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# Overseas R&D by Multinationals in Foreign Centers of Excellence

Gunnar Fors and Mario Zejan

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# OVERSEAS R&D BY MULTINATIONALS IN FOREIGN CENTERS OF EXCELLENCE*

Gunnar Fors**
The Industrial Institute for Economic and Social Research (IUI)

Mario Zejan
Stockholm School of Economics

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*Abstract* - This paper examines the determinants of overseas R&D by Swedish multinationals. Our empirical results indicate that the location of R&D abroad to a large extent is motivated by the need to adapt products and processes to conditions in the foreign markets where the firms operate. However, we also find that the MNEs tend to locate their R&D in host countries which are relatively specialized technologically in the firms' own areas. This finding may suggest that one additional motive to locating R&D abroad is to gain access to knowledge in foreign "centers of excellence" and benefit from localized spillovers.

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**Correspondence to: Gunnar Fors, IUI, Box 5501, S-114 85 Stockholm, Sweden. Fax: +46-8-661 7969, email: gunnarf@iui.se

## I. Introduction

To a large extent, overseas R&D by multinational enterprises (MNEs) is explained by the need to adapt products and processes to foreign markets. Recently, it has been suggested that overseas R&D is also undertaken to gain access to knowledge in foreign "centers of excellence", and to benefit from localized R&D spillovers. This motive behind the location of R&D has been pointed out as potentially important e.g. by Behrman and Fischer (1980), but the issue has not yet been subjected to a more systematic empirical investigation. The aim of this paper is to fill part of this gap.

Multinational enterprises still perform the major part of their R&D at home, because of scale economies in R&D, proximity to the company headquarters, and maintaining the secrecy of firms' technologies, to name a few of the main reasons. Yet, a trend of increased internationalization of their R&D activities has been observed over time.[1] A number of factors underlying the decision to decentralize R&D outside the home country have been identified in the empirical literature. Production in foreign affiliates, the size of the host country market, and the technological intensity of the MNE have been shown to be positively related to the internationalization of R&D (Mansfield *et al.*, 1979, Lall, 1980, and Zejan, 1990). These factors essentially capture the overseas R&D undertaken to adapt the MNEs' technologies to the conditions and requirements prevailing in the host countries where the firms operate.[2]

[1]Swedish MNEs in manufacturing located around 19% of their R&D expenditures overseas in 1990. The corresponding figure was 9% for 1970, and 13-14% for the years 1974, 1978 and 1986. A trend of increased internationalization of R&D has been observed for MNEs from other countries as well (see Caves, 1996).

[2]Adaptive overseas R&D is here taken to encompass: direct adaptation of products and processes, technical support to production activities taking place in foreign affiliates, and R&D to facilitate technology transfer from the parent company to foreign affiliates.

Even if the adaptation argument is likely to remain important, there may be other explanations for why firms locate R&D abroad. The present study analyzes whether Swedish MNEs in manufacturing locate overseas R&D activities according to the relative technological specialization of host countries. The question we ask is whether Swedish firms locate overseas R&D to foreign "centers of excellence" in their particular industry. To answer this question we use data for 1978 and 1990 on Swedish firms' overseas production and R&D activities in different OECD countries together with indices of the host countries' technological specialization in terms of R&D in a number of manufacturing industries.

The paper is organized as follows: Determinants of overseas R&D are discussed in section II. Data and variables are introduced in section III, and the econometric method is described in section IV. Empirical results are presented in section V, and the final section concludes.

## II. Determinants of overseas R&D

Three factors which mainly relate to the adaptation motive of overseas R&D have been examined in the literature. First, *production in affiliates* requires overseas R&D to adapt a MNE's products and processes to local conditions. Consequently, overseas R&D to a large extent will be found where overseas production is taking place. Adaptation is pointed to as the most important motive for overseas R&D in the case studies by Ronstadt (1978) and Behrman and Fisher (1980). In the econometric studies by Mansfield, *et al.* (1979), Lall (1980), Hirschey and Caves (1981), and Pearce (1989), who all examine data on US firms, production in foreign affiliates turns out to be the most powerful determinant of overseas R&D. Pearce and Singh (1992), employing a patent based proxy for internationalization of R&D, obtain a positive association between this proxy and the share of production abroad for

European-based MNEs as well. These empirical studies use "share of total R&D undertaken abroad" as the dependent variable in the regressions, and do not separate overseas R&D by host county. Lack of detailed data on the R&D undertaken in different host countries has generally prevented the earlier literature to examine host country determinants.

Second, a positive relationship is expected between *market size of the host country* and overseas R&D. A larger market should provide incentives to perform overseas R&D for the purposes of adapting products and processes to local conditions, which may not be worthwhile in a small host country. Zejan (1990) finds a positive association between the R&D intensity of Swedish foreign affiliates and the host country GDP. It could be argued that market size is already accounted for in a measure of affiliate production since there should be incentives to locate more production to larger countries.[3] Yet, a large market size, given the location of production, may have a separate positive effect on the location of R&D, e.g. to adapt products in view of an expected higher future potential in a larger market.

Third, firms with *more technologically advanced products or processes* should have a greater need to undertake overseas R&D for adaptation. Lall (1980) reports a positive and significant influence of R&D intensity on the share of R&D located abroad for US firms. Empirical analysis of Swedish firms by Zejan (1990) suggests a positive relationship between parent company and affiliate R&D intensity. However, Pearce and Singh (1992), using a patent-based intensity measure and a proxy for overseas R&D, could not verify this result.

In addition to the above factors relating mainly to adaptive R&D, it has been shown that MNEs locate overseas R&D facilities to countries with a highly skilled workforce (Pearce and Singh, 1992). Figures reported in OECD (1994) for Japanese firms and in

[3]For Swedish MNEs, Braunerhjelm and Svensson (1996) found a positive relationship between affiliate production and market size of the host country.

Åkerblom (1994) for Finnish MNEs point in the same direction, although the effect of a skilled workforce on the decision as to where to locate R&D appears to be of second order importance in the Japanese and Finnish firms. We argue that a high skill level should attract technology sourcing R&D as well as adaptive R&D, since firms undertaking both kinds of R&D will need to recruit qualified personnel locally.

Another motive for MNEs to undertake overseas R&D may be to source technology in foreign countries and benefit from localized spillovers. We argue that MNEs can more efficiently appropriate R&D spillovers if they undertake their own R&D near the sources of the spillovers.[4] Two sets of empirical findings support this view:

Knowledge spillovers appear to increase with proximity. Jaffe, *et al.* (1993) compare patent citations with the origins of the cited patents and conclude that citations to domestic patents tend to be domestic, and that citations are more likely to come from the same state within the US as the origin of the patent. Analyzing innovation data across US states, Audretsch and Feldman (1996) find that the propensity for innovative activity to agglomerate spatially is higher in industries where the creation of new knowledge and spillovers is more important. The authors take this as a sign of localized spillovers.

R&D spillovers have also been argued to increase if the potential recipient of the spillover undertakes own R&D. Cohen and Levinthal (1989) propose two functions for R&D: to generate innovations and to absorb spillovers from other firms, and they present evidence for both. Jaffe (1986) concludes that the payoff in terms of patents, profits, or market value to a firm's own R&D is higher in technological areas where there is much R&D undertaken by

[4] Marshall (1920) provides three reasons why industries cluster spatially: a pooled market for labor with specialized knowledge, development of specialized inputs and services, and the possibility to benefit from knowledge spillovers. In a survey of empirical studies, Griliches (1992) concludes that knowledge spillovers are both prevalent and important for economic growth in general.

other firms. Furthermore, Levin, *et al.* (1987) find that independent R&D is the most effective method of "learning" about other firms' products and processes, compared with licensing, patent disclosures, hiring competitors' R&D employees and reverse engineering.

The following hypothesis comes out of the above arguments: MNEs may locate overseas R&D activities to countries that are technologically specialized in their industry in order to benefit from localized spillovers.[5]

From the literature concerning the *location of production* by MNEs, some empirical results have suggested that firms locate production activities to host countries to source technology. Results reported by Kogut and Chang (1991) indicate that Japanese investments in the United States are attracted to industries that are relatively R&D intensive. Cantwell (1989) finds that US and German firms establish production in foreign "centers of excellence" in their respective technological fields. Furthermore, Braunerhjelm and Svensson (1996) present evidence that Swedish MNEs in high-tech industries tend to locate production facilities to industrial clusters abroad. But these studies on the location of production do not evaluate the role of overseas R&D in sourcing technology in host countries, which is the focus of the current paper.

To the best of our knowledge, the only empirical study that systematically addresses the above hypothesis is Cantwell and Hodson (1991).[6] Their findings indicate that the distribution of aggregate overseas R&D across countries is positively related to the overall

[5]Such a knowledge-seeking strategy should potentially benefit the entire MNE, and not merely the units abroad performing the overseas R&D. These units are to be seen as an MNE's interface with technological knowledge in the host country.

[6]A few case studies and descriptive papers also give some support to the view that MNEs locate R&D abroad to source technology. These studies include: Behrman and Fischer (1980), which analyzes selected overseas R&D laboratories of a few major US firms, Håkansson and Nobel (1993), which surveys the 20 largest Swedish MNEs, and OECD (1994), which presents information regarding the motives of overseas R&D in Japanese firms.

pattern of innovation. However, the empirical results were only significant for some countries and periods. Moreover, they did not control for the location of overseas production. This is of major importance, since overseas R&D for adaptation is basically located where overseas production is taking place. Hence, to test if the location of overseas R&D is directly related to host countries' R&D specialization, the location of production must be controlled for.

## III. Data and variables

The firm-level data set used in the estimations has been collected by the Industrial Institute for Economic and Social Research (IUI), of Stockholm, Sweden. All Swedish MNEs in the manufacturing sector having more than 50 employees and at least one majority-owned production affiliate abroad are included. The response rate to the survey exceeds 90%. Information on the firms' production and R&D by host country and data on the MNEs' global operations are included in the data set. Country-specific variables are taken from OECD (1995) and various issues of the *Statistical Yearbook* published by the United Nations. The firm and country data are available for 1978 and 1990 and pooled for these two years to obtain the sample to be analyzed.

The data make it possible to analyze the R&D that takes place in foreign production affiliates in OECD countries. One observation is generated for each location *l* (country outside Sweden) and industry *k* where MNE *j* undertakes production. For Swedish firms only a small part of overseas R&D is undertaken in sales affiliates or "R&D affiliates".[7] In most cases an observation represents an individual foreign affiliate, which commonly corresponds to a single production plant. In the instances where a MNE has more than one affiliate in a

[7] In 1990, the MNEs in the IUI survey had together less than 400 employees classified as "R&D affiliates". Only four large MNEs indicated that they had affiliates solely dealing in R&D.

host country, the data for the MNE's individual affiliates in the country are summarized. Firms that do not perform any R&D in Sweden or abroad are excluded. This is not a serious restriction on the sample size. In 1990, about 20 small MNEs, each with very few establishments abroad, out of the population of 120 MNEs did not record any R&D.[8]

Furthermore, we only include foreign operations established up to ten years prior to the years 1978 and 1990, respectively. This is in accordance with others who have studied the location of economic activities, e.g. Head, *et al.* (1995), who argue that it is likely that there are more unobserved factors behind "older" establishments. The 10-year limitation also implies that no observation occurs twice in the samples, when pooling the data for 1978 and 1990.[9]

With the above constraints applied to the data set, we obtain a sample of 244 observations, of which 107 recorded overseas R&D.[10] The sample contains information on 17 manufacturing industries in 11 OECD countries (see Table A1 in Appendix).[11]

Below we introduce the variables included in the analysis. Table 1 provides a list of the variables and their definitions and sources. Table A2 shows the means of the variables. The dependent variable is:

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[8]The difference in size, in terms of average firm employment, between the following groups of Swedish MNEs is striking; (i) less than 300 employees for firms without R&D, (ii) almost 1.600 for firms only undertaking R&D in Sweden, and (iii) around 11.000 employees for firms recording overseas R&D (Fors and Svensson 1994).

[9]In the empirical analysis we altered the age limitation from 0-5 years to 0-12 years, and obtained basically the same results. Hence, the exact age limit adopted does not appear to have a major impact on the results. An age limit shorter than five years generated a very small sample.

[10]Of the 244 observations, 149 relate to 1990 and 95 to 1978. Of the 107 observations with overseas R&D, 75 relate to 1990 and 32 to 1978.

[11]The 17 industries together comprise the total of manufacturing, with the exception of *Office & Computing Machinery*, *Petroleum Refineries & Products* and *Other Manufacturing not elsewhere classified,* which are relatively unimportant industries in the Swedish MNE context.

***RSHARE***: The share of MNE *j*'s total R&D expenditures performed in industry *k* in country *l*. Since there is a large concentration of zeroes in the sample (the countries where the MNE does not undertake overseas R&D), we also specify a dummy variable;

***RKL***, which takes the value one if MNE *j* undertakes overseas R&D in industry *k* in country *l*, and zero otherwise.

The explanatory variables in the empirical model are the following:

***PROD***: The share of firm *j*'s total value-added accounted for by operations in industry *k* in country *l*. *PROD* captures the overseas R&D geared toward adaptation, and is expected to have a positive influence on the location of overseas R&D. By including *PROD* as a control variable for adaptive R&D, we are able to examine additional motives for undertaking overseas R&D.

***GDP***: The logarithm of the GDP of country *l*, to take account of the size of the host country market.[12] We expect a positive association between overseas R&D and market size, since there should be more incentives to adapt products and processes to a larger market.

***RINT***: The technological intensity of MNE *j*, measured as total R&D expenditures divided by total sales of the entire enterprise. A higher technological intensity is expected to increase the need to undertake overseas R&D for adaptation. *RINT* should be positively related to *RKL*, the decision as to whether to undertake overseas R&D or not, but not necessarily to *RSHARE*, the share of total R&D located to a certain foreign country.

***RSPEC***: The host country's technological specialization index measured by R&D expenditures. *RSPEC* for industry *k* in country *l* is calculated as

[12]We take the logarithm of GDP to facilitate the interpretation of the parameter of this variable in the estimations, since the dependent variable and all other explanatory variables are defined as ratios or shares.

$$RSPEC_{kl} = \frac{RD_{kl} \;/\; \sum_{l} RD_{kl}}{\sum_{k} RD_{kl} \;/\; \sum_{k}\sum_{l} RD_{kl}} \quad ,$$

i.e. country *l*'s share of R&D in industry *k*, divided by country *l*'s share in overall manufacturing R&D. A value exceeding unity indicates that country *l* has a higher technological specialization in industry *k* compared with other countries.[13] As already discussed, MNEs are expected to locate R&D to countries that are technologically specialized.

***RSET***: Relative endowment of high-skilled labor in the host country, defined as the number of researchers, scientists, engineers and technicians per thousand inhabitants in host country *l*. We interpret *RSET* as a proxy for a country's general skill level.

A time dummy is included to control for possible time-specific effects, since the analysis uses a sample based on pooled observations from two years. We know for example that the internationalization of R&D has increased over time. Additive industry dummies are also included in the estimations to take into account of industry-specific effects. To summarize the preceding discussion, we will test the following relationships (expected sign in parentheses):

$$RKL = g[\,(+)PR0D,\ (+)GDP,\ (+)RINT,\ (+)RSPEC,\ (+)RSET]$$

$$RSHARE = h[\,(+)PR0D,\ (+)GDP,\ (+)RSPEC,\ (+)RSET]$$

An additional variable proposed to exert a negative impact on the internationalization of R&D is economies of scale in the R&D function. These may arise from indivisibility of the equipment used and the need for a critical mass of researchers. Unfortunately no such

[13] This index is similar to the one used by Feldman (1994) to measure the agglomeration of innovation across US states.

variable could be included in the present analysis. First, the variable is not directly available.[14] With mixed results, Mansfield, *et al.* (1979) used the absolute size of the firm as an alternative. However, a measure of absolute firm size turns out to be strongly correlated with the variable *PROD* in our data set.

## IV. Econometric method

Since the dependent variable *RSHARE* contains a large share of zeroes (56%), we use a selection bias corrected regression method, see e.g., Fomby, *et al.* (1984, ch. 16). The method enables a separation of the probability and marginal effects of the explanatory variables on the location of overseas R&D.[15] First a Probit function is estimated via maximum likelihood procedures for the overall sample to obtain the probability effect

$$Pr( RKL_{jkl} ) = F( \alpha_0 + \alpha_1 Z_{j'kl} ) \ ,$$

where $F$ denotes the cumulative standard normal distribution and *RKL* takes the value one if *RSHARE* > 0 and zero if *RSHARE* = 0. Hence, $Pr(RKL_{jkl})$ is the probability that MNE $j$ undertakes overseas R&D in industry $k$ in country $l$, given the values of the vector of explanatory variables $Z$. The vector of parameters $\alpha_1$ indicates the influence of the explanatory variables on $F^{-1}[Pr(RKL_{jkl})]$. Based on the Probit estimates, the sample selection correction variable Heckman's lambda, $\lambda_H$, is computed according to

[14] Hirschey and Caves (1981) used average plant size as a proxy for the relative efficient scale of R&D units between industries, and found a negative relationship between efficient scale and share of R&D abroad. As many firms in the present sample have several plants in Sweden (and in some cases even in the same host country) we do not have a good measure of plant size.

[15] Alternatively a Tobit model could have been used; however, the disadvantage with such a model is that the interpretation of the probability and marginal effects is less straight forward.

$$\lambda_{Hjkl} = \frac{f(-\alpha_0 - \alpha_1 Z_{j'kl})}{[1F(-\alpha_0 - \alpha_1 Z_{j'kl})]} \quad ,$$

where *f* is the standard normal density function, and *F* is defined as above. In a second step, OLS is applied to observations with *RSHARE* > 0, with the estimated Heckman's lambda included,

$$RSHARE_{jkl} = \beta_0 + \beta_1 Y_{j'kl} + \gamma \hat{\lambda}_{Hjkl} + \nu_{jkl} \quad ,$$

where the vector *Y* denotes another set of explanatory variables (in the present analysis the same as *Z* with the exception of *RINT*), $\beta_1$ denotes the corresponding parameters showing the marginal effect on *RSHARE,* $\gamma$ is the parameter for Heckman's lambda and $\nu$ is the error term. OLS estimation of (3) yields consistent parameter estimates.

## V. Empirical results

In this section we report the results from the first stage Probit analysis and the second stage Heckman's lambda corrected OLS regressions. To investigate the stability of the results, four different versions of the model are estimated. We also consider an alternative measure of the technological specialization of host countries.

Table 2 reports the results from the Probit estimations with *RKL* as the dependent variable. We see that the share of a MNE's production accounted for by operations in a certain host country, *PROD*, and the R&D intensity of the MNE, *RINT*, are both positively associated with the probability to undertake R&D in a host country. The estimated parameters for *PROD* and *RINT* are positive and significantly different from zero at the 1% level, using a two-tailed t-test. The results are stable across the four versions. The parameters for *RSPEC* and the other explanatory variables are not significantly different from zero. Hence, there is no significant relationship between the probability to undertake R&D in a host country and the technological specialization of that country. Additive time and industry dummies were included in the regressions, but only a few of the industry dummies are significant.

The results from the OLS regression with *RSHARE* as the dependent variable are shown in Table 3. First we note that *PROD* is positive and significantly different from zero at the 5% level. Hence, the higher the share of a firm's production located to a certain host country, the higher the share of the firm's total R&D located to that country. The results from both the Probit and OLS analysis for *PROD* suggest, in accordance with the earlier literature, that adaptation may be an important motive behind undertaking overseas R&D. Host-country market size, measured by *GDP*, turns out not to be significant. This means that we do not find any additional effect of market size on the location of overseas R&D apart from what can be captured by *PROD*. As already noted, *RINT* is not included in the OLS estimations, since the share of total R&D located to a certain country is not expected to be associated with the R&D intensity of the entire MNE.[16]

Turning to the explanatory variable of main interest in this paper, *RSPEC,* the estimated parameter has the expected positive sign in the OLS regression. The results are significant at the 5% level in the first three versions of the regression, and at the 10% level in the last version, and the estimated parameter of *RSPEC* is relatively stable across the different versions. Hence, MNEs appear to locate a larger share of their total R&D expenditures to host countries that are relatively specialized technologically in their particular industries. By use of an interaction dummy variable to take into account possible changes over time, we allowed the slope coefficient for *RSPEC* to vary; however, no significant difference between 1978 and 1990 can be discerned.

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[16] With regard to the identification of the two equations, it is also desirable that not exactly the same set of variables are used to explain the two dependent variables *RKL* and *RSPEC*, respectively.

The general skill level of host countries, *RSET*, is not significant in any estimations. Finally, the correction variable $\lambda_H$ and the industry and time dummies do not turn out to be significant in the OLS regressions.

*RTA as a measure of technological specialization*

To check the estimation results obtained with the R&D-based measure of technological specialization, *RSPEC*, we also use an alternative measure which is based on patents, "Revealed Technological Advantage", *RTA*. This index is calculated in the same way as *RSPEC*, but the number of patents granted in the US is inserted into the formula, instead of R&D expenditures. As the US is an important market for most countries, patents granted in the US can be used as an indicator of innovative capacity (Pearce and Singh, 1992). The data on *RTA* are from Cantwell (1989) and they generate a considerably smaller sample than the one analyzed above, since fewer industries are included. The sample comprises 87 observations, of which 35 recorded overseas R&D.[17]

From Table 4, showing the results from the Probit analysis, it is seen that the results for *PROD* and *RINT* are in line with the earlier estimations. The parameter for *RTA* is not significant when considering the pooled sample of observations from 1978 *and* 1990. However, when we include an interaction dummy for *RTA* for the year 1978, the parameter for *RTA* is positive and significant at the 5% level for 1990.[18] Even if the two samples when

[17] *RTA* was only available as an average for the period 1963-83. This average is used in connection with firm and other country data from 1978 and 1990, respectively. Since the *RTA* indices are rather stable over time (Cantwell 1989), this should not pose a major problem. For example, the Pearson correlation coefficient between *RSPEC*(1978) and *RSPEC*(1990) is as high as 0.80, indicating little change in the countries' positions over a 12-year period when using the R&D-based measure.

[18] In Table 4, we only report the estimation results for the model without *GDP* and *RSET*. Inclusion of these two variables did not change the results, and non of the variables turned out significant.

analyzed using *RSPEC* and *RTA* differ considerably in size and industry coverage, they both point in the same direction, although we only find significant effects with *RTA* for 1990. We do not report the results from the OLS, since no significant results were obtained. This is probably explained in part by the small sample considered in the OLS regression when we use the *RTA* measure.

## VI. Concluding remarks

The empirical evidence from this study first suggest that the location of overseas R&D by Swedish multinational enterprises is motivated to a large extent by the need to adapt products and processes to conditions in the foreign markets where the firms operate. This is consistent with the earlier literature on overseas R&D.

When we control for the factors related to adaptation, we also find that the Swedish firms locate a higher share of their R&D expenditures to host countries which are relatively specialized technologically in their industry. We measure a country's specialization in a particular industry in terms of R&D expenditures relative to other countries. This finding may suggest that one additional motive to locating R&D abroad is to gain access to knowledge in foreign "centers of excellence" and to benefit from localized spillovers.

Hence, it is possible that the foreign affiliates could be seen as a MNE's interface with technological knowledge in host countries. However, in the present analysis we have only established a positive relationship between the share of R&D located to a certain host country and the country's technological specialization. In future work it would be interesting to analyze the effects of this suggested "technology sourcing strategy" on both the parent company and the foreign affiliates performing the overseas R&D. The important question to answer is whether the technology sourced in a host country will benefit the entire MNE, or only the units located in the foreign country.

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TABLE 1. DESCRIPTION OF VARIABLES

| *Variable name* | *Description* | *Source* |
|---|---|---|
| *RSHARE* | Share of firm j's total R&D performed in industry *k* in country *l*, expressed in nominal SEK. | IUI-database |
| *RKL* | *RKL* takes the value 1 if firm *j* undertakes R&D in industry *k* in country *l*, zero otherwise. | IUI-database |
| *PROD* | Share of firm j's total value-added accounted for by operations in industry *k* in country *l*. (Value-added is measured as wages + operating income before depreciation and financial items). Expressed in nominal SEK. | IUI-database |
| *GDP* | log of GDP in country *l*, expressed in constant US dollars. | United Nations |
| *RINT* | R&D intensity of firm *j*, measured as total R&D expenditures divided by total sales, expressed in nominal SEK. | IUI-database |
| *RSPEC* | Index of country *l*'s relative specialization in R&D in industry *k*. *RSPEC* is calculated as country *l*'s share of R&D expenditures in industry *k*, divided by country *l*'s share in overall R&D. (See Table A1 in Appendix for included industries and countries). Calculated from OECD's ANERD PPP US$ R&D data set. | OECD (1995) |
| *RSET* | Researchers, scientists, engineers and technicians per 1.000 inhabitants in country *l*. | United Nations |
| *D78* | Additive dummy 1978. (Reference year: 1990). | |
| *Industry dummies* | Additive industry dummies (see Table A1 in Appendix). | |

TABLE 2. ESTIMATION RESULTS PROBIT. DEPENDENT VARIABLE: *RKL*

| *Explanatory variables* | *(i)* | *(ii)* | *(iii)* | *(iv)* |
|---|---|---|---|---|
| *PROD* | 3.81*** | 3.73*** | 3.73*** | 3.79*** |
| | (0.94) | (0.93) | (0.93) | (0.94) |
| *GDP* | 0.12 | 0.11 | -- | -- |
| | (0.077) | (0.076) | | |
| *RINT* | 24.22*** | 24.01*** | 23.39*** | 23.48*** |
| | (5.91) | (5.87) | (5.81) | (5.83) |
| *RSPEC* | -0.11 | -0.14 | -0.19 | -0.17 |
| | (0.12) | (0.12) | (0.12) | (0.12) |
| *RSET* | -0.082 | -- | -- | -0.065 |
| | (0.078) | | | (0.077) |
| Correct pred. | 71% | 70% | 71% | 70% |
| Number of obs. | 244 | 244 | 244 | 244 |
| Numb. of *RKL*=0 | 137 | 137 | 137 | 137 |

Notes: *** indicates significance at the 1% level, using a two tailed t-test. Standard errors in parentheses. The intercept is allowed to vary across different industries and over time (see Table A1), by use of additive dummy variables. The results are not reported here, but available on request.

TABLE 3. ESTIMATION RESULTS OLS WITH HECKMAN's λ. DEPENDENT VARIABLE: *RSHARE*

| *Explanatory variables* | *(i)* | *(ii)* | *(iii)* | *(iv)* |
|---|---|---|---|---|
| *PROD* | 0.52** | 0.52** | 0.57** | 0.57** |
| | (0.26) | (0.26) | (0.27) | (0.26) |
| *GDP* | 0.0073 | 0.0090 | -- | -- |
| | (0.011) | (0.011) | | |
| *RSPEC* | 0.055** | 0.062** | 0.055** | 0.049* |
| | (0.025) | (0.026) | (0.026) | (0.026) |
| *RSET* | 0.014 | -- | -- | 0.014 |
| | (0.0085) | | | (0.0085) |
| *HECKMAN's* λ | -0.028 | -0.037 | -0.0063 | 0.0025 |
| | (0.066) | (0.068) | (0.069) | (0.067) |
| Adj $R^2$ | 0.30 | 0.31 | 0.31 | 0.31 |
| F-value | 3.44 | 3.59 | 3.75 | 3.62 |
| Number obs. | 107 | 107 | 107 | 107 |

Notes: ** and * indicate significance at the 5 and 10% level, respectively, using a two tailed t-test. Standard errors in parentheses, are White (1980) heteroskedasticity consistent. The intercept is allowed to vary across different industries and over time (see Table A1), by use of additive dummy variables. The results are not reported here, but available on request.

TABLE 4. ESTIMATION RESULTS PROBIT WITH *RTA* AS MEASURE OF TECHNOLOGICAL SPECIALIZATION. DEPENDENT VARIABLE:*RKL*

| *Explanatory variables* | *No interaction dummy for RTA* | *With interaction dummy for RTA Reference group: 1990* |
|---|---|---|
| *PROD* | 3.10* | 3.61** |
| | (1.58) | (1.72) |
| *RINT* | 14.72* | 18.52** |
| | (8.55) | (8.83) |
| *RTA* | 0.59 | 1.49** |
| | (0.48) | (0.68) |
| *RTAxD78* | -- | -2.48** |
| | | (1.18) |
| Correct pred. | 69% | 77% |
| Number of obs. | 87 | 87 |
| Numb. of *RKL*=0 | 52 | 52 |

*Notes*: ** and * indicate significance at the 5 and 10% level, respectively, using a two tailed t-test. Standard errors in parentheses. The intercept is allowed to vary across different industries and over time (see Table A1), by use of additive dummy variables. The results are not reported here, but available on request.

## Appendix

TABLE A1. INDUSTRIES AND COUNTRIES INCLUDED IN SAMPLE
NUMBER OF OBSERVATIONS

| Industries (*k*) | | Countries (*l*) | |
|---|---|---|---|
| Food, Beverages & Tobacco | 5 | France | 24 |
| Textiles, Apparel & Leather | 3 | Italy | 10 |
| Wood products & Furniture | 18 | Netherlands | 18 |
| Paper, Paper prod. & Printing | 25 | Germany (a) | 39 |
| Chemicals excl. Drugs | 26 | Denmark | 28 |
| Drugs & Medicines | 6 | Finland | 22 |
| Rubber & Plastic Products | 13 | United Kingdom | 38 |
| Non-metallic Mineral Prod. | 8 | | |
| Iron & Steel | 10 | Japan | 4 |
| Non-ferrous Metals | 2 | USA | 45 |
| Metal Products | 38 | Canada | 9 |
| Non-electrical Machinery | 52 | Australia | 7 |
| Elec. Mach. excl. Comm Eq. | 21 | | |
| Communication Eq. Radio, TV | 4 | | |
| Motor Vehicles | 8 | | |
| Other Transport Equipment | 1 | | |
| Professional Goods | 4 | | |
| **All industries** | **244** | **All countries** | **244** |

*Note*: (a) Germany in 1978 refers to West Germany.

TABLE A2. MEANS OF VARIABLES

| *Variables* | *PROBIT (n=244)* | *OLS (n=107)* |
|---|---|---|
| *RKL* | 0.44<br>(0.50) | -- |
| *RSHARE* | -- | 0.11<br>(0.17) |
| *PROD* | 0.087<br>(0.12) | 0.12<br>(0.16) |
| *GDP* | 8.39<br>(1.29) | 8.61<br>(1.18) |
| *RINT* | 0.025<br>(0.024) | -- |
| *RSPEC* | 1.14<br>(1.15) | 1.02<br>(0.70) |
| *RSET* | 4.11<br>(1.18) | 4.07<br>(1.18) |
| *HECKMAN's* $\lambda$ | -- | 0.73<br>(0.37) |

*Note*: Standard deviations in parentheses.

TABLE A3. CORRELATION MATRIX FOR SAMPLE USED IN THE PROBIT
PEARSON CORRELATION COEFFICIENTS

| *Variable* | *RKL* | *PROD* | *GDP* | *RINT* | *RSPEC* |
|---|---|---|---|---|---|
| *PROD* | 0.25*** | -- | -- | -- | -- |
| *GDP* | 0.15** | 0.056 | -- | -- | -- |
| *RINT* | 0.24*** | -0.044 | 0.081 | -- | -- |
| *RSPEC* | -0.094 | 0.069 | -0.33*** | -0.063 | -- |
| *RSET* | -0.030 | 0.12 | 0.060 | 0.056 | 0.21*** |

*Notes*: *** and ** indicate significance at the 1 and 5% level, respectively.

TABLE A4. CORRELATION MATRIX FOR SAMPLE USED IN THE OLS
PEARSON CORRELATION COEFFICIENTS

| *Variable* | *RSHARE* | *PROD* | *GDP* | *RSPEC* | *RSET* |
|---|---|---|---|---|---|
| *PROD* | 0.58*** | -- | -- | -- | -- |
| *GDP* | 0.053 | 0.088 | -- | -- | -- |
| *RSPEC* | 0.24** | 0.17* | -0.22** | -- | -- |
| *RSET* | 0.17* | 0.15 | 0.13 | 0.23** | -- |
| $\lambda_H$ | -0.26*** | -0.53*** | -0.31*** | 0.16 | 0.080 |

*Notes*: ***, ** and * indicate significance at the 1, 5 and 10% level, respectively.