate whether the particular firm has a position on a large market or not.

In his work on innovation, Schumpeter focuses much more on the absolute size of the firm than on the concentration of the market. If larger firms are more innovative, one would expect a positive relationship between firm size and research intensity. On the other hand, the largest firm may become more lax, which may result in less R&D. Therefore, an inverted U-relationship between R&D performance and firm size is expected.[3]

As firm size is not equally distributed within an industry, an important aspect of market structure is the market share of the firm. As with the market concentration, the research intensity may be expected to increase with market share but to level off and maybe fall when a company captures the whole market. Lunn and Martin (1986) found a positive effect from the market share on the research intensity in the low-tech sector but no effect in the high-tech sector.

In industries with a high minimum efficient scale, new entries are already impeded and the existing firms may have less incentive to invest in R&D as a competitive strategy. In general, barriers to entry may have a negative effect on the research intensity. In the analysis below, a measure for minimum efficient scale is included.

Finally, a number of control variables are included in the R&D equation, i.e. dummy variables for manufacturing firms and dummy for ownership (Ltd) in order to deal with risk factors because

[3] Lunn and Martin (1986) tested this Schumpeterian hypothesis for about 2,300 lines of business in the US by including a variable for the total assets in the firm. A positive parameter was reported indicating that large firms spend more per dollar of sales on research and development than smaller ones.

investment in R&D is considered to be risky with a long and uncertain pay-back period compared to other investments. The age of the firm is included in the R&D equation as it was in the export equation. Firm's age is an indicator of the product life cycle of the firm. Older firms already have an established position at the market and compared to younger firms with a samller market share they have a smaller growth potential and threrefore the incentive to invest in R&D is smaller. Note, that the very youngest firms (which are often the smallest ones with the smallest financial solvency) are also expected to be less likely R&D performers than firms in the middle of their product life cycle.[4]

3. Data

This study is based on R&D information at the firm level from the official Danish R&D statistics containing - in principle - all R&D investments in Danish firms. The concept of R&D comprises *creative work undertaken on a systematic basis in order to increase the stock of knowledge of man and society, and the use of this stock in order to devise new applications*; see the Frascati-manual p. 29. The basic reporting unit of the R&D survey is the legal firm unit, which can be identified in the account statistics. The sample used in this paper use the 1997 R&D survey where the number of respondents was 4,082. 3,424 firms returned the questionnaire, giving a response rate of 85%. Of these, 1,013 firms have reported a positive R&D expenditure.

This information has been merged with information from the official firm register at Statistics Denmark. This data set includes information on all Danish firms such as annual turnover, export revenue, value added, financial solvency, net capital, wage costs, number of employees etc. In general, this information originally comes from the Danish Value Added Statistics and from the annual reports from the firms to the Danish Tax Authorities.

The merged data set includes account data from 1995-1997 and information on R&D activities of the firms in the years 1995 and 1997. Table 1 presents means of the variables from the final data set of 3,428 firms used in this analysis. Two thirds of these firms have an export activity and they are generally much larger and have a larger domestic market share. The R&D intensity is 50% higher in exporting firms and below we will analyse whether this is due to a firm-size effect. Considering the cost structure, exporting firms are 50% more capital intensive and they have lower labour unit cost. However, the average wage is 12% higher which may reflect a higher human capital as mentioned above. It is not surprising that 70% of the exporting firms are in the manufacturing industries with only 44% of the non-exporters. They are also better suited to take

[4] Note that this argument does not hold for firms that are initiated as e.g. spinn offs from R&D environments or from existing high tech firms.

the high risk in foreign markets as they have a higher solvency and the owner structures are based on the Ltd. company.

Table 1. Means of the main variables in 1997 split up on exporting and non-exporting firms.

	All firms	Firms with export	Firms without export
Export share	0.253	0.380	
R&D intensity (R&D expenditure in percent of turnover)	0.017	0.020	0.013
Firm size (number of employees)	161.1	205.9	71.5
Domestic market share	0.036	0.048	0.013
Capital labour ratio	273.4	308.3	203.7
Wage share (total wage costs divided by turnover)	0.333	0.303	0.393
Average wage (wage costs per employee)	227.4	236.2	209.9
Solvency (net capital divided by total capital)	0.308	0.323	0.278
Dummy for industry (manufacturing firm = 1, else = 0)	0.621	0.707	0.447
Dummy for ownership (Ltd=1, else=0)	0.067	0.064	0.073
Dummy for age: Old firm = 1 (Age>50 year)	0.690	0.812	0.445
Dummy for age: Young firm = 1 (Age<10 year)	0.631	0.632	0.631
Dummy for food industry = 1, else 0.	0.077	0.063	0.104
Observations	3428	2285	1143

To highlight the impact of firm size, Table 2 shows the export share, the R&D intensity and the capital labour ratio for different firm-size categories. On average the export share is three times higher for the largest firms compared to firms with less than 20 employed. However, the export share levels off for firm size above 500 employed indicating an export barrier for small and medium-size companies.

Table 2. The export share and R&D intensity related to firms size, 1997.

Number of employees	Number of firms	Export share	R&D intensity	Capital labour ratio
0 – 20	1137	0.135	0.018	241.3
21 – 50	719	0.228	0.020	237.1
51- 250	1113	0.342	0.015	268.6
251 – 500	261	0.377	0.019	367.2
511 +	198	0.360	0.018	493.0
Total	3428	0.253	0.017	273.4

Contrary to this, the R&D intensities are rather stable across the different size categories indicating that small firms that actually invest in R&D have the same incentive to invest in R&D as the larger companies. The last column of Table 2 shows the capital labour ratio and it increases dramatically for firms with more than 250 employed, probably reflecting the economies of scale in large companies.

Table 3. Firms in the sample distributed according to their activity in R&D and export in 1997.

	No R&D expenditures	R&D expenditures > 0	Total
No export	1024 (29.9)	1558 (45.5)	2582 (75.3)
Export >0	119 (3.5)	727 (21.2)	846 (24.7)
Total	1143 (33.3)	2285 (66.7)	3428 (100.0)

To focus on the interaction between firms with export and/or R&D activities, Table 3 splits the total sample of firms on these two activities. 24.7% of the firms in the sample have invested in R&D in 1997 but of these firms 86% also have export activities. For the 75.3% without investment in R&D, only 60% also have export activities. The average shares of companies clearly indicate that firms with R&D investment are more likely also to have export activities and below we will analyse this question in more detail.

4. Empirical analyses of export intensity

This section presents the estimation results where the dependent variable is the export intensity. 1,143 of the 3,428 firms included in the analyses do not have any export. Consequently, ordinary least square regression is not the optimal estimation technique and therefore a single censored Tobit model has been applied.[5] The standard Tobit model can be written as

$$
\begin{aligned}
& y_i^* = x_i'\beta + u_i, \qquad i = 1,2,....,n, \\
(3) \qquad & y_i = y_i^* \ \ if \ \ y_i^* > 0, \\
& \quad = 0 \ \ \ if \ \ y_i^* \le 0,
\end{aligned}
$$

where *y* corresponds to the export intensity and the error term u_i is assumed to be normal distributed with zero mean. The likelihood function of (3) becomes

$$
(4) \qquad L = \prod_0 [1 - \Phi(x_i'\beta/\sigma)] \prod_1 \sigma^{-1}\phi[(y_i - x_i'\beta)/\sigma]
$$

where Φ and ϕ are the cumulative distribution and density function of the standard normal variable. Finally, the model is estimated using maximum likelihood regression analysis in SAS.

Models 1 and 2 include the estimated coefficients from the preferred model with and without an interaction term between R&D intensity and firm size. Except for this variable and the dummy variable controlling for young firms, all coefficients are highly significant and correctly signed. The influence from size has an inverse U-shaped form, however with maximum influence on the export intensity at a fairly high firm size, i.e. 5900 employees. In accordance with the results of Wakelin (1998) the wage share affects the export intensity negatively but in accordance with the human capital explanation higher average wages have a positive influence.

In addition, in model 1 the export intensity is affected positively by higher capital intensity and higher financial solvency, if the firm is organized as Ltd or if it belongs to the manufacturing industry. The Danish food industry is considered to be relatively oriented towards the international markets. Therefore control has been made explicitly for the sub-industries representing the food producing industries. Compared to the other manufacturing firms, however, the export intensity of the food-producing firms seems to be lower. Still, it is above the level of non-manufacturing firms. Finally, it should be noted that the estimation results concerning the influence from the home market position do not seem to be in favour of the arguments of Porter (1990). The estimated

[5] See Amemiya (1984)

parameter is negatively signed and therefore in accordance with the view of Wakelin (1998), i.e. a high domestic market share gives only little incentive to export.

The influence from R&D is highly significant, stable and of a certain size, suggesting that export performance depends on the R&D efforts in Danish firms. In order to investigate this relationship further, an interaction term between size and R&D was included (column 2). However, as can be seen the influence from R&D is general and there seems to be no special effect for e.g. large firms with a high R&D intensity as compared to small firms with only little R&D effort.

Another way to analyse the influence from R&D behaviour on export performance is to split the sample into groups of R&D-performing firms and non-R&D-active firms. Model (1) is repeated for these two groups of firms in columns (3) and (4). In order to make the coefficients comparable, the R&D intensity is not included in column (3). The influence of average wages on export seems to be largest for R&D-active firms. On the other hand, the influence from capital seems to be most important in non-R&D-active firms. The maximum influence from firm size is reached at 5,300 employees for R&D-active firms and at 6,300 employees for non-R&D-active firms (generally, large non-R&D-active firms are not manufacturing firms). But except for these differences, the estimated parameters are basically similar and the strength by which they affect the export intensity is quite alike.

Table 4. Various estimations of Tobit models for the export intensity, 1997.

	Dependent variable: Export intensity			
	All firms		R&D firms	Non-R&D firms
	Model (1)	Model (2)	Model (3)	Model (4)
Intercept	-0.2292** (0.0392)	-0.2284** (0.0394	-01162 (0.0827)	-0.2222** (0.0453)
R&D intensity	0.7516** (0.0925)	0.7479** (0.0943)	-	-
Firm size (x 10^3)	0.1984** (0.0271)	0.1972** (0.0276)	0.1949** (0.0477)	0.1572** (0.0350)
Firm size (squared, x 10^8)	-1.6674** (0.3124)	-1.6691** (0.3125)	-1.8395** (0.6961)	-1.2525** (0.3685)
Interaction between R&D intensity*size, (x $10^{8)}$	-	0.0365 (0.1850)	-	-
Domestic market share	-0.3881** (0.0765)	-0.3872** (0.0758)	-05699** (0.1026)	-0.3109** (0.1043)
Capital labour ratio (x 10^4)	0.5982* (0.2391)	0.5969* (0.2392)	0.2234 (0.3787)	0.7962** (0.2962)
Wage share	-0.6460** (0.05229)	-0.6461** (0.0529)	-0.5188** (0.0963)	-0.6235** (0.0612)
Average wage cost per employee (x 10^3)	0.8734** (0.1050)	0.8723** (0.1052)	0.0013** 0.0002)	0.6715** (0.1210)
Financial solvency of the firm	0.1357 0.0710	0.1352 (0.072)	0.0466 (0.1194)	0.1289 (0.0859)
Dummy for manufacturing industry	0.2989** (0.0163)	0.2986** (0.0163)	0.3377** (0.0321)	0.2506** (0.0192)
Dummy for food industry	-0.1150** (0.0306)	-0.1148** (0.0306)	-0.1575** (0.0554)	-0.0930** (0.0360)
Dummy for kind of ownership, Ltd. = 1, else D = 0.	0.2140** (0.0178)	0.2140** (0.0177)	0.1152** (0.0369)	0.2084** (0.0203)
Dummy for old firms (Age>50 years)	-0.0299 (0.1572)	-0.0299* (0.0157)	-0.0283 (0.0261)	-0.0009 (0.0192)
Dummy for young firms (Age<10 years)	-0.0390 (0.0292)	-0.0391 (0.0292)	-0.0962* (0.0445)	-0.0022 (0.0367)
Normal scale parameter	0.3817** (0.0059)	0.3817** (0.0059)	0.3413** (0.0092)	0.3873** (0.0073)
Log Likelihood	-1794.3	-1794.3	-359.6	-1365.2
Observations	3428	3428	846	2582
Number of firms without export	1143	1143	119	1024

Notes: Numbers in brackets are standard errors of the coefficient. * denotes that the estimated coefficient is significant at the 5% level, ** at the 1% level.

5. A simultaneous model for export orientation and investments in R&D.

The following section analyses the relation between firm exports and investments in R&D. In section 2, we found that R&D investments affect the export like a catalyst for increased exports. The positive circle between R&D investments and exports appears as a simultaneous decision and hence the econometrics model must deal with this simultaneity.

The decision to export and the corresponding R&D decision are determined in a standard probit model. With two sets of explanatory variables in matrix X_1 and X_2, we formulate the model

$$(5) \qquad Y'_1 = \beta'_1 X_1 + \varepsilon_1 , \qquad y_1 = 1 \text{ if } Y'_1 > 0, \text{ else } y_1 = 0$$
$$Y'_2 = \beta'_2 X_2 + \varepsilon_2 , \qquad y_2 = 1 \text{ if } Y'_2 > 0, \text{ else } y_2 = 0$$

where the residuals are standard residuals with zero means and a variance equal one.

$$(6) \qquad COV (\varepsilon_1 , \varepsilon_2) = \rho$$

One way to estimate the simultaneous models is to follow the two-stage procedure presented in Maddala (1989) ending up with two reduced equations including fitted left-hand side variables. Here we follow the set up from bivariate probit models estimating the two structural equations in (5) simultaneously.

The bivariate probit model, see Greene (2000), is estimated using the maximum likelihood method maximizing the likelihood function with respect to the traditional parameters and the interaction between the two residuals in the probit models, ρ.

The two single equations explaining the decision to export and to invest in R&D are presented in the first two columns of Table 5. The general picture of these models is that they perform very well explaining around 75% of all firms' export and R&D activities and with significant parameters at a 1% significance level (the parameters will be interpreted below in the bivariate model).

The following two columns in Table 5 are the results of the same two probit models including the correlations between the residuals in (6). The bivariate formulation of the model is significant by the estimate of ρ equal 0.259 and the overall picture is that the parameters are all significant at a 1% level and that they change only slightly compared to the univariate case in the first two columns.

The effect of firm size is almost identical on export and R&D decision. Large companies have a higher probability of being export orientated and of investing in R&D except for the very big firms (with more than 5,000 employees).

The same effect is found from the age of the firm. The older the firm is, the higher is the probability of being export orientated and of investing in R&D although the probability goes up with a declining speed.

The effect from the market conditions is in line with the tobit models presented in the earlier part of this paper. We measure the market conditions by the minimum efficiency scale and the 4-firm concentrations index and these measures have no influence on the export decision. In contrast to these results, we find that the decision to invest in R&D is affected positively by market concentration (supporting Schumpeter) and is affected negatively by increases in entry barriers (higher minimum efficiency scale).

Columns 3 and 4 in Table 5 present the results from the simultaneous model. The bivariate probit model is estimated using a full information maximum likelihood method and the interaction parameter, ρ, is significant at a 1% level. Comparing the bivariate results with the univariate results in columns 1 and 2 show, that the changes in the estimated coefficients are very small and the significance is unaffected. Increases in size and age, producing in manufacturing industries (except food industries) and being a Ltd. firm increases the probability of being export-orientated and investing in R&D.

The last bivariate model including the R&D dummy in the export model is presented in the last two columns of Table 5. The estimated coefficient for R&D activities is positive and strongly significant which underlines the results from the previous sections: R&D investment is a major determinant for firms being export-orientated. The other parameters in the bivariate model change only slightly with the only exception of age: Although still holding the sign, the age effects become insignificant due to the positive relation between age and R&D activity.

Table 5. Simultaneous estimations of probit models for the export share and R&D intensity in 1997.

	Single equation		Simultaneous equations		Simultaneous equations	
	Export orientation	R&D Activity	Export orientation	R&D Activity	Export orientation	R&D Activity
Intercept	-102.02** (37.94)	-135.13** (33.76)	-107.92** (37.28)	-134.24** (34.41)	-51.78** (37.38)	-137.56** (34.28)
Firm size (x 10^3)	0.817** (0.132)	0.546** (0.108)	0.812** (0.099)	0.538** (0.106)	0.548** (0.114)	0.576** (0.102)
Firm size – squared (x 10^7)	-0.620** (0.123)	-0.679** (0.172)	-0.613** (0.010)	-0.644** (0.173)	-0.406** (0.115)	-0.755** (0.156)
Wage share	-1.843** (0.153)		-1.841** (0.142)		-1.714** (0.153)	
Average Salary (x 10^2)	0.273** (0.034)		0.251** (0.033)		0.228** (0.032)	
Manufacturing (Dummy)	0.686** (0.053)	0.281** (0.059)	0.689** (0.055)	0.288** (0.058)	0.513** (0.068)	0.272** (0.058)
Ltd. Firms (Dummy)	0.684** (0.056)	0.423** (0.062)	0.701** (0.057)	0.435** (0.061)	0.514** (0.070)	0.392** (0.061)
Solvency	0.826** (0.256)		0.727** (0.248)		0.527** (0.238)	
Age	0.107** (0.040)	0.138** (0.036)	0.113** (0.040)	0.137** (0.037)	0.055 (0.040)	0.141** (0.036)
Age - squared (x 10^4)	-0.282** (0.017)	-0.357** (0.095)	-0.299** (0.010)	-0.355** (0.097)	-0.148 (0.105)	-0.364** (0.096)
Food industries (Dummy)		-0.403** (0.111)		-0.363** (0.114)		-0.447** (0.113)
Concentration		1.065** (0.125)		0.984** (0.127)		1.115** (0.126)
Minimum efficiency scale (x 10^4)		-0.130* (0.075)		-0.104* (0.065)		-0.170* (0.088)
R&D-activity (Dummy)					1.341** (0.185)	
Log Likelihood	-1712.0	-1667.0		-3354.9		-3342.3
Rho, ρ				0.26**		-0.52**
Observations	3420	3420		3420		3420

Notes: Numbers in brackets are standard errors of the coefficient. * denotes that the estimated coefficient is significant at the 10% level, ** at the 1% level.

6. Conclusion

This paper analyses the role of R&D in the export behaviour of Danish firms. Export behaviour is defined in terms of the export intensity and the likelihood of a firm being an exporter. In the theoretical part of the paper, it was argued that export and R&D behaviour are mutually dependent. Therefore, the optimal empirical model must integrate R&D as well as export in order to estimate the factors affecting the firm's export. In addition, it was argued that besides R&D factors such as firm size, wages, capital intensity and a number of other firm-specific factors controlling for risks should be considered highly important for the export performance. Focussing on the R&D behaviour, sales market concentration, firm size and minimum efficient scale are all together with the export performance expected to affect the R&D decision of the firm.

In the empirical part of the paper, the model is tested on a sample of 3,500 Danish firms. First, using a censored regression technique, i.e. the Tobit model, to explain the export intensity, it was found that firm size, average wages, relative use of capital, financial solvency and R&D intensity have a positive and highly significant influence on export. Furthermore, if the firm has a dominant position at the home market, has a high wage share in output or is either young or old, the export intensity becomes lower. In sum, the signs of all the estimated parameters are in accordance with the theoretical arguments in the first part of the paper.

In the last section, R&D and export are considered as mutually dependent, and a ML estimation technique is needed in order to deal with this potential endogeneity problem. Using a bivariate probit specification, the likelihood of being an exporter and to invest in R&D is shown to depend positively of firm size and age. This is especially prevalent in manufacturing industries (except the food industries) and for firms organised as Ltd's.

While the export orientation also depends on relative high capital-labour ratio, relative abundant free resources and high salary (interpreted as firms with skilled labour force) the decision to invest in R&D is higher in concentrated industries and lower for firms in industries with high entry barriers. Finally we find the export positive influence from R&D investments on the export activity.

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