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R&D and Foreign Sales: Evidence from Swedish Multinationals

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Abstract

The simultaneous relationship between industrial R&D and internationalization is investigated, using unique data on Swedish multinationals in manufacturing 1986-90. The statistical analysis supports the view that MNCs partly base their international competitiveness, measured as foreign sales, on technological capabilities created through R&D. On the other hand, the analysis also indicates that more sales in foreign markets induce larger R&D expenditures, e.g. by increasing the rate of return on each R&D dollar spent.

Keywords: R&D, foreign sales, multinational corporations.
JEL Classification: F23, O32.

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R&D and Foreign Sales: Evidence from Swedish Multinationals

1. Introduction

Multinational corporations (MNCs) account for an increasing share of the world's industrial R&D, and dominate in terms of aggregate manufacturing exports and output as well. In a small open economy like Sweden, where industrial firms are dependent on foreign markets, MNCs play an even more pronounced role. In 1990, 80% of industrial R&D, 52% of exports, and 40% of industrial production were attributed to these firms in Sweden. The Swedish economy is also one of the most R&D intensive in the world. In 1989, the share of national R&D expenditures to GDP was 2.9% for Sweden and Switzerland, followed by United States and Japan with 2.7% (United Nations 1992).

The present study analyzes the simultaneous relationship between MNCs' R&D and their internationalization. It is proposed that firms with more R&D expenditures have a competitive advantage and will therefore be more international, in terms of foreign sales. At the same time, higher presence on international markets should induce more investments in R&D, due to, e.g. higher rate of return on each R&D dollar spent. Some firms have very large R&D expenditures and in order to finance these they must have large sales abroad. The analysis is based on unique data covering practically all Swedish MNCs in manufacturing 1986 and 1990.

Theoretical aspects and previous empirical literature regarding R&D and foreign operations are discussed in section 2. The data base and the econometric method are described in section 3. In section 4, hypotheses are set up. The empirical results are presented in section 5, and the final section concludes.

2. Theoretical background and earlier empirical studies

Possession of oligopolistic advantages is argued to be required before a firm is able to penetrate foreign markets (Caves [1971], Dunning [1973]). Such advantages are considered necessary to offset the excessive costs of setting up and operating affiliates across geographical, cultural or legal boundaries, or transport costs, import

tariffs and other trade barriers in the case of exports. Oligopolistic advantages increase the market concentration and can be derived from factors which create barriers to entry for new competitors, e.g. superior technology, human capital, high initial capital costs or product differentiation (Lall [1980]). Furthermore, these advantages are not necessarily dependent on factor intensities. A firm's products may be internationally competitive regardless of whether the production process utilizes intensively scarce or abundant productive inputs.[1]

In particular, firms develop new, and improve existing, products and processes by spending resources on R&D.[2] They may then obtain a technologically based competitive edge relative to competitors, in turn leading to possible increase in foreign market shares. Several empirical studies have supported such one-way causal relationship, for example Swedenborg [1982], using Swedish data, Lall [1980] and Kravis and Lipsey [1992]. Hirsch and Bijaoui [1985] used an Israel data set and concluded that innovative firms tend to have a better export performance than non-innovative ones. The long term objective for the firm is to maximize profits. In the short and intermediate term, however, the firm may try to obtain larger market shares in order to have a greater base to exploit profits from in the future.[3] Larger market shares will also make it possible for the firm to reap oligopoly profits. If the firm origins from a small country where the domestic market is of limited size such as Sweden, the expansion has to be undertaken abroad.

When a firm expands in foreign markets, the R&D-created knowledge will be utilized more extensively due to the public good character of R&D within the MNC (Markusen [1984]), leading to an increased rate of return to each dollar spent on R&D. More internal funds will also be available to finance further R&D

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[1] The theory of factor intensities (Heckscher-Ohlin) does not need to contradict the theory of barriers to entry. Competitive advantage can be achieved by offering products that contain a high share of relatively abundant inputs, but also by products characterized by superior technology or proprietary knowledge.

[2] An alternative is to buy technology, e.g. through licensing. Furthermore, a large share of R&D undertaken by firms uses existing technologies to create new, or imitate competitors', products. A good example is the automobile industry.

[3] Profit maximization in the short-run is, in fact, inconsistent with the presence of R&D expenditures. A firm that maximize profits with a time horizon of one or two years will never undertake any R&D investments, since the time horizon is much longer.

activities if the firm earns profits from its foreign operations (Pugel [1985]).[4] Foreign markets will especially offer a higher return on R&D than the domestic market, if goods with a high R&D content make up a greater proportion of foreign sales than domestic sales. There are two reasons why it should be like this; (1) to overcome barriers to entry into foreign markets as noted above; (2) from the firm's point of view, competition is more intensive abroad, since the home market is often protected in some sense, or 'basic' versions of the product are sold at home where the firm has a strong market share due to historical factors (Hughes [1985]).

This implies that R&D and foreign sales should reinforce each other in a simultaneous manner (Caves [1982], Mansfield et al. [1979]). Hughes [1985], using U.K. industry data, took the simultaneity between R&D and exports into account and found that R&D exerted a positive, significant impact on exports.[5] A study on U.S. MNCs by Hirschey [1981] tested the causal relationship between R&D and foreign sales in both directions with a simultaneous method, but found only a significant impact of foreign sales on R&D expenditures.

The above arguments are especially valid if the firms originate from small countries like Sweden, Switzerland or the Netherlands. In this case, growth potential in domestic sales is limited, and there are also little scope to finance large R&D investments by sales in the home market alone. Foreign markets will then be very important for the possibilities of expansion as well as financing R&D activities. If firms have a large country as home-base as for instance the United States or Japan, the arguments are weaker. Total sales may then be a better variable to relate R&D expenditures to.

Sales on foreign markets can be undertaken either through exports from the home country or by production in foreign affiliates. The theory does, however, not predict whether R&D activities determine the choice between exports and foreign production. According to the product cycle theory (Vernon [1966]), the choice between exports and foreign production depends on the historical phase of the product. R&D used for new products and processes will, primarily, result in exports

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[4] It can be argued that large firms have greater possibilities to raise external funds for R&D. This capacity is, however, rather related to the solidity and profitability of the firm and not to the size.

[5] Although the simultaneity was taken into account, the reverse impact, i.e. how exports affect R&D activities, was never tested.

from the home country, while R&D used for improving existing products and processes tends to favor foreign production.[6]

3. Data and econometric method

The data base on Swedish MNCs has been collected by the Industrial Institute for Economic and Social Research (IUI) in Stockholm. It has been updated about every fourth year since 1965 and detailed statistics about individual foreign affiliates as well as information about trade and R&D at the firm-level are available. The data set includes all Swedish-owned firms in manufacturing with more than 50 employees and with at least one majority-owned producing affiliate abroad.[7] Only the last two years (1986 and 1990) are included in the empirical analysis, since data on market concentration, which is used as an explanatory variable in the model, is only available for these years.

When relating R&D to foreign operations, previous studies have used several different measures, e.g. intensities have been compared with absolute levels and foreign operations have often been represented by exports. In the present study, the firm's total R&D expenditures, RD, is divided by total sales of the firm, TS, in order to obtain the R&D intensity, RD/TS. This is the standard measure of technological intensity (Caves [1982]). Foreign sales, FS, here defined as exports plus foreign production, is used as the other main variable, since it is a better measure of the firm's international competitiveness than either exports or foreign production separately. In order to make the interpretation in the statistical analysis more convenient, FS is also divided by TS. Thus, FS/TS measures the firm's share of total sales in foreign markets. The use of intensities controls for historical factors of the firm as well as for firm size and is also a way to avoid heteroscedasticity in the regression analysis below. From the plot in Figure 1, there appears to be a

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[6] In a product's introductory phase, the innovative firm tends to export. In a later phase when demand is higher, competitive firms are stimulated to imitate the product. The innovative firm will respond to the increased competition and defend its market share by, e.g. serving foreign markets through local production.

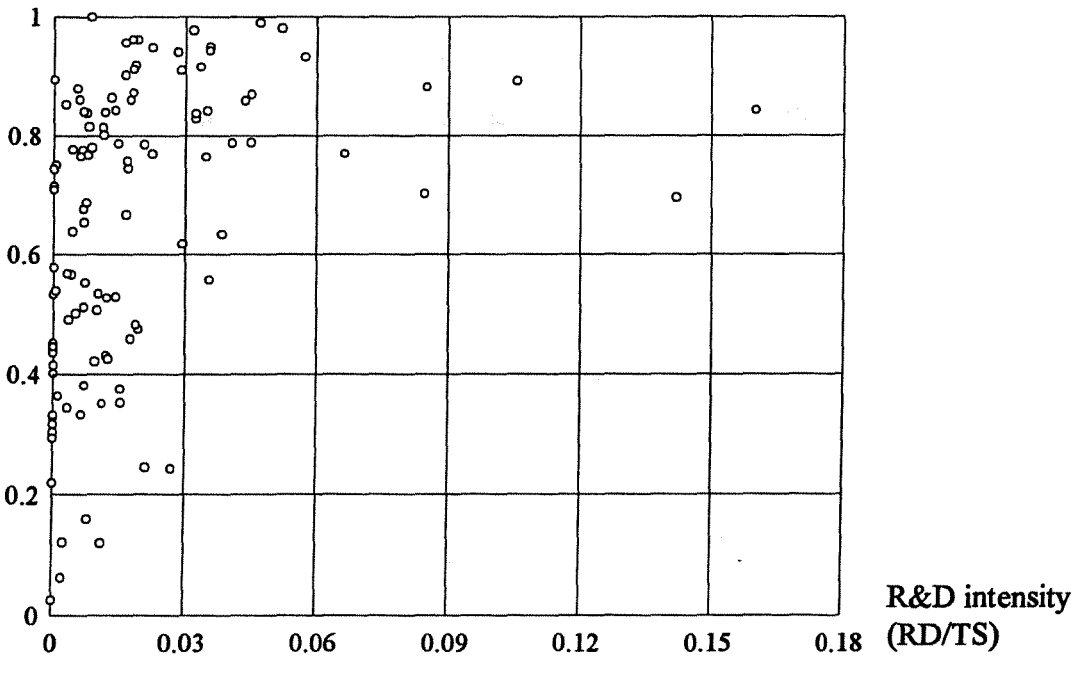
[7] It could be argued that the sample should also contain firms with no production and sales abroad. Many small firms which have had production abroad only in 2-3 years are, however, included. These small MNCs should represent a group of firms with limited experience of foreign markets.

positive relationship between RD/TS and FS/TS for the firms included in the 1990 survey. It is interesting to note that the right lower corner in the figure is empty, i.e. firms which have a low share of foreign to total sales do not have high R&D intensity.

Measuring the strength of the linear relationship, the Pearson correlation coefficient between RD/TS and FS/TS in 1990 is 0.41 and significant at the 1%-level. This positive relationship also holds when foreign sales are decomposed into exports from Sweden and foreign production. The correlations between RD/TS and the share of exports and foreign production to total sales are 0.25 and 0.35, respectively, and are both significant at the 1%-level.

Turning to the regression analysis, a positive, simultaneous relationship is expected to exist between firm *f*'s R&D intensity, RD_{ft}/TS_{ft}, and its degree of

Figure 1. Plot between R&D intensity and the share of foreign to total sales in 1990.



Note: Number of observations equals 116.

internationalization, FS_{ft}/TS_{ft}, at time t.[8] The hypothesis of no simultaneity was tested, and rejected, using a Hausman [1978] test.[9] The simultaneous method, used to estimate the interactions between RD/TS and FS/TS, is a variant of 2SLS with limited endogenous variables outlined in Nelson and Olson [1978], and is specified as:

$$\frac{FS_{ft}}{TS_{ft}} = \beta_0 + \beta_1 \frac{RD_{ft}^*}{TS_{ft}} + Z_1'\beta + \epsilon_{ft} , \tag{1}$$

$$\frac{RD_{ft}^*}{TS_{ft}} = \gamma_0 + \gamma_1 \frac{FS_{ft}}{TS_{ft}} + Z_2'\gamma + \mu_{ft} , \tag{2a}$$

$$\frac{RD_{ft}}{TS_{ft}} = \begin{cases} \dfrac{RD_{ft}^*}{TS_{ft}} & \text{if } \dfrac{RD_{ft}^*}{TS_{ft}} > 0 \\ 0 & \text{if } \dfrac{RD_{ft}^*}{TS_{ft}} \leq 0 \end{cases} . \tag{2b}$$

In the first stage of 2SLS, instruments are created for the endogenous variables. This is accomplished by regressing each endogenous variable on all exogenous variables in the system. In the second stage, the predicted values of FS/TS and RD/TS are substituted for the corresponding RHS variables.

OLS is the appropriate statistical technique to estimate the reduced and structural forms of equation (1). The second endogenous variable, RD/TS, is, however, characterized by some concentration of zeroes (about 18%), i.e. the firms

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[8] There are two reasons why we did not decompose foreign sales into exports and foreign production in the regression analysis. First, the theoretical discussion in section 2 indicated that such an analysis would require R&D to be decomposed in a research and a development part. Second, regression analysis that included exports (EXP) as well as foreign production (FQ) were undertaken by the authors, but with three equations instead of two (Equation (1) was estimated twice with EXP/TS and FQ/TS, respectively, as dependent variables.). The results were not satisfactory, however, since multicollinearity arose in equation (2) in the second stage of 2SLS. This is a common problem in models where several variables are correlated with each other.

[9] To implement the Hausman test, we first estimated the reduced form of equation (2) by Tobit, retrieved the fitted values from this regression and denoted them (rd/ts). Next we estimated by OLS the expanded regression equation:

$$(FS/TS)_{ft} = \beta_0 + \beta_1(RD/TS)_{ft} + \beta_2 HIC_{ft} + \beta_3 LS_{ft} + \beta_4 HOME_{ft} + \beta_5(rd/ts)_{ft} + \epsilon_{ft} , \tag{1'}$$

where (rd/ts) is an added regressor. The null hypothesis that no simultaneity is present (that RD/TS and ϵ are uncorrelated in large samples) then reduces to a test of the simple hypothesis that $\beta_5=0$, which can easily be tested by a t-test.

with no R&D expenditures. When estimating equation (2) in the first and second stage of 2SLS, the Tobit method is used. The latent variable, $(RD/TS)^*$, can be interpreted as an index of R&D intensity, of which FS/TS will be a function. The Z's correspond to firm specific attributes.

The residuals are assumed to have the desired properties: $\epsilon \sim N(0,\sigma_\epsilon^2)$ and $\mu \sim N(0,\sigma_\mu^2)$; $E(\epsilon_{ft}\epsilon_{gt})=0$ and $E(\mu_{ft}\mu_{gt})=0$ for $f \neq g$.[10] However, $E(\mu_{ft}\epsilon_{ft}) \neq 0$, since simultaneity is present. The simultaneous Tobit method yields consistent parameter estimates, but the asymptotic standard errors of the parameter estimates are underestimated. In order to avoid this, the asymptotic variance-covariance-matrix is derived and the standard errors are recalculated according to Amemiya [1979].

The parameters in equation (1) are marginal effects. The estimate of γ_1 in the Tobit equation may not be interpreted as a marginal effect, however. Rather, it is a combination of the marginal effect on the R&D intensity and the effect on the probability that the firm will have any R&D at all (McDonald and Moffitt [1980]).[11] There are two alternative ways to interpret the parameters of the endogenous variables, β_1 and γ_1. First, they show the direct effect of one intensity on another. Second, the effect of R&D on foreign sales, and vice versa, can be obtained by the following formulas (derived in appendix A).

$$\frac{\partial FS}{\partial RD} = \frac{\beta_1}{1 - A}, \qquad (3)$$

$$\text{where } A = \beta_0 + Z_1'\beta .$$

$$\frac{\partial^* RD}{\partial^* FS} = \frac{\gamma_1}{1 - C}, \qquad (4)$$

$$\text{where } C = \gamma_0 + Z_2'\gamma .$$

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[10] It should be noted that $E(\mu_{fs}\mu_{ft}) \neq 0$ and $E(\epsilon_{fs}\epsilon_{ft}) \neq 0$ for $s \neq t$. A firm which, e.g. has a high R&D-intensity in time s, is also expected to have a high R&D-intensity in time t. This will, however, not yield inconsistent parameter estimates.

[11] The marginal effect of FS/TS on RD/TS, $\partial(RD/TS)/\partial(FS/TS)$, simply equals $F(z)\gamma_1$, where $F(z)$ is the cumulative normal distribution and $z=X'\gamma/\sigma_\mu$. X is a vector of explanatory variables and γ is the vector. of estimated Tobit parameters. The z is calculated around the means of X.

The ∂^* in equation (4) indicates the marginal *and* probability effect.

It could be argued that a time lag in the R&D variable should be used, since today's R&D investment will not yield profits or enhance competitiveness until future time periods. Time lags in the regression parameter effects are, however, always a problem in cross-section analysis. Furthermore, firms' R&D intensities are rather stable considering the short or medium term. R&D investment is not an activity which is very extensive one year in order to be neglected the next year, but it is instead characterized by continuity and long term objectives.

4. Hypotheses for exogenous variables

In the following, we present the exogenous variables in the model, their definitions and expected impact on the dependent variables. Table 1 below summarizes the explanatory variables included in each equation. The signs (+ or -) show the expected impact on the dependent variable.

HIC; According to the theory of oligopolistic advantages (section 2), high initial capital costs, HIC, limits competition, since it makes it costly for new firms to enter the market. HIC therefore renders a competitive advantage for firms already in the market and is expected to exert a positive impact on FS/TS. HIC is the average plant size, measured as the book value of real estate, equipment and tools, of the MNC's foreign affiliates.[12] It is, however, not expected that HIC exerts any effect on RD/TS. These two variables are instead regarded as independent of each other.[13]

LS; Firms endowed with skilled labor are assumed to have a advantage relative to other firms. LS is measured as the average wage in the home country part of the firm, and is expected to have a positive influence on FS/TS.

HOME; Several empirical observations about Swedish MNCs indicate that

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[12] This definition is made under the assumption that each affiliate operates at the optimal level of scale.

[13] There are no empirical evidence for any relationship between HIC and RD/TS, which both are oligopolistic advantages. For example, firms operating in the basic industry often have high initial capital requirements to their large plants, but very low R&D intensity. On the other hand, firms in chemicals have high R&D intensity and small plants.

they are more international than MNCs originating from large countries. The size of the home country market, HOME, is included in equation (1), suggesting that a small home market force firms to locate a large share of their sales on foreign markets. HOME is measured as total sales on the Swedish market of the product groups produced by the firm, and is expected to have a negative effect on FS/TS.

CONC; Firms operating in oligopolistic industries are more inclined to compete with other strategies than price, including advertising, product differentiation and, above all, R&D activities. The market concentration, CONC, is measured as the world market share of the four largest firms of the MNC's largest division. A positive effect of CONC on R&D intensity is expected. CONC is not included in equation (1), however, since it is regarded more as an outcome of various oligopolistic advantages than a cause of such advantages.

PROFIT; A higher profit implies a greater ability to raise internal funds to finance R&D projects. The profit variable, PROFIT, is defined as operating income before depreciation divided by total assets. We expect this variable to exert a positive impact on firms' R&D intensity.

Except HOME, all explanatory variables included in equation (1) are related to oligopolistic advantages. The explanatory variables in equation (2), on the other

Table 1. Explanatory variables included in each equation and the expected impact on the dependent variable.

Dependent variable		FS/TS	RD/TS
Explanatory variables	Description	Equation (1)	Equation (2)
RD/TS	Total R&D / Total sales	+	
FS/TS	Foreign sales / Total sales		+
HIC	High initial costs	+	
LS	Labor skill	+	
HOME	Size of home market	-	
CONC	Concentration		+
PROFIT	Profit margin		+

hand, are more related to market structure and the possibilities to raise funds for R&D. It should also be noted that size of the firm by itself does not confer a distinct firm-specific advantage, but is rather a consequence of different oligopolistic advantages, e.g. scale economies, technological and human skills.

We also control for different industry categories and time periods, which may affect the level of FS/TS and RD/TS.[14] By including interaction dummies, it is also checked if the parameters to the endogenous variables, β_1 and γ_1, are different for industries undertaking R&D aimed for product and process innovations, respectively. R&D undertaken in the engineering and pharmaceutical industries is assumed to primarily aim for product innovations. In the iron & steel, paper & pulp and 'other' industries, including textile, food, cement and wood industries, R&D is assumed to be basically aimed at process innovations. The 'product-R&D' group is the reference industry and it is in this group where the large R&D spenders are included.

Finally, with regards to exogenous variables, a few comments on the interaction of competing firms' R&D levels are provided. The R&D activities of a firm may increase or decrease the R&D undertaken by its competitors, and vice versa. This depends on if the firms' R&D are substitutes or complements, whether R&D spillovers between the firms are present, and the market structure of the industry in question. It is true that most of the MNCs in the Swedish sample have their competitors abroad, but in a few cases we can identify Swedish MNCs which are close competitors. An important observation in the data material is that rivals tend to have similar R&D intensities.[15] By using additive dummies for different industries, described above, we indirectly control for R&D interactions between firms. Furthermore, the inter-firm R&D behavior is also taken into account by

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[14] This is done by assigning an additive time dummy for 1986 and additive dummies for different industries: food, textile, chemical, basic, machinery, electronics and transport equipment. Since an individual firm is never included more than twice in the sample, there is no room for the use of firm-specific effects.

[15] There are around 10 cases in the data set where two or more firms are close rivals to each other, e.g. pharmaceuticals, transport equipment, paper, pulp and wood products, machinery, textile and concrete industries. In almost all cases, the competing firms have their R&D intensities on approximately the same level. Due to confidentiality, however, we can not report figures on individual firms.

including the market structure variable, CONC. Close rivals should have similar market concentration, partly explaining the correspondence in R&D intensities.

5. Results of the estimations

The results of the simultaneous estimation are provided in Table 2 below. As expected, the effect of an increase in RD/TS on FS/TS is positive and we can with

Table 2. Results of simultaneous estimations.

Method = Simultaneous Tobit	Dependent variable	
	FS/TS	RD/TS
Explanatory variables	Equation (1)	Equation (2)
RD/TS	6.40 *** (1.74)	---
FS/TS	---	0.0845 *** (0.0303)
HIC	6.02 E-4 ** (3.03 E-4)	---
LS	-0.512 (0.430)	---
HOME	-5.27 E-6 * (3.22 E-6)	---
CONC	---	2.21 E-4 * (1.33 E-4)
PROFIT	---	0.027 (0.026)
Adjusted R^2	0.37	---
F-value	10.83	---
Log-likelihood ratio	---	118.82
Number of observations	201	201
Left-censored obs.	---	34

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. Standard errors in parentheses. Intercepts, dummies for time and industries as well as first-stage estimates are not shown but are available from the authors on request.

99 percent confidence say that the estimated parameter differs from zero. This strongly supports the hypothesis that R&D expenditures create competitive advantages on foreign markets. Furthermore, an increase in FS/TS exerts a positive impact on RD/TS, and the parameter is also in this case significant at the 1%-level.

By recalculating the parameter estimates of β_1 and γ_1 according to equations (3) and (4), the direct effect of an increase in RD on FS, and vice versa, is obtained. The first row in Table 3 indicates that both $\partial FS/\partial RD$ and $\partial^* RD/\partial^* FS$ are significant at the 1%-level. Thus, R&D expenditures and foreign sales seem to reinforce each other.

Considering the recalculated parameter estimates for the two groups 'product-R&D' and 'process-R&D' industries in Table 3, we notice that $\partial FS/\partial RD$ is significant at the 1%-level for both groups. It can also be shown that the difference in parameter estimate across the two groups is not significant (see Table 4, appendix B). The difference is, however, significant for $\partial^* RD/\partial^* FS$. The parameter for the 'product-R&D' group is significant at the 1%-level, while it is insignificant for the 'process-R&D' industry, meaning that we can not tell if there

Table 3. Recalculated parameter estimates for the main variables, total and across industries.

Recalculated parameter	$\partial FS/\partial RD$	$\partial^* RD/\partial^* FS$
Industries	Equation (3)	Equation (4)
All industries (n=201)	13.20 *** (3.69)	0.0805 *** (0.0293)
'Product-R&D' group (n=105)	10.61 *** (2.35)	0.0753 *** (0.0236)
'Process-R&D' group (n=96)	12.92 *** (4.68)	0.0423 (0.0286)
Significant difference between industries?	No	Yes

Note: ***, ** and * indicate significance at 1, 5 and 10 percent, respectively. Standard errors in parentheses. The parameter estimate equals the marginal effect in equation (3), but the marginal *and* probability effect in equation (4). The original regression with industry estimates is available in Table 4, appendix B.

is any causal relationship of RD on FS in the 'process-R&D' group at all.

Turning to the exogenous variables included in the model, the variable measuring high initial capital costs, HIC, has the expected positive impact on FS/TS and the parameter is significant at the 5%-level. This gives some support to the view that high initial costs limit entry by new firms and give an advantage to firms already established in the market. The parameter of LS, labor skill in the MNC, has a surprisingly negative sign, but is not significant. If the size of the home market of the firm's products, HOME, is small, then sales on foreign markets is stimulated. The parameter is significant at the 10%-level. The concentration ratio, CONC, exerts a positive impact on RD/TS, and the parameter is significant at the 10%-level. This is in line with the hypothesis that an oligopolistic market structure favors competition by other strategies than pricing. The parameter of the profit variable, PROFIT, is positive but not significant.

6. Conclusions

Statistical analysis of the relationship between R&D investments and sales on foreign markets produces strong evidence of a positive two-way relationship. When estimating a simultaneous regression model using data on Swedish multinationals in manufacturing 1986-90, it is concluded that MNCs with large R&D expenditures are more successful in foreign markets with respect to sales. This relationship holds regardless if the R&D activities in the MNC aim for product or process innovations. R&D is, however, only one of several investigated factors which increase international competitiveness.

The analysis also indicates that more foreign sales tend to induce larger R&D investments. It is argued that a MNC with a relatively large share of sales in foreign markets, can obtain a higher rate of return on each R&D dollar spent, and also that increased foreign operations raise internal funds to finance additional R&D projects. However, this relationship holds only for firms with product related R&D. Firms dealing with product innovations have often large R&D expenditures, e.g. firms in the automobile, telecommunication and pharmaceutical industries. Finally, it is found that a high world market concentration induces firms to

undertake more R&D investments. This is typical for oligopolistic industries where firms compete with other strategies than pricing, e.g. R&D, advertising or product differentiation.

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Appendix A

The marginal effect of an increase in RD on FS can be derived by first dividing total sales, TS, in equation (1) into foreign, FS, and domestic sales, DS:

$$\frac{FS}{FS + DS} = A + \beta_1 \frac{RD}{FS + DS}, \qquad (5)$$

$$where\ A = \beta_0 + Z_1'\beta,$$

$$TS = FS + DS.$$

After that one solves for FS:

$$FS = \frac{1}{1 - A}(A\ DS + \beta_1 RD). \qquad (6)$$

This gives the partial derivative:

$$\frac{\partial FS}{\partial RD} = \frac{\beta_1}{1 - A}. \qquad (7)$$

In a similar way, the effect of FS on RD can be derived:

$$\frac{\partial^* RD}{\partial^* FS} = \frac{\gamma_1}{1 - C}, \qquad (8)$$

$$where\ C = \gamma_0 + Z_2'\gamma.$$

In this case, ∂^* indicates the total partial effect (marginal and probability effect). A and C are calculated around the means of Z_1 and Z_2.

The standard error of $\partial FS/\partial RD$ is calculated, using a first-order linear approximation, according to Blom [1980]:

$$\sigma_{\partial FS / \partial RD} = \sqrt{Var\left(\frac{\beta_1}{1 - A}\right)} = \sqrt{Var\ (g\ (\beta_0, \beta_1, ..., \beta_k))} \qquad (9)$$

$$= \sqrt{\sum_{i=0}^{k} Var(\beta_i)\left(\frac{\partial g}{\partial \beta_i}\right)^2 + 2\sum_{i=0,\, i<j}^{k} Cov(\beta_i, \beta_j)\left(\frac{\partial g}{\partial \beta_i}\right)\left(\frac{\partial g}{\partial \beta_j}\right)} \ ,$$

where

$$\frac{\partial g}{\partial \beta_1} = \frac{1}{1 - A} \ ,$$

$$\left.\frac{\partial g}{\partial \beta_i}\right|_{i \neq 1} = \frac{\beta_1}{(1 - A)^2} X_i \ .$$

The standard error of $\partial^* RD / \partial^* FS$ is calculated in a similar manner:

$$\sigma_{\partial^* RD / \partial^* FS} = \sqrt{\sum_{i=0}^{k} Var(\gamma_i)\left(\frac{\partial h}{\partial \gamma_i}\right)^2 + 2\sum_{i=0,\, i<j}^{k} Cov(\gamma_i, \gamma_j)\left(\frac{\partial h}{\partial \gamma_i}\right)\left(\frac{\partial h}{\partial \gamma_j}\right)} \ , \qquad \textbf{(10)}$$

where

$$h = h(\gamma_0, \gamma_1, \ldots, \gamma_k) \ ,$$

$$\frac{\partial h}{\partial \gamma_1} = \frac{1}{1 - C} \ ,$$

$$\left.\frac{\partial h}{\partial \gamma_i}\right|_{i \neq 1} = \frac{\gamma_1}{(1 - C)^2} X_i \ .$$

Appendix B

Table 4. Results of simultaneous estimations including estimates for different industries.

Method = Simultaneous Tobit	Dependent variable	
	FS/TS	RD/TS
Explanatory variables	Equation (1)	Equation (2)
RD/TS	4.91 *** (1.30)	---
$(RD/TS)\times D_{Process}$	1.37 (2.62)	---
FS/TS	---	0.0777 *** (0.0254)
$(FS/TS)\times D_{Process}$	---	-0.0349 *** (0.0115)
HIC	7.54 E-4 ** (2.41 E-4)	---
LS	-0.227 (0.408)	---
HOME	-5.12 E-6 (3.24 E-6)	---
CONC	---	2.21 E-4 * (1.33 E-4)
PROFIT	---	0.027 (0.026)
Adjusted R^2	0.36	---
F-value	9.74	---
Log-likelihood ratio	---	152.40
Number of observations	201	201
Left-censored obs.	---	34

Note: ***, ** and * indicate significance at 1, 5 and 10 percent level respectively. Standard errors in parentheses. Intercepts, dummies for time and industries as well as first-stage estimates are not shown but are available from the authors on request.