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# Swedish Business R&D and its Export Dependence

Karin Bergman (karin.bergman@nek.lu.se)
Department of Economics, Lund University, Sweden

Olof Ejermo (olof.ejermo@circle.lu.se)
CIRCLE, Lund University, Sweden

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Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE)
Lund University
P.O. Box 117, Sölvegatan 16, S-221 00 Lund, SWEDEN
http://www.circle.lu.se/publications

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**ABSTRACT**

Sweden has seen a rise in business R&D intensities and dependence on exports to make its economy grow since the early 1990s. This paper examines the role of foreign sales for stimulating R&D as compared to a domestic sales effect. In line with the literature, we find in cross-sections from 1991 to 2001 that R&D rises proportionally to sales. But among manufacturing firms foreign sales is distinctly more strongly associated with an increase in R&D than domestic sales. For service firms domestic sales are as important as foreign. The results are consistent with the hypotheses that manufacturing firms more easily separate production from R&D, that they economize on transport costs and are subject to learning-by-export effects. In general, the results highlight the dependence and the role of openness for stimulating R&D in a small economy, especially among manufacturing firms.

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R&D, size, exports, Sweden

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Karin Bergman[1] and Olof Ejermo[2]

**Abstract**

Sweden has seen a rise in business R&D intensities and dependence on exports to make its economy grow since the early 1990s. This paper examines the role of foreign sales for stimulating R&D as compared to a domestic sales effect. In line with the literature, we find in cross-sections from 1991 to 2001 that R&D rises proportionally to sales. But among manufacturing firms foreign sales is distinctly more strongly associated with an increase in R&D than domestic sales. For service firms domestic sales are as important as foreign. The results are consistent with the hypotheses that manufacturing firms more easily separate production from R&D, that they economize on transport costs and are subject to learning-by-export effects. In general, the results highlight the dependence and the role of openness for stimulating R&D in a small economy, especially among manufacturing firms.

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**JEL classification**:

[1] Corresponding author, Department of Economics, Lund University, P.O. Box 7082, SE-220 07 Lund, Sweden, karin.bergman@nek.lu.se

[2] CIRCLE (Centre for Innovation, Research and Competence in the Learning Economy), Lund University, P.O. Box 117, SE-22100 Lund, Sweden, olof.ejermo@circle.lu.se

# 1 Introduction

Sweden's research and development expenditures (R&D) as a share of GDP is among the highest in the world with business R&D being the most important constituent. The trend towards such a high business R&D ratio has origins from the mid-1980s (Table 1) and continued at least throughout the 1990s. Other countries, especially among the Nordic countries, have seen similar upward trends, but in Sweden this has been more pronounced than elsewhere.

TABLE 1

*Business R&D as a share of GDP 1981-2008 in selected OECD countries, percent.*

| | 1981 | 1985 | 1989 | 1993 | 1997 | 2001 | 2005 | 2008 |
|---|---|---|---|---|---|---|---|---|
| Denmark | 0.5 | 0.7 | 0.8 | 1.0 | 1.2 | 1.6 | 1.7 | 2.0 |
| Finland | 0.6 | 0.9 | 1.1 | 1.2 | 1.8 | 2.4 | 2.5 | 2.8 |
| France | 1.1 | 1.3 | 1.3 | 1.5 | 1.4 | 1.4 | 1.3 | 1.3 |
| Germany | 1.6 | 1.9 | 2.0 | 1.5 | 1.5 | 1.7 | 1.7 | 1.9 |
| Israel | .. | .. | .. | 1.4 | 1.9 | 3.5 | 3.4 | 3.8 |
| Japan | 1.4 | 1.8 | 2.0 | 1.9 | 2.1 | 2.3 | 2.5 | 2.7 |
| Netherlands | 0.9 | 1.1 | 1.2 | 0.9 | 1.1 | 1.1 | 1.0 | 0.9 |
| Norway | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.8 | 0.9 |
| Sweden | 1.4 | 1.9 | 1.8 | 2.2 | 2.6 | 3.2 | 2.6 | 2.7 |
| Switzerland | 1.6 | .. | 2.0 | .. | .. | .. | .. | 2.2 |
| United Kingdom | 1.5 | 1.4 | 1.5 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 |
| United States | 1.6 | 2.0 | 1.8 | 1.7 | 1.9 | 2.0 | 1.8 | 2.0 |
| OECD Total | 1.2 | 1.5 | 1.5 | 1.4 | 1.4 | 1.6 | 1.5 | 1.6 |

Source: SourceOECD, Main Science and Technology Indicators and own calculcations. ".." denotes missing data.

Parallel to this rising trend has been a shift in terms of the Swedish economy's dependence on trade. Trade has always been important and Sweden is a country that for decades has had an unusually high concentration of multinationals, and in 1988-91 Sweden actually had the highest share of large firms among 12 European countries (Henrekson and Johansson 1999, Henrekson and Jakobsson 2001). From 1950 until the mid 1970s exports as a share of GDP was stable at 20-25 %. Then, after a series of devaluations in the 1970s and early 1980s, exports temporarily rose above 30 %. An increasing problem of high domestic inflation forced the government to float the currency in 1992. Immediately the Swedish krona lost 25 % in value, which seems to be permanent. At the same time Sweden experienced a permanent shift towards higher levels of trade, in part stimulated by EU membership in 1995. Export and import levels are now firmly established above 40 % as a share of GDP (Statistics Sweden 2011).

In principle, there could be many reasons for why Swedish firms increasingly chose R&D intensive paths relative to firms in other countries. Derived from the work by Schumpeter (1934, 1950) small firms, more flexible by nature, might have an advantage from R&D. Large firms, on the other hand, have advantages that stem from e.g. scale economies. Thus two economies with different size distributions may have different R&D-intensities. It is also possible that Swedish firms might have been especially focused in sectors where technological opportunities were emerging, or there might have been a supply effect from budding inventors inspired by e.g. the higher education system. Another explanation might be that the Swedish wage structure has been institutionally compressed compared to other countries, with lower wages among engineers and other highly educated professions compared to e.g. German workers. These low wages could have induced higher demand for R&D services.

Yet another explanation might be increased exports. In fact, there are several reasons why firms engaging internationally are more likely to do R&D. Foreign sales provide a way for firms to spread fixed costs incurred by R&D. Moreover, as stressed by recent literature, by learning from exporting, firms may enter virtuous circles where exports enhance the productivity effects of R&D which induce further R&D and so on.

The purpose of this paper is to re-investigate the classic size-R&D relationship but with a focus on the size effects of foreign sales. We use data on the firm level for the years 1991-2001 and we divide total sales into foreign and domestic to investigate which is more important for stimulating R&D. As Sweden has continuously increased its trade dependence, we investigate whether the effect of foreign sales on R&D have increased in importance over time. We further argue that there is a qualitative difference between manufacturing and service sectors as the former can more easily separate R&D activities from production. Service development can more rarely be standardized as solutions need to be more adapted to local conditions. Moreover, overseas sales often induce production establishment there. Hence, scale effects from R&D should be more pronounced in manufacturing.

Recognizing the potentially endogenous nature of R&D and foreign sales we pursue our empirical analysis by first examining the extent to which endogeneity is an issue. Moreover, R&D is an activity for which firms of higher quality are likely to be observed and firms of less quality may exit. Thus samples of R&D performers are likely to suffer from selection bias. Therefore, we estimate two-step Heckman selection equations of the relationship between R&D and size correcting for sample selection bias. Regression analysis as specified here, gives us information about the average relationship from size to R&D, but does not inform us about whether the relationship differs across the sample distribution. This investigation can give useful policy advice as it informs us about how trade policies might affect R&D investments for *different* types of firms. For that reason, we examine the relative role of foreign vs. domestic sales across the distribution of firms in terms of their R&D expenditures in quantile regressions to shed further light on the size-R&D relationship studied in the literature.

Our findings generally support the idea that foreign sales are more important than domestic to stimulate R&D. This result suggests that open trade policies aimed at stimulating competitiveness are effective ways to raise R&D levels at the firm level. We also find that this effect is clearly more pronounced for manufacturing than for service sector firms, in line with our hypothesis. Our results cannot decisively support a conclusion that the foreign sales effect has increased systematically in importance over time. During the investigated period foreign sales has, however, increased dramatically. In all, our results imply that R&D increases at about the same proportion over time relative to foreign sales, but since foreign sales has picked up in speed – R&D has as well. However, we find that the distributional differences differ somewhat over time. Our quantile regressions reveal that the sales effect, mainly that of domestic sales, in later years is more important for high level R&D performers than for low level R&D performers.

The paper proceeds as follows. In section 2 we provide a literature review where we first summarize the theoretical arguments in favor of small and large firms in innovation processes, which the literature refer to as the Schumpeterian hypotheses. We then also demonstrate the link to a literature on why foreign sales is an important factor determining R&D investments[3] and discuss recent developments in the literature on export and learning. In section 3 we conduct our empirical analysis. We describe the database at hand, its limitations and our empirical strategy. The results of the analysis are presented. In section 4 the results are summarized and policy conclusions are drawn.

[3] Formally, R&D expenditures comprise current costs and investments. We use R&D expenditures and R&D investments although our data are always on R&D expenditures.

# 2 Size and innovation – theory and evidence

## 2.1 Why does size matter?

Any attempt to explain the level of R&D conducted in firms should recognize the work of Schumpeter (1934, 1950), which has led to two conflicting hypotheses – 'The Schumpeterian hypotheses' (Breschi et al. 2000). In *The Theory of Economic Development* Schumpeter (1934) discussed how innovations tended to arrive in swarms in the wake of pioneering entrepreneurs. Seemingly opposed, Schumpeter observed in *Capitalism, Socialism and Democracy* (Schumpeter 1950) the efficiency by which large corporations handled their innovation processes in formalized R&D departments. Indeed, the development of firms in western economies seemed to follow trajectories of scale economies during the 1950s-70s.

Theoretical arguments rest ambiguous on whether large firms should have advantages over smaller ones when it comes to the implementation of innovation processes in production. Cohen (2010) surveys the literature and mentions several possible explanations for large firm advantages. These explanations include i) scale economies in R&D, where higher returns from R&D arise as innovators can spread the fixed costs of R&D over larger volumes of sales, ii) complementarities between R&D and other activities and iii) fewer financial constraints due to capital market imperfections. These advantages also suggest that large firms may be inclined to direct their innovative efforts towards incremental, process-oriented innovations, which can be applied on large production volumes. On the other hand, organization theory stresses the incapability of large firms to foresee shifts in new modes of production. That is, the same bureaucracies that render large corporations more effective under a regime of gradual innovation, 'static efficiency', inhibit them in situations, such as under fast technological change, where 'dynamic progressivity' is required (Nelson and Winter 1982, Tidd et al. 2005).

## 2.2 The role of foreign markets

In a static product quality setting, process R&D can be thought to have a fixed cost part (e.g. lab equipment) and a variable part that cuts unit costs. As specified in a model by Cohen and Klepper (1996), large-sales firms have an opportunity to spread their fixed costs of R&D, and the marginal effect of an R&D dollar spent is higher than for smaller firms as a cost-cutting effect can be applied on many units. From this perspective, exports are no different from ordinary sales as they would both equally induce a size effect given that the *same* good is exported. But export goods are not the same; they are likely to be more competitive than goods intended for a domestic market. Consistent with this idea, Andersson and Ejermo (2008) find that Swedish regions more technologically specialized in certain technologies tend to export goods of higher prices. The home market effect described by Krugman (1980) suggests that countries with initially high domestic demand for a differentiated product produced under monopolistic competition, i.e. subject to scale economies, will tend to export this good later on. This idea links to that of R&D scale economies. Innovation scholars (e.g. Edquist et al. 2000, Klepper and Malerba 2010) stress the role of demand and demonstrate many case studies of technology where government has played a role of formulating demand for a product. A Swedish example from history is the role of former government monopoly Televerket which worked with Ericsson to develop telephone services. Mowery and Rosenberg (1998) describe several industries' development in the US. In e.g. the industries for aircraft, pharmaceuticals and electronics, innovation development was highly influenced by federal government programs, civilian or military. In the small market of Sweden, domestic competence (and incompetence!) has sometimes developed in firms sheltered from international competitiveness which flourish (or perish) as the economy opens up.

Recent literature (Keller 2010) emphasize that exported goods are subject to *dynamic* learning effects, in the sense that the product is prone to change when subject to international competitive pressure and the firm gets feedback from customers and suppliers. By this reasoning producers learn from being active on other markets about product characteristics that appeal to a more diverse set of customers rather than only being sold domestically. This learning effect might stimulate further R&D that generates more exports and so on. For small countries these dynamic effects may be substantial compared to the limited potential to exploit domestic scope effects.

Another potential link between R&D and the export market concerns the need to establish production activities in the foreign country to economize on transport costs. Thus a firm might keep R&D in the home country to exploit scale economies of R&D and apply production techniques overseas. This behaviour might also protect knowledge from spilling over to foreign competition. The extent to which R&D is kept in the home country is labeled a home bias effect (Belderbos et al. 2011). This home bias does not only result from installed capital used for R&D, but primarily from trained human capital and the need for transferring important (tacit) knowledge within the firm through face-to-face communication. These attributes of knowledge tend to lead to path dependence in the location of R&D activities. As manufacturing goods are generally more costly than services to export in terms of transport costs, manufacturing R&D should be more closely linked to a foreign sales effect. This reasoning makes the division between manufacturing and services firms relevant for the study of sales effects. In addition, a sales variable indicating size is likely to be downward biased as production operations opened up abroad and subsequent sales are not included.

## 2.3 Empirical findings

Studies on the size-R&D relationship usually aim to study the size-innovation relationship. However, as innovation is difficult to measure, they tend to rely on R&D as an indicator for innovation. R&D is, however, an input into the innovation process, not necessarily linked to innovation.[4] Cohen and Klepper (1996) outline how a simple model of R&D and output can explain the stylized fact that R&D levels are found to be proportional to output. In this model R&D affects costs (process R&D) and is subject to diminishing returns. The effects are diminishing in the sense of their cost-cutting effect. But since large firms have larger output, more output units are affected by process R&D. Thus large firms (in terms of their output) have an intrinsic advantage in conducting R&D, which is in a sense ‘balanced’ by diminishing returns.

### *2.3.1 The size-innovation relationship*

As has been discussed, the theoretical motivation for a large firm advantage in innovative activity is mixed, and size-advantages have also been difficult to establish empirically. Many studies examine the link between innovation and size (see e.g. Scherer 1965, Bound 1984, Cohen and Klepper 1996), where size is usually measured by sales or number of employees and innovation by R&D expenditures. Bound et al. (1984) found that R&D intensity fell slightly with size among the very smallest firms and rose somewhat with size among the very largest firms and Scherer (1965) found that R&D personnel increased more than proportionally with firm size up to a threshold, and then the relationship was proportional. However, the consensus view has become that R&D rises proportionately with firm size among R&D performers, with an elasticity of close to unity (Cohen 1995).

At the same time several studies suggest that the number of innovations per employee declines with firm size (Pavitt et al. 1987, Acs and Audretsch 1990, Acs and Audretsch 1993, Kleinknecht et al. 1993, Santarelli and Piergiovanni 1996) so that small firms account for a disproportionately large share of innovations relative to their size. There are exceptions to this

[4] Discussions on different innovation indicators can be found in Kleinknecht et al. (2002) and Smith (2005).

finding. Acs and Audretsch (1990) point out that the pattern varies across industries and Pavitt et al. (1987) suggest the relationship to be somewhat U-shaped.

These results indicate that although there might be scale advantages to R&D, these are in a sense offset by a lowered productivity in terms of product innovations, not giving rise to a general advantage for large firms in innovation. However, not all studies control for sample selection bias, a possible problem as surviving small firms recorded in the samples also tend to be the successful ones (Bound 1984).

A few studies analyze the innovation-size relationship on Swedish data. Wallmark and McQueen (1991) presented the '100 most important innovations' in Sweden 1945-1980. Granstrand and Alänge (1995) examined and extended these data. They found that 20 % of innovations originated from autonomous entrepreneurs, 76.5 % from corporate entrepreneurship and 3.5 % from state entrepreneurship. After dividing the period into four subperiods, the authors find that the role of autonomous entrepreneurs increased over time despite the fact that the economic system favored large firms.

In a Swedish firm level study focusing on market concentration and R&D, Gustavsson Tingvall and Karpaty (2011) also controls for size in terms of the number of employees and find the elasticity to be clearly above unity, indicating a large firm advantage in R&D

### *2.3.2 Exports, R&D and productivity*

Fors and Svensson (2002) examine how foreign sales affect R&D intensity (R&D/total sales) in Swedish multinationals and find a two-way relationship where a higher intensity of foreign sales increases the R&D intensity and that a higher R&D intensity increases the foreign sales intensity. They also control for the size of the firm in terms of employment in one of their specifications and find a very small insignificant effect indicating a proportional relationship between size and R&D.

With regard to the earlier discussed potential role of export for learning, and hence for providing a theoretical link that export may foster learning, Keller (2010) reports mixed evidence on a variety of approaches investigating such a link, although later studies tend to find some effects of learning. It is well known that exporting firms are more productive than non-exporting firms, but the fundamental reason could well be that firms self select into exporting. In other words, since they were already more productive than the average firm, they chose to enter the export market. Clerides et al. (1998) examine if firms' average costs, as a symptom of learning effects, are affected by exports among firms in Columbia, Morocco and Mexico. They control for the selection effect in a first step equation but found no effect from starting to export. Similar to Clerides et al. (1998), van Biesebroeck (2005) investigate average cost effects of exporting for firms in nine African sub-Saharan countries and find a 25 % productivity boost which is attributed to previously non-exploited scale effects. Hallward-Driemeier et al. (2002) find that firms from South Asia that plan to start exporting invest more resources to raise productivity and quality than non-exporters. Keller (2010), however, argues that such investments should be deducted from any learning effects as they consume real resources. De Loecker (2007) employs a matched firm sample of Slovenian firms and finds that exporting firms become more productive after they start exporting. Andersson and Lööf (2009) differentiate between small and large exporters (in terms of export intensity), and between temporary and persistent exporters among Swedish firms. They find that learning effects require persistent export activity for small and large firms, while large firms also need a high intensity to be effective. Fryges and Wagner (2010) are able to construct profitability measures rather than productivity measures for German firms, which enables the sorting out of productivity effects from those of rising wages. They find a small statistically significant productivity premium which is not absorbed by higher wages.

# 3 Empirical analysis

## 3.1 Data and variables

The data for our analysis consist of firm level observations from different databases compiled by Statistics Sweden (SCB). With respect to R&D we had the choice of two sources of data. One source was the Swedish firm register (Structural Business Statistics – SBS) that had annual R&D data between 1985 and 2002, but for firms with R&D expenditures less than 10 MSEK data were only given on an interval. Another source was the data that form the foundation for the Swedish official R&D statistics used to report to the OECD. These data on R&D expenditures are collected from a biennial R&D survey which is more specific. However, it only covers the period from 1991 to 2005 and in practice the time limit is 2001 in order to be able to match it with our other sources of data. This data set covers all firms with reported R&D expenditures over 5 MSEK and a sample of firms reporting less than 5 MSEK. Because the quality of the data from the R&D statistics is higher and more comprehensive we chose this source of data, even though we get a smaller sample. However, the qualitative nature of the main relationships does not change when using annual data instead.[5] The average time span is rather short using the biennial data, the average number of observations per firm is only 2.4. Hence, panel estimations are of limited use which is why we chose to use cross section estimation methods and present the results for a few specific years (1993, 1997 and 2001).[6] Table 2 shows the number of firms in the sample for the investigated years divided by size groups in terms of the number of employees. The sample frame is restricted to firms with more than 50 employees, though the number of employees may have changed from the population frame to the actual sampling, so that a few firms exist in the smallest group. The majority of firms are in the group with at least 200 employees.

TABLE 2

*Number of firms in the sample per year and size class.*

| | Size class (number of employees) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | < 50 | | 50-199 | | ≥ 200 | | Total | |
| 1993 | 6 | (1.3 %) | 195 | (43.5 %) | 247 | (55.1 %) | 448 | (100 % ) |
| 1997 | 2 | (0.6 %) | 82 | (26.4 %) | 227 | (73.0 %) | 311 | (100 % ) |
| 2001 | 5 | (1.4 %) | 109 | (31.1 %) | 236 | (67.4 %) | 350 | (100 % ) |

The sales variables come from the Structural Business Statistics. The foreign sales variable is exports, which is the sum of sales to foreign firms within the corporate group and sales to other foreign customers.

We also include a number of control variables. Since the level of R&D is likely to be affected by the education level at the firm, we have gathered information on the share of employees at each firm with any type of post-gymnasium education.[7] Capital intensity, measured as the book value of capital divided by total sales, is also included on the basis that technological progress usually is interlinked with capital investments.

The nature of R&D and innovation can be expected to differ between sectors, and technological opportunities differ as well. We include industry dummies to pick up some of these differences as well as possible differences in the market structure. Following Ejermo and Kander (2011), firms have been classified to belong to one of 10 sectors. Sectors 1-7 belong to manufacturing, while sectors 8-10 are in services. This division of sectors is based

[5] Both sources of data on R&D expenditures show a very high correlation on the firm level.
[6] Despite this short time horizon, we ran panel estimations which gave similar results as in the paper.
[7] Swedish gymnasium education roughly corresponds to upper secondary education in the American education system (years 10-12).

on different R&D intensities. Moreover, as discussed earlier, we expect R&D in manufacturing firms to be more strongly linked to foreign sales. We therefore conduct estimations for manufacturing and service industries separately.

The organization of R&D activities could in large corporations be organized in sub-parts, or specific firms, of the larger corporation. Thus the R&D levels could in principle be misleading as one firm within the larger corporate group could draw on investments done elsewhere in the corporation. We have analyzed our main equation using the corporate level as our unit of analysis with no difference in results. Thus using the firm level does not seem to significantly bias our results.

Another aspect of the organization of R&D activities concerns the possibility of a differential effect between Swedish vs. foreign owned firms. As mentioned earlier, home bias effects in terms of the localization of R&D might induce foreign owned firms active in Sweden to reduce their R&D levels in Sweden relative to sales. To test for this possibility we introduce a dummy variable for foreign-owned firms, hypothesized to impact negatively on R&D levels. However, this variable only is available from 1997 and is hence not included in the regressions for the years before that.

All nominal variables are deflated using an index of civil engineering wages (Ljungberg 1990) when needed, and are expressed in 1985-year prices. Table 3 shows summary statistics for 1997, which is representative for all years between 1991 and 2001.

TABLE 3

*Descriptive statistics of variables for 1997 in all sectors, manufacturing and services.*

| | All sectors | | | | | Manufacturing sectors | | | | | Service sectors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | N | Mean | SD | Min | Max | N | Mean | SD | Min | Max | N | Mean | SD | Min | Max |
| R&D (R&D stat) | 311 | 75445 | 254683 | 1102 | 2620000 | 261 | 76324 | 267451 | 1102 | 2620000 | 50 | 70860 | 175464 | 2885 | 1130000 |
| Foreign sales | 311 | 728111 | 2460000 | 37 | 30800000 | 261 | 838901 | 2670000 | 837 | 30800000 | 50 | 149785 | 437860 | 37 | 2820000 |
| Domestic sales | 311 | 444255 | 1390000 | 649 | 19000000 | 261 | 351875 | 666379 | 649 | 5800000 | 50 | 926477 | 3090000 | 682 | 19000000 |
| Capital intensity | 311 | 0.25 | 0.46 | 0 | 6.93 | 261 | 0.23 | 0.25 | 0 | 1.81 | 50 | 0.31 | 0.99 | 0 | 6.93 |
| Highly educated, share | 311 | 0.31 | 0.2 | 0.05 | 0.89 | 261 | 0.26 | 0.16 | 0.05 | 0.77 | 50 | 0.58 | 0.18 | 0.12 | 0.89 |
| Foreign ownership | 311 | 0.38 | 0.49 | 0 | 1 | 261 | 0.4 | 0.49 | 0 | 1 | 50 | 0.28 | 0.45 | 0 | 1 |
| County R&D | 311 | 2540000 | 2830000 | 86976 | 8110000 | 261 | 2340000 | 2690000 | 86976 | 8110000 | 50 | 3580000 | 3260000 | 86976 | 8110000 |
| Metro | 311 | 0.49 | 0.41 | 0 | 1 | 261 | 0.47 | 0.42 | 0 | 1 | 50 | 0.59 | 0.35 | 0.01 | 1 |
| HHI sector 10 | 311 | 0.05 | 0.06 | 0 | 0.36 | 261 | 0.05 | 0.06 | 0 | 0.36 | 50 | 0.03 | 0.03 | 0 | 0.09 |

R&D and the sales variables are in thousands of SEK (1985-year prices).

### 3.2 Time trends in the distribution of innovative activities and exports

Figures 1-4 summarize trends in R&D expenditures and exports in Sweden, where we also include the observations for 2003. Figure 1 shows that large firms have a somewhat decreasing share of total R&D expenditures. We should, however, observe that R&D expenditures are still extremely concentrated towards large firms, since almost 94 % was done in firms with at least 200 employees in 1991, a figure that only dropped to 91 % in 2003. Figure 2 shows that mean R&D expenditures per firm clearly has increased over the period even though they diminished from 1991 to 1993 and from 2001 to 2003.

**Figure 1.** Share of R&D in firms with at least 200 employees.

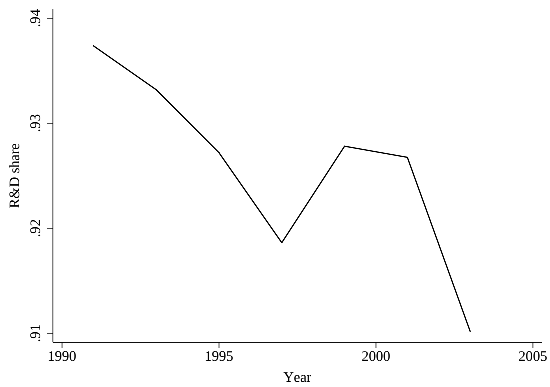



**Figure 2.** Mean R&D expenditures per firm (in 1985-year prices).

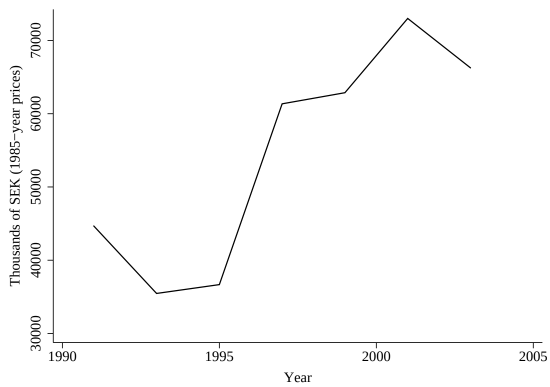



Figure 3 shows that R&D still takes place predominantly in the manufacturing sector. Manufacturing firms conduct about 80 % of total R&D in Sweden with only slowly increasing shares for service sector firms. Figure 4 shows the development of the export intensity (exports/total sales) for firms with positive R&D expenditures. This intensity has increased from 0.42 in 1991 to 0.57 in 2003 showing the increased trade dependency for Swedish R&D performers.

**Figure 3.** Share of R&D in manufacturing and service sector firms.

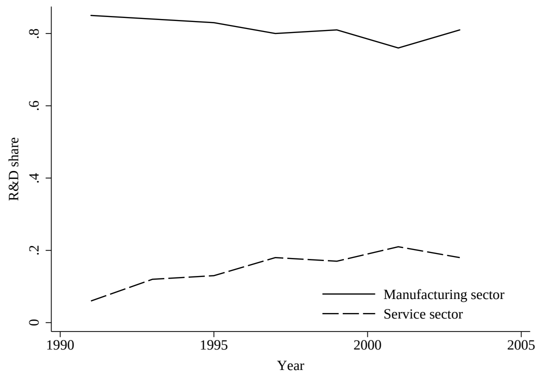
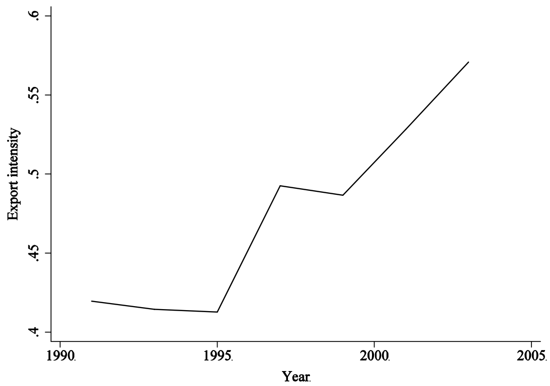



**Figure 4.** Export intensity for R&D performing firms.




### 3.3 Regressions on the size-R&D relationship

In this section we conduct the regression analysis, which enables us to sort out the role of the two sales variables – foreign and domestic – for R&D expenditures, while also taking into account effects related to the sample at hand. Equation (1) depicts the main estimated equation.

$$\ln RD_{it} = \beta_1 \ln S_{it}^F + \beta_2 \ln S_{it}^D + \beta_3' X_{it} + u_{it}, \quad t = 1993,1997,2001, \tag{1}$$

where *i* is a firm and *t* denotes year. The dependent variable is the log of R&D expenditures, the explanatory variables of main interest are the log of foreign sales ($S^F$) and the log of domestic sales ($S^D$), *X* is a row vector of control variables including capital intensity, the share of highly educated, a dummy for foreign ownership, industry dummies for our ten sectors and a constant, and *u* is an idiosyncratic error term. For space reasons we only present regressions for the years 1993, 1997 and 2001 even though we also run the regressions for the years 1991, 1995 and 1999. These latter regressions are presented in the Appendix, Tables A2 and A3.

If $\beta_1 = \beta_2$ then there is no difference in the effect on R&D expenditures from changes in these two types of sales variables, but if $\beta_1 > \beta_2$ then changes in foreign sales have a larger impact than changes in domestic sales. There would then be evidence of a learning by exporting effect or of scale economies in R&D. We expect this latter effect to be more pronounced for manufacturing than for service sectors. Following the literature we expect $\beta_1 + \beta_2 = 1$ resulting in a proportional relationship between R&D expenditures and size.

Several issues with the estimation of this equation need attention. First, due to the log specification we exclude non-R&D performers which might lead to biased results using OLS estimation. To correct for sample selection bias concerning the R&D variable we use the Heckman (1979) two-step estimator where, in the first stage, we specify an equation for the probability of engaging in R&D. From this stage, an inverted Mills ratio is estimated and used to correct for selection. Because our R&D data only include R&D performers we construct the selection variable with the help of the Structural Business Statistics data set. We believe that zero values can be expected to be accurate from the SBS, and thus complement the data from the R&D statistics. Therefore, the selection variable is created as follows:

$$s(R\,\&\,D) = \begin{cases} 1 \quad \text{if} \quad R\,\&\,D_{stat} > 0 \\ 0 \quad \text{if} \quad R\,\&\,D_{stat} = 0 \\ 0 \quad \text{if} \quad R\,\&\,D_{stat} = \text{missing and } R\,\&\,D_{SBS} = 0 \\ \text{missing} \quad \text{if} \quad R\,\&\,D_{stat} = \text{missing and } R\,\&\,D_{SBS} = \text{missing} \end{cases} , \qquad (2)$$

where $R\&D_{stat}$ is R&D data from the R&D statistics and $R\&D_{SBS}$ is from the Structural Business Statistics.

As we also log the export variable, we exclude non-exporters. These are about 10 percent of the R&D performers in our data. There is no easy way to control for this exclusion and hence, we just have to acknowledge that this exclusion is a shortcoming and that our results are valid only for firms with positive domestic and foreign sales.

Second, another major issue is the possibly endogenous relationship with the sales variables, and specifically the variable for foreign sales. It is rather well documented in the literature that it is a simultaneous decision to perform R&D and to export (Fors and Svensson 2002, Lileeva and Trefler 2007, Aw et al. 2008). However, Lileeva and Trefler (2007) point out that it is exporting that makes it more profitable to improve productivity (investing in R&D) because it increases the output over which the productivity gains will be spread. We deal with this possible endogeneity problem by using an instrumental variable estimator and instrument foreign sales with its lagged values.

#### *3.3.1 Estimation results*

First we examine the results from our three estimators, OLS, IV and Heckman, for one specific year, 1997, gauging if there are problems of endogeneity and/or selection bias. For the IV estimation we use the two-stage least squares estimator where we instrument foreign sales with its first and second lag. Including more than one instrument allows us to test the validity of the instruments using the Hansen test of overidentifying restrictions, a test which our instruments pass. However, it could be discussed if the first lag of foreign sales actually is an appropriate instrument even though it passes the validity test. Therefore we have also tried with only the second and third lag as instruments but we get no differences in the results or in the validity tests. In addition, we have also instrumented domestic sales and the human capital variable and tested these variables for endogeneity. We conclude that they can be treated as exogenous and do not need to be instrumented. For the selection equation in the two-step Heckman estimator, all the previously discussed variables are included in addition to variables for competition, total (logged) R&D in the region and metropolitan area. Following the Industrial Organization literature we include a measure of competition to control for effects of market structure (see e.g. Vossen 1999, Aghion et al. 2005, Gustavsson Tingvall and Karpaty 2011). We use the Hirschmann Herfindahl Index (HHI), defined as

$$HHI_k = \sum_{i \in k} s_i^2 , \qquad (3)$$

where $s_i^2$ is the squared market share of firm *i* belonging to sector *k*.[8] The variable for total R&D in the region is intended to capture the potential for knowledge spillovers measured by the county total R&D (minus R&D of the own firm) where the firm has its main workplace. Other firms' R&D may stimulate own R&D investments in order to 'absorb' their results (Cohen and Levinthal 1989) and may make it more profitable to invest in own R&D (Audretsch and Feldman 1996). The metropolitan variable shows the share of employees that reside in one of the counties of Stockholm, Gothenburg or Malmoe. The variable uses the location of the individual rather than that of the firm as firms' county judicial seating, which we had information on, does not always appropriately reflect the true county of the firm's activity. Both the R&D county and the metropolitan variable are intended to capture advantages for the firm of being located in an agglomeration where much R&D activity takes place, and hence may have a positive influence, a spillover effect, on the probability of engaging in R&D.

TABLE 4

[8] The results are mainly unchanged when instead using the market share of the top four firms (C4) in the sector. The HHI index carries information on the dispersion of all firms in a sector whereas the C4 only considers the top four.

*Estimation results, OLS, IV and second stage Heckman, 1997*

| Dependent variable: Log R&D expenditures | OLS | IV | Heckman |
|---|---|---|---|
| Log foreign sales | 0.37*** | 0.40*** | 0.60*** |
| | (0.045) | (0.050) | (0.076) |
| Log domestic sales | 0.33*** | 0.32*** | 0.43*** |
| | (0.041) | (0.041) | (0.055) |
| Capital intensity | 0.20 | 0.20 | 0.19 |
| | (0.319) | (0.311) | (0.283) |
| Highly educated, share | 3.67*** | 3.65*** | 5.69*** |
| | (0.481) | (0.467) | (0.739) |
| Foreign ownership | -0.14 | -0.15 | -0.10 |
| | (0.111) | (0.108) | (0.123) |
| Constant | 1.43** | 1.37** | -2.51* |
| | (0.726) | (0.653) | (1.318) |
| Observations | 275 | 275 | 275 |
| Censored observations | | | 907 |
| R-squared | 0.686 | 0.685 | |
| Lambda | | | 1.31*** |
| | | | (0.297) |
| Hansen | | 0.900 | |

Robust standard errors in parenthesis. ***, **, * Coefficients are significant on the 1, 5 and 10 % level respectively. Sector dummies not reported. P-values are reported for the Hansen test of overidentifying restrictions. In the IV estimation, log foreign sales is instrumented with its first and second lag.

Table 4 shows the results for the OLS, the IV and the second stage Heckman for the year 1997. The samples for the OLS and the Heckman estimations are limited to those observations where the first and second lag of log foreign sales is available so as to use the same observations as for the IV.

We can observe that the estimates are very similar across the OLS and the IV specifications, indicating that there is effectively no problem of endogeneity, even though we reject exogeneity of foreign sales for this year. Thus we can rely on the OLS in this sense. Comparing the OLS estimates with those of the Heckman estimator, we see that the Heckman estimates for the sales variables are higher than when we use OLS, especially for foreign sales. The other variable estimates are pretty similar. This higher elasticity in the Heckman estimates indicates the existence of sample selection bias and the lambda coefficient, i.e. for the Mill's ratio, is significantly different from zero. These results show that it is the sample selection bias that is the most important to control for and the Heckman estimator is therefore our most preferred estimator even though we cannot control for endogeneity. Moreover, in the IV estimations we reject that foreign sales is exogenous only for about half of the years.

Now that our strategy[9] for the specifications has been laid out, we present the Heckman estimates for the first stage, i.e. the selection equation, in Table 5.[10] Here, we also differentiate between manufacturing and service sectors.

The results show that both foreign and domestic sales are important determinants for the decision to perform R&D and the coefficient on foreign sales is significantly higher than that for domestic sales in each of the investigated years except for 1991, when firms from both sectors are examined together. Moreover, the coefficient on foreign sales is higher for the manufacturing sector than when all firms are included. For the service sector the results are somewhat more varied. Domestic sales are only significant in 1997 and 2001 and the estimates of the sales variables are much lower than for the manufacturing sector.

Concerning the control variables, capital intensity is almost never significant and does not seem to affect the decision to perform R&D. The share of highly educated at the firm is an important determinant for having R&D for all years and in all sectors. Being in a county with much R&D or having employees in a metropolitan area actually seems to have a negative effect on the decision to perform R&D, but these variables are not often significant. Also the competition variable HHI is significantly negative for most years. This result means that the decision to perform R&D is negatively affected by a more concentrated market structure. It should be stressed, however, that this variable mainly captures domestic competition.

[9] The panel regressions reported on in footnote 6 were done using an IV fixed effect estimator since no Heckman panel estimator could be found.
[10] In Table A1 in the Appendix, we present descriptive data of all firms, i.e. including also those firms that only are used in the first stage.

TABLE 5

*First stage Heckman estimates*

| Dependent variable: s(R&D) | 1993<br>1. All | 2. M | 3. S | 1997<br>4. All | 5. M | 6. S | 2001<br>7. All | 8. M | 9. S |
|---|---|---|---|---|---|---|---|---|---|
| Log foreign sales | 0.28*** | 0.38*** | 0.10** | 0.38*** | 0.56*** | 0.15*** | 0.33*** | 0.55*** | 0.13*** |
| | (0.023) | (0.030) | (0.041) | (0.030) | (0.045) | (0.042) | (0.024) | (0.040) | (0.032) |
| Log domestic sales | 0.15*** | 0.24*** | -0.03 | 0.21*** | 0.17*** | 0.16*** | 0.09*** | 0.06* | 0.08* |
| | (0.033) | (0.041) | (0.065) | (0.035) | (0.045) | (0.058) | (0.027) | (0.038) | (0.041) |
| Capital intensity | 0.02 | -0.02 | -0.01 | 0.10 | -0.05 | 0.16* | -0.06 | -0.21* | 0.00 |
| | (0.080) | (0.152) | (0.079) | (0.076) | (0.133) | (0.083) | (0.074) | (0.129) | (0.056) |
| Highly educated, share | 1.26*** | 1.14*** | 1.34*** | 3.70*** | 4.47*** | 2.89*** | 2.49*** | 2.24*** | 2.42*** |
| | (0.295) | (0.430) | (0.411) | (0.330) | (0.496) | (0.432) | (0.234) | (0.360) | (0.324) |
| Log county R&D | -0.07** | -0.03 | -0.10 | -0.02 | -0.10** | -0.07 | 0.04 | -0.00 | 0.04 |
| | (0.035) | (0.041) | (0.071) | (0.041) | (0.044) | (0.074) | (0.032) | (0.038) | (0.057) |
| Metro | 0.15 | 0.18 | -0.30 | -0.21 | -0.01 | -0.80** | -0.17 | 0.09 | -0.61* |
| | (0.122) | (0.134) | (0.352) | (0.144) | (0.163) | (0.332) | (0.152) | (0.181) | (0.332) |
| HHI sector 10 | 14.85 | -1490.32*** | -114.79 | -63.15*** | -2491.92*** | -4078.73*** | -75.19*** | -3113.25*** | -3655.56*** |
| | (0.000) | (156.135) | (228.207) | (9.972) | (204.431) | (1,027.015) | (8.899) | (246.948) | (639.418) |
| Observations | 1428 | 966 | 462 | 2185 | 1176 | 1009 | 2398 | 1297 | 1101 |
| T-test log foreign sales = log domestic sales (p-value) | 0.00 | 0.01 | 0.13 | 0.00 | 0.00 | 0.95 | 0.00 | 0.00 | 0.37 |
| T-test log foreign sales + log domestic sales = 1 (p-value) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Turning to the specification of main interest – the determinants of the amount of R&D conducted at the firm – Table 6 displays the second stage Heckman estimates for the three chosen years, 1993, 1997 and 2001 where we now have included all available observations. In line with our expectations, the elasticity with respect to foreign sales is again generally higher than for domestic sales. The estimate for foreign sales ranges between 0.47 (in 1991) and 0.65 (in 1993 and 1995) whereas that for domestic sales ranges between 0.29 (in 2001) and 0.45 (in 1991 and 1993). This difference between the estimates on the sales variables is significant and rather constant over the years except for 1991 where the estimates are almost the same. Thus we cannot really claim that Swedish firms increasingly link their R&D behaviour to foreign sales relative to their domestic sales, when studying all firms together.

The combined elasticity ranges from 0.82 (in 1999) to 1.05 (in 1995). It is thus very close to one and we can only reject that it is one for 1999. Thus on average, when sales increase, R&D expenditures increase in the same pace and there does not seem to be a large firm advantage in performing R&D.

With regard to the control variables, capital intensity is not very robust. Most of the time it is significant but the size of the estimate changes a lot. The share of highly educated is on the other hand significant and positive for all years, indicating that having a well educated work force is an important determinant for the amount of R&D undertaken at the firm, in line with our expectations. The variable for foreign ownership which is only available from 1997, is as expected negative and significant for both 1999 and 2001.

TABLE 6

*Second stage Heckman estimates*

| Dependent variable:<br>Log R&D expenditures | 1993 | 1997 | 2001 |
|---|---|---|---|
| Log foreign sales | 0.65*** | 0.58*** | 0.60*** |
| | (0.081) | (0.068) | (0.098) |
| Log domestic sales | 0.45*** | 0.38*** | 0.29*** |
| | (0.050) | (0.044) | (0.042) |
| Capital intensity | 0.60** | 0.46*** | -0.12 |
| | (0.255) | (0.112) | (0.174) |
| Highly educated, share | 6.25*** | 5.59*** | 5.10*** |
| | (0.577) | (0.614) | (0.696) |
| Foreign ownership | | -0.09 | -0.24** |
| | | (0.108) | (0.109) |
| Constant | -3.80*** | -2.60** | -2.27 |
| | (1.251) | (1.266) | (1.719) |

| | | | |
|---|---|---|---|
| Uncensored observations | 448 | 311 | 350 |
| Censored observations | 980 | 1874 | 2048 |
| Lambda | 1.45*** | 1.08*** | 1.37*** |
| | (0.432) | (0.265) | (0.413) |
| T-test log foreign sales = log domestic sales (p-value) | 0.01 | 0.01 | 0.00 |
| T-test log foreign sales + log domestic sales = 1 (p-value) | 0.37 | 0.66 | 0.38 |

Standard errors in parenthesis. ***, **, * Coefficients are significant on the 1, 5 and 10 % level respectively. Sector dummies not reported.

To investigate if the results differ between manufacturing and service sectors, Table 7 shows the second stage Heckman estimates for these sectors separately. The first thing to note is that the coefficient on lambda is insignificant for all years except 1999 for the service sector indicating that the Heckman estimator is not always needed for this sector.

The elasticity for foreign sales ranges from 0.48 (in 1991) to 0.88 (in 2001) for the manufacturing sector. It ranges from -0.03 (in 2001) to 0.23 (in 1997), and is not always significant, for the service sector. The domestic sales elasticity ranges from 0.21 (in 2001) to 0.47 (in 1991) for the manufacturing sector and from -0.27 (in 1991 and not significant) to 0.42 (in 1993) for services. The difference between the estimates for foreign and domestic sales becomes increasingly bigger over the years for the manufacturing sector indicating that manufacturing firms increasingly link their R&D spending to exports. The post 1994 period is one where Swedish exports have increased dramatically, following a depreciated currency and membership to the European Union. Our results suggest that R&D has been affected as well by these trends. For the service sector, on the other hand, domestic sales seems to be slightly more important in determining the amount of R&D than foreign sales, although we can only reject equality between the coefficients for two of the years (1999 and 2001). This result means that the overall patterns are driven by the manufacturing sector.

TABLE 7

*Second stage Heckman for manufacturing and service sectors respectively*

| Dependent variable: | 1993 | | 1997 | | 2001 | |
|---|---|---|---|---|---|---|
| Log R&D expenditures | 1. M | 2. S | 3. M | 4. S | 5. M | 6. S |
| Log foreign sales | 0.68*** | 0.15 | 0.65*** | 0.23** | 0.88*** | -0.03 |
| | (0.078) | (0.131) | (0.075) | (0.110) | (0.129) | (0.128) |
| Log domestic sales | 0.46*** | 0.42*** | 0.32*** | 0.24*** | 0.21*** | 0.17 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | (0.053) | (0.128) | (0.042) | (0.093) | (0.052) | (0.108) |
| Capital intensity | 0.43 | 0.69* | -0.05 | 0.45*** | 0.58** | -0.61** |
| | (0.316) | (0.415) | (0.272) | (0.176) | (0.296) | (0.247) |
| Highly educated, share | 6.03*** | 3.67*** | 5.56*** | 2.63* | 4.37*** | 1.18 |
| | (0.581) | (1.263) | (0.579) | (1.385) | (0.667) | (2.119) |
| Foreign ownership | | | -0.10 | -0.05 | -0.22 | -0.27 |
| | | | (0.110) | (0.382) | (0.135) | (0.274) |
| Constant | -7.03*** | 2.51 | -4.77*** | 2.87 | -6.93*** | 9.60* |
| | (1.500) | (2.669) | (1.296) | (3.291) | (2.092) | (5.387) |
| Uncensored observations | 398 | 50 | 261 | 50 | 273 | 77 |
| Censored observations | 568 | 412 | 915 | 959 | 1024 | 1024 |
| Lambda | 1.25*** | -1.16 | 0.95*** | -0.01 | 1.57*** | -1.48 |
| | (0.343) | (0.988) | (0.239) | (0.610) | (0.399) | (1.167) |
| T-test log foreign sales = log domestic sales (p-value) | 0.00 | 0.22 | 0.00 | 0.91 | 0.00 | 0.06 |
| T-test log foreign sales + log domestic sales = 1 (p-value) | 0.17 | 0.00 | 0.73 | 0.00 | 0.50 | 0.00 |

Standard errors in parenthesis. ***, **, * Coefficients are significant on the 1, 5 and 10 % level respectively. Sector dummies not reported.

The combined elasticity ranges from 0.93 (in 1999) to 1.14 (in 1993) for the manufacturing sector and from 0.03 (in 1991) to 0.57 (in 1993) for the service sector, though the sales variables are not always significant. For the service sector we reject that the combined elasticity equals one for all time periods whereas we never reject it for the manufacturing sector. Hence, for the service sector there seems to be a small firm advantage in R&D.

Turning to the control variables, the capital intensity variable is again shown not to be very robust and is only significant for two of the years for manufacturing firms and three of the years for service firms, and it shows up with opposite signs. The share of highly educated is positive and significant for all years in the two sectors except in 1991 and 2001 for the service sector. The size of the estimate is also in general lower for service sectors but it is clearly important to have a highly educated work force in order to conduct R&D.

### 3.4 Quantile regressions

In this section we report on quantile regressions that allow us to investigate in more detail if and how the estimated effects vary across the distribution of R&D expenditure values. This investigation allows us to more clearly understand the role of the two sales effects for different levels of R&D performers. This understanding may also be important for policies which try to stimulate R&D. The technique is based on the minimization of the sum of absolute residuals which orders the dependent variable by size and then changes the weight in the regression depending on which part of the sample is addressed.

Formally, the $\theta$th regression quantile of the dependent variable $y$ is the solution to (Buchinsky 1998)

$$\min_{\beta}\left(\sum_{i:y\geq x'\beta}\left|y_i - x_i'\beta\right|\theta + \sum_{i:y<x'\beta}\left|y_i - x_i'\beta\right|(1-\theta)\right). \tag{4}$$

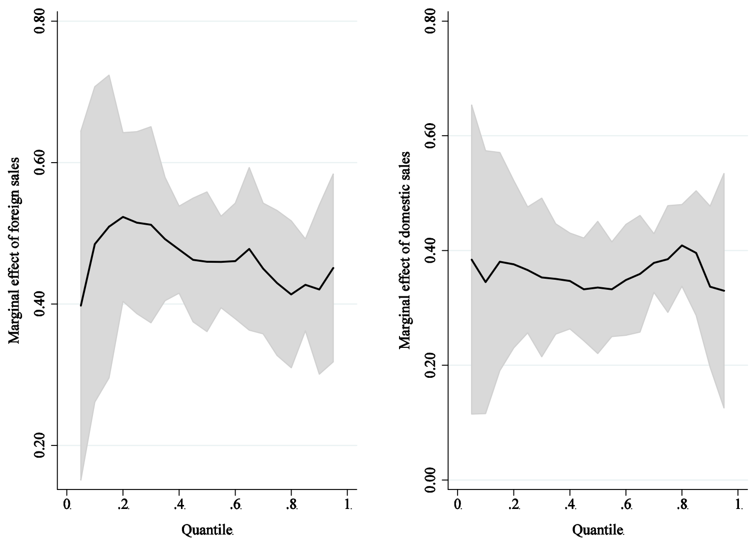
Hence, the estimated coefficients vary as residuals are successively given different weights in the estimation procedure. For the median regression, all residuals receive equal weight. However, when estimating the 75th percentile, negative residuals are weighed by 0.25 and positive residuals by 0.75. The criterion is minimized, when 75 % of the residuals are negative.[11]

It is not easy to control for sample selection bias in the quantile regressions, even though Buchinsky (1998, 2001) has done some work in this direction. Moreover, it is not evident if the selection bias changes or not with the amount of R&D expenditures. To get some idea of the size of the selection bias over the distribution we have reestimated our regression separately using only those firms with high R&D expenditures (above the 75th percentile) and those with low R&D expenditures (below the 25th percentile). In these regressions we see that the selection bias seems to be greater for firms with high R&D levels, and the coefficient on lambda is not even significant for the firms with low R&D levels. Hence, if the estimated elasticity differs with the amount of R&D using quantile regression it is reasonable to assume that the same pattern would occur if we could control for the sample selection, only the estimates for high R&D performers would in general be higher.

Quantile regressions are run every fifth quantile (Q5, Q10, … , Q95) for all firms. Quantile regressions are more robust to outliers, but are subject to heteroscedasticity problems. In order to solve potential heteroscedasticity problems, bootstrap with 3,000 replications are conducted.[12] The 95% confidence band from bootstrapped estimation errors are shown as shaded (grey) areas in the figures. We show results on the marginal effects of (log) sales for 1993 and 2001 in Figures 5 and 6.

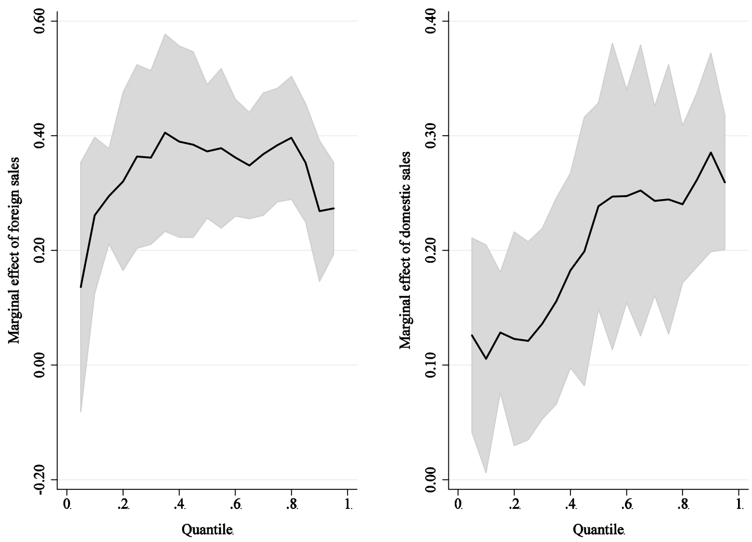
**Figure 5.** Quantile regressions for R&D in 1993. Left graph: marginal effects for foreign sales. Right graph: marginal effects for domestic sales.

[11] Koenker and Hallock (2001) provide an intuitive explanation.
[12] See Rogers (1992) and Gould (1992). This procedure is automated in the STATA statistical package.




The graph for 1993 is representative also for the situation in 1991 and the graph for 2001 is representative for the distribution of marginal effects for 1995, 1997 and 1999 as well. The difference is dramatic: while the marginal effects are fairly stable for both foreign and domestic sales in 1993, in 2001 marginal effects for domestic sales rise from about 0.10 to 0.25 as we move to higher values for R&D. This result means that firms increasingly link their R&D expenditures to domestic sales the more R&D they conduct. This result could possibly be explained by the fact that Swedish customers could be considered to be advanced users of new products. As sales start to pick up on the domestic market, they start to stimulate R&D as there is an expectation that the product may take off, possibly also on the international market. In a range of products such as mobile telephones and broadband, Swedish customers have been early to adopt new technology. The elasticity for foreign sales has somewhat of an inverted U-shaped pattern with values ranging from 0.18 to 0.40 and back to 0.25. When R&D expenditures start to increase, they quickly become more and more sensitive to changes in foreign sales but after a while the level of sensitivity stabilizes and even diminishes to some extent. However, since the sample selection bias seemed to be more pronounced for high R&D performers, this stabilization or fall in the estimates should be considered with care. It should also be noted, that the foreign sales effect is almost invariably stronger than that of domestic sales for the entire R&D distribution.

**Figure 6.** Quantile regressions for R&D in 2001. Left graph: marginal effects for foreign sales. Right graph: marginal effects for domestic sales.




Thus during the 1990s, R&D expenditures' sensitivity to changes in sales has changed over the distribution of firms. In the early 1990s, all firms were more or less equally sensitive to changes in sales, whereas in the later 1990s and early 2000s it is the firms with high levels of R&D that are the most responsive to changes in sales, especially concerning domestic sales. This result show that in these later years, the level of sales is not that important as a determinant for R&D expenditures in firms with lower levels of R&D and that we here would need to look for other variables to explain the R&D efforts.

## 4 Summary and conclusions

The Swedish economy has undergone dramatic changes in the last decades in terms of openness. This paper examines if exports has impacted on the firms' R&D efforts. We divide firms into manufacturing and service sectors and compare effects at different points in time. In line with the 'stylized fact' presented in Cohen and Klepper (1996), we find the average combined elasticity from sales to R&D to be close to one, suggesting a proportionate relationship. This average relationship masks several differences revealed after more detailed analyses. For service firms the elasticity is less than one. This result indicates that among service firms, a small firm advantage is discerned implying that being small and flexible might be advantageous for service firms. In the words of Breschi et al. (2000) they would belong to the Mark I regime, referring to Schumpeter's (1934) notion of the dynamic young entrepreneurial (and small) firms. Another possibility is that smaller firms cater the R&D needs of large corporations to a larger extent and R&D is increasingly conducted in smaller consultancy firms in services. For manufacturing firms there is clear evidence that foreign sales have a stronger effect on R&D expenditures than domestic sales. There are several reasons for why foreign markets can be expected to provide more stimulus to R&D. First, learning-by-exporting may have firms enter into virtuous circles of export-R&D-export. Second, we argue that export sales are in a sense a low estimate of the sales effect. In multinational firms, that Sweden has many of, with production operations abroad, the exported good is often refined in foreign affiliates and hence the total sales effect becomes underestimated. Third, we have argued that in manufacturing firms, scale effects should be more pronounced as production and R&D can be more distinctly separated. Moreover, for manufacturing firms the weight of goods may make it more economical to establish plants abroad to economize on transport costs. Our results in general support these hypotheses, but our study does not distinguish between the alternative hypotheses explaining the link from exports to R&D; this question is left for future research.

Our study does not either differentiate between the type of products that are exported or to which markets the exports are sold, something that could influence the sensitivity to changes in sales. The R&D expenditures of a firm that exports an R&D intensive product are probably more sensitive to changes in the exports of that product than the R&D expenditures of a firm that exports low R&D intensive products. The same reasoning goes for the markets receiving the exports. If the exported goods are sold to R&D intensive countries then a firm probably needs to put more resources on R&D itself to keep the products competitive, in line with the 'advanced user' argument put forward above. Support for these conjectures can be found in (Andersson and Ejermo 2008). Deeper exploration of these hypotheses is left future research.

During the investigated time period, Sweden experienced a sharp depreciation of the currency in 1992-93 and became a member of the European Union in 1995. The 1990s was a period of export-led recovery. Some Swedish policy discussions (Braunerhjelm 1998, Edquist and McKelvey 1998) have stated that Sweden 'underperforms' with respect to R&D in terms of innovative performance, exports and growth, what has been labeled the Swedish paradox. Recent contributions examining R&D-productivity in terms of patents suggest, however, a much more positive outlook and a taxonomy based on growth patterns (Ejermo and Kander 2011). Ejermo et al. (2011) reveal that it is the growing sectors that are responsible for R&D expenditures, which suggests that the growth effects might be undervalued. Our results support this idea: 'underperformance' may simply arise from a neglect of accounting for sales effects abroad, i.e. the reasons for investing in R&D depends on the degree of internationalization and exports in the firm. Interestingly, foreign ownership of Swedish firms may result in less R&D being allocated to Sweden which gives fuel to the discussion of cross-border ownership. Our results also suggest that the export-led growth experienced since the 1990s, has led to a two-tiered structure in terms of R&D organization. On the one hand, manufacturing firms' R&D efforts are to some extent driven by economies of scale. On the other hand, R&D in the service sector has been on the rise and in this sector the R&D efforts seem relatively more linked to domestic sales and small firms are more important. Again, a clear possibility is that these firms cater the needs of multinationals at home in the sense that they conduct R&D based on the needs of these other large firms. It is also possible that these firms represent increasing dynamics in terms of innovation and entrepreneurship. We believe that these are important venues for further research.

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**Appendix A**

TABLE A1

*Descriptive statistics for 1997 including all firms that are in the first stage of the Heckman estimation*

| | All sectors | | | | | Manufacturing sectors | | | | | Service sectors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | N | Mean | SD | Min | Max | N | Mean | SD | Min | Max | N | Mean | SD | Min | Max |
| R&D | 2185 | 10738 | 99509 | 0 | 2620000 | 1176 | 16939 | 129749 | 0 | 2620000 | 1009 | 3511 | 41634 | 0 | 1130000 |
| Foreign sales | 2185 | 138746 | 971200 | 1 | 30800000 | 1176 | 218659 | 1300000 | 5 | 30800000 | 1009 | 45608 | 238654 | 1 | 5010000 |
| Domestic sales | 2185 | 190436 | 727586 | 379 | 19000000 | 1176 | 140291 | 378478 | 493 | 5800000 | 1009 | 248880 | 986743 | 379 | 19000000 |
| Capital intensity | 2185 | 0.22 | 0.58 | 0 | 11.64 | 1176 | 0.23 | 0.45 | 0 | 8.97 | 1009 | 0.21 | 0.7 | 0 | 11.64 |
| Highly educated, share | 2185 | 0.22 | 0.2 | 0 | 1 | 1176 | 0.15 | 0.13 | 0 | 0.77 | 1009 | 0.29 | 0.24 | 0 | 1 |
| Foreign ownership | 1807 | 0.23 | 0.42 | 0 | 1 | 1031 | 0.24 | 0.43 | 0 | 1 | 776 | 0.22 | 0.42 | 0 | 1 |
| County R&D | 2185 | 2820000 | 3050000 | 15737 | 8110000 | 1176 | 1810000 | 2400000 | 15737 | 8110000 | 1009 | 4010000 | 3290000 | 15737 | 8110000 |
| Metro | 2185 | 0.53 | 0.41 | 0 | 1 | 1176 | 0.42 | 0.43 | 0 | 1 | 1009 | 0.65 | 0.35 | 0 | 1 |
| HHI sector10 | 2185 | 0.02 | 0.03 | 0 | 0.36 | 1176 | 0.03 | 0.04 | 0 | 0.36 | 1009 | 0.01 | 0.01 | 0 | 0.09 |

TABLE A2

*First stage Heckman estimates for 1991, 1995 and 1999*

| Dependent variable: | 1991 | | | 1995 | | | 1999 | | |
|---|---|---|---|---|---|---|---|---|---|
| s(R&D) | 1. All | 2. M | 3. S | 4. All | 5. M | 6. S | 7. All | 8. M | 9. S |
| Log foreign sales | 0.31*** | 0.34*** | 0.20** | 0.27*** | 0.35*** | 0.12*** | 0.38*** | 0.64*** | 0.15*** |
| | (0.028) | (0.031) | (0.088) | (0.022) | (0.029) | (0.036) | (0.027) | (0.046) | (0.036) |
| Log domestic sales | 0.26*** | 0.31*** | -0.01 | 0.12*** | 0.16*** | 0.04 | 0.10*** | 0.09** | 0.07 |
| | (0.039) | (0.043) | (0.105) | (0.030) | (0.038) | (0.055) | (0.031) | (0.042) | (0.051) |
| Capital intensity | 0.50** | 0.39 | 2.38** | -0.05 | -0.13 | 0.70*** | -0.08 | 0.04 | -0.07 |
| | (0.245) | (0.256) | (1.064) | (0.051) | (0.176) | (0.269) | (0.097) | (0.134) | (0.123) |
| Highly educated, share | 2.64*** | 2.37*** | 2.59*** | 2.54*** | 2.52*** | 2.45*** | 2.94*** | 3.18*** | 2.35*** |
| | (0.430) | (0.541) | (0.849) | (0.296) | (0.461) | (0.399) | (0.268) | (0.400) | (0.352) |
| Log county R&D | 0.01 | 0.01 | 0.18 | -0.05 | -0.03 | -0.09 | 0.02 | 0.01 | -0.04 |
| | (0.038) | (0.040) | (0.161) | (0.033) | (0.038) | (0.064) | (0.040) | (0.048) | (0.068) |
| Metro | -0.12 | -0.05 | -1.70** | -0.01 | 0.04 | -0.35 | -0.36** | -0.09 | -1.00*** |
| | (0.135) | (0.139) | (0.739) | (0.119) | (0.130) | (0.338) | (0.155) | (0.187) | (0.313) |
| HHI sector 10 | -3.28 | -2,156.16*** | -1,466.79*** | 21.58 | -1,124.97*** | -583.75** | -30.51*** | -3,416.29*** | -2,949.09*** |
| | (0.000) | (187.120) | (549.700) | (0.000) | (124.868) | (253.673) | (5.141) | (296.045) | (898.582) |
| Observations | 1504 | 1031 | 473 | 1564 | 1049 | 515 | 2177 | 1194 | 983 |
| T-test log foreign sales = log domestic sales (p-value) | 0.30 | 0.51 | 0.19 | 0.00 | 0.00 | 0.27 | 0.00 | 0.00 | 0.25 |
| T-test log foreign sales + log domestic sales = 1 (p-value) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

TABLE A3

*Second stage Heckman for manufacturing and service sectors respectively, for 1991, 1995 and 1999*

| Dependent variable: | 1991 | | | 1995 | | | 1999 | | |
|---|---|---|---|---|---|---|---|---|---|
| Log R&D expenditures | 1. All | 2. M | 3. S | 4. All | 5. M | 6. S | 7. All | 8. M | 9. S |
| Log foreign sales | 0.47*** | 0.48*** | 0.30 | 0.65*** | 0.66*** | 0.14 | 0.51*** | 0.66*** | 0.09 |
| | (0.073) | (0.073) | (0.273) | (0.077) | (0.069) | (0.093) | (0.064) | (0.074) | (0.068) |
| Log domestic sales | 0.45*** | 0.47*** | -0.27 | 0.40*** | 0.39*** | 0.23*** | 0.31*** | 0.27*** | 0.30*** |
| | (0.061) | (0.064) | (0.357) | (0.047) | (0.041) | (0.067) | (0.031) | (0.034) | (0.066) |
| Capital intensity | 0.16*** | 0.16*** | -0.40 | 0.36 | 0.38 | 0.35 | 0.41** | 0.15 | 0.69** |
| | (0.047) | (0.046) | (3.867) | (0.267) | (0.300) | (0.522) | (0.202) | (0.264) | (0.344) |
| Highly educated, share | 5.49*** | 5.45*** | 1.63 | 6.27*** | 5.62*** | 3.16*** | 4.64*** | 4.55*** | 2.17*** |
| | (0.659) | (0.635) | (1.636) | (0.702) | (0.539) | (1.222) | (0.464) | (0.425) | (0.841) |
| Foreign ownership | | | | | | | -0.20** | -0.19** | -0.12 |
| | | | | | | | (0.089) | (0.093) | (0.226) |
| Constant | -2.57 | -4.02** | 6.91* | -3.66*** | -5.85*** | 3.02 | -0.40 | -3.84*** | 5.15*** |
| | (1.629) | (1.686) | (3.549) | (1.347) | (1.277) | (2.371) | (0.982) | (1.193) | (1.760) |
| Uncensored observations | 310 | 298 | 12 | 515 | 447 | 68 | 641 | 278 | 63 |
| Censored observations | 1194 | 733 | 461 | 1049 | 602 | 447 | 1836 | 916 | 920 |
| Lambda | 0.97*** | 0.92*** | 0.95 | 1.71*** | 1.22*** | 0.03 | 0.83*** | 0.92*** | -0.96** |
| | (0.350) | (0.333) | (1.002) | (0.425) | (0.333) | (0.685) | (0.247) | (0.227) | (0.435) |
| T-test log foreign sales = log domestic sales (p-value) | 0.79 | 0.92 | 0.34 | 0.00 | 0.00 | 0.49 | 0.01 | 0.00 | 0.04 |
| T-test log foreign sales + log domestic sales = 1 (p-value) | 0.51 | 0.64 | 0.00 | 0.59 | 0.56 | 0.00 | 0.01 | 0.35 | 0.00 |

Standard errors in parenthesis. ***, **, * Coefficients are significant on the 1, 5 and 10 % level respectively. Sector dummies not reported.

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