TECHNOLOGY, RESOURCE ENDOWMENTS AND INTERNATIONAL COMPETITIVENESS†

by

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Abstract

The paper evaluates the impact of technology together with resource endowments, factor prices and economies of scale on international competitiveness in OECD countries. Knowledge capital stocks are obtained by cumulating R&D expenditure. Results show that competitiveness is determined not only by the R&D activity of the representative firm, but also by total R&D in the domestic industry as well as economy wide stocks of knowledge, indicating the presence of local externalities. Competitiveness is also affected by factor prices and resource endowments as well as scale economies and learning by doing. Further results points to the importance of economies of scale in R&D internal to the firm, of the degree of openness for the capacity to utilize global spillovers and of investment for introduction of embodied technical progress. Finally, the R&D impact is higher in high- and medium- than in low-tech industries.

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1. Introduction

This paper attempts to evaluate the role of technology in combination with domestic resource prices and endowments and economies of scale as determinants of industrial patterns of comparative advantage, international competitiveness and specialization within manufacturing among OECD countries. Thus we attempt to combine two paradigms from trade theory, namely the technology or Ricardian view, and the factor proportions or Heckscher-Ohlin explanations of trade patterns.

Within the large empirical literature on the determinants of patterns of comparative advantage and specialization (for surveys see Deardorff 1984 and Leamer and Levinsohn 1995), most studies treat the role of factor endowments. Technology has been introduced into the empirical analysis of comparative advantage in various ways. Early studies used relative labor productivity data (MacDougall 1951, 1952) to explain countries' specialization. Other studies found R&D intensity, in addition to a set of factor proportions variables, to be positively related to US export performance (Gruber, Metha and Vernon 1967, Stern and Maskus 1981). Variables like product age or income elasticity have been used (Wells 1969, Hufbauer 1970, Finger 1975) to proxy various aspects of technology.

Introducing R&D intensity as a product characteristic, as in these studies, implies that R&D capacity is treated as just another resource. A more satisfactory approach, based on Posner's (1961) concept of technology gaps, is to explain competitiveness in terms of *relative* R&D intensity, where high values are assumed to result in better products and/or more efficient methods. On the macro level, differences in national R&D activity has been shown to influence export growth, i.e. *absolute* advantage, more than traditional measures of price competitiveness (Fagerberg 1988).

There is a growing literature on the role of technology for *comparative* advantage or *relative* international competitiveness, measured on the industry level by (gross) exports, export shares, revealed comparative advantage or net export shares of consumption (for a survey see Verspagen and Wakelin 1997). These studies use various proxies for technology. While R&D expenditure measures the input of resources in the production of new knowledge, patents or total factor productivity growth (TFP) may be proxies for the output.

Dosi, Pavitt and Soete (1990) found that countries' share of the number of patents in a product group was positively related to export shares. In a study by Amable and Verspagen (1995) changes in bilateral market shares among OECD countries were found to be positively related to relative (bilateral) R&D as well as the relative number of patents. Fagerberg (1997) found knowledge achieved by R&D as well as knowledge emerging in other industries and spread via goods' trade to be important for exports in a cross-industry/cross-country study. That relative rates of TFP growth seem to influence changes in comparative advantage has been demonstrated by Wolff (1997) and Gustavsson, Hansson and Lundberg (1997).

Most of these studies, however, do not explicitly include other potentially important variables such as factor endowments.[1] In this paper we want to do a comprehensive evaluation, based on an explicit theoretical model -- developed in order to give some structure to the empirical analysis -- of the role of technology, together with economies of scale and factor prices/factor endowments in combination with factor intensities, for costs, prices and thus for the competitiveness of firms and industries.

In the paper we attempt to evaluate the different sources of technology available to firms, such as learning, the stock of (firm specific) knowledge generated by own R&D cumulated over time, knowledge evolving in the rest of the industry and spread via local externalities, global technology spillovers and technical progress embodied in new capital goods. Moreover, we study if the impact on cost and competitiveness of a given increase in the R&D stock depends on firm size, i.e. if there are economies of scale in R&D internal to the firm,[2] and if the R&D impact differs between high- and low-tech industries.[3]

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[1] Some studies (e.g. Amable and Verspagen 1995 and Fagerberg 1997) introduce variables measuring price competitiveness, such as relative unit labor cost, the performance of which tends to be inferior to the "non-price competitivness" factors such as R&D and investment. However, in our view this is not equivalent to a test of the factor endowments approach.

[2] If the effect on efficiency of a firm's own research increases with the size of the total stock of knowledge in the industry there is a scale effect on the industry level, i.e. external to the firm.

[3] The results of Fagerberg (1997) indicate that the impact of R&D may differ among industries.

The paper is organized as follows. In section 2 we derive the impact of technology on costs, prices and world market shares -- i.e. "revealed" international competitiveness -- starting from a production function and the corresponding cost function.[4] This approach is basically the same as in most studies of the impact of R&D on productivity (for a survey see Griliches 1995). Section 3 describes the data, including the industry and country pattern of the knowledge capital stocks constructed by summing R&D expenditure over time. Section 4 contains the results from the empirical analysis. Section 5 discusses some limitations of the analysis and section 6 concludes.

2. The model

2.1 Factor prices, costs, technology and goods prices

Assume *n* traded goods, *i = 1. . .n*, each produced by N_{ij} firms, $h = 1. . . N_{ij}$, in each of *M* countries, *j = 1. . .M*, with *m* factors of production, *k = 1. . .m*, which are perfectly mobile between sectors but immobile between countries. Each firm sells a differentiated product under monopolistic competition with free entry. For the case of a generalized Cobb-Douglas technology, the production function of firm *h* in industry *i* and country *j* may be written as[5]

$$q_{hij} = A_{hij} \prod_{k=1}^{m} x_{khij}^{\alpha_{ki}} \qquad (2.1.1)$$

where returns to scale is given by

$$\mu_i = \sum_{k=1}^{m} \alpha_{ki} \qquad (2.1.2)$$

Technology in a particular industry is the same for all firms in a certain country and differs across countries only with a shift factor A_{hij} that corresponds to Hicks-neutral

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[4] Regarding the choice of model, we want to set up the simplest framework possible, linking technology, scale and factor prices to competitiveness, using assumptions on supply, demand and market form which are standard in the literature, and containing characteristics which we believe are empirically relevant, such as economies of scale and product differentiation. The model structure resembles the standard model outlined in Helpman and Krugman (1985), part III.

[5] Unless stated otherwise we suppress the time index.

technical change. The elasticities α_{ki} and the scale parameter μ_i are identical across countries.

For the case of perfectly competitive factor markets, we derive the unit cost function dual to the Cobb-Douglas function by cost minimization, following Berndt (1991, p. 68 ff.) to obtain:

$$\ln c_{hij} = \phi_i + \left(\frac{1-\mu_i}{\mu_i}\right)\ln q_{hij} - \mu_i^{-1}\ln A_{hij} + $$
$$+\sum_{k=1}^{m}\mu_i^{-1}\alpha_{ik}\ln w_{kj} \qquad (2.1.3)$$

If all firms in industry *i*, country *j* are identical, they will produce the same output at the same cost; the unit cost function for the industry ($\ln c_{ij}$) is then also given by (2.1.3).

Monopolistic competition with free entry ensures that prices equal unit costs. Consider now a particular country *j* versus the rest of the world *w*. Assume that factor prices are not equalized, that firm size may differ among countries in each industry and that there are no transport costs. The unit cost, and thus the price in all markets, for the *i*:th good produced in *j*, relative to the cost and price of the same good produced in the rest of the world, will then be

$$\ln p_{ij} - \ln p_{iw} = \left(\frac{1-\mu_i}{\mu_i}\right)(\ln q_{hij} - \ln q_{hiw}) - \mu_i^{-1}(\ln A_{hij} - \ln A_{hiw}) +$$
$$+\sum_{k=1}^{m}\mu_i^{-1}\alpha_{ki}(\ln w_{kj} - \ln w_{kw}) \qquad (2.1.4)$$

2.2 Demand

Consumer demand is assumed to be determined by a Spence-Dixit-Stiglitz (S-D-S) utility function, identical for all consumers and all countries. Let products of firms in the *i*:th industry be differentiated in such a way that the elasticity of substitution for any pair of firms -- domestic or foreign -- is the same. Since all firms in the *i*:th industry in a particular country are identical and charge the same price, we may aggregate across firms to obtain the demand for the output of each country in a particular industry. The analysis may then proceed as if products were differentiated only with respect to country of origin ($j = 1 \ldots M$) (Armington 1969). If the products of all firms in the *i*:th industry in country *j* are treated as an aggregate, the S-D-S function gives the utility of the representative consumer as

$$U = \prod_{i=1}^{n} \left(\sum_{j=1}^{M} D_{ij}^{b_i} \right)^{\frac{a_i}{b_i}} \qquad \sum_{i=1}^{n} a_i = 1 \tag{2.2.1}$$

where D_{ij} denotes consumption of the "aggregate product" in the *i*:th industry produced in country *j*.

From (2.2.1) we derive the demand for the *i*:th good produced in country *j* in any market *g*, and thus the imports of good *i* from *j* to *g* (cf. Helpman and Krugman 1985, p. 118 ff.). Demand will depend only on relative price and total income in *g*:

$$D_{ijg} = \frac{p_{ij}^{-\sigma_i}}{\sum_{j=1}^{N} p_{ij}^{1-\sigma_i}} a_i Y_g \qquad \sigma_i > 1 \tag{2.2.2a}$$

where $\sigma_i = 1/(1-b_i)$ is the elasticity of substitution among products in the *i*:th industry. Using the definitions of the CES price-index,

$$\sum_{j=1}^{N} p_{ij}^{1-\sigma_i} = p_{iw}^{1-\sigma} \tag{2.2.2b}$$

expenditure in *g* of good *i* imported from *j* is

$$C_{ijg} = p_{ij} D_{ijg} = \left[\frac{p_{ij}}{p_{iw}} \right]^{1-\sigma_i} a_i Y_g \tag{2.2.2c}$$

where Y_g is aggregate income in *g* and p_{iw} is an aggregate price index for all products in the *i*:th industry (Varian 1992, p. 112).

2.3 The coefficient of specialization

Consider now a particular country's trade with the rest of the world. A measure of international competitiveness, specialization and net exports in the *i*:th industry in country *j* is given by the coefficient of specialization, defined as the ratio of domestic production in the *i*:th industry to domestic consumption of the *i*:th good, including imports:

$$r_{ij} = \frac{Q_{ij}}{C_{ij}} = \frac{C_{ij} + X_{ijw} - X_{iwj}}{C_{ij}} \qquad (2.3.1)$$

where X_{ijw} is the exports of good *i* from country *j*, X_{iwj} is imports and Q_{ij} is gross production; *r* equals the net export ratio plus one.

Inserting (2.2.2c) into (2.3.1), setting $X_{ijw} = C_{ijw}$ and $X_{iwj} = C_{iwj}$, we obtain

$$r_{ij} = \left[\frac{p_{ij}}{p_{iw}}\right]^{1-\sigma_i} [(Y_w / Y_j) + 1] \qquad (2.3.2)$$

Inserting the expression (2.1.4) for the relative price into (2.3.2) and rewriting in log form gives

$$\ln r_{ij} = \ln F_j - \frac{(1-\sigma_i)}{\mu_i}(\ln A_{hij} - \ln A_{hiw}) + \frac{(1-\sigma_i)(1-\mu_i)}{\mu_i}(\ln q_{hij} - \ln q_{hiw})$$
$$+ \frac{(1-\sigma_i)}{\mu_i}\sum_{k=1}^{m} \alpha_{ki}(\ln w_{kj} - \ln w_{kw}) \qquad (2.3.3)$$

where the first term is a country-specific constant. Thus the value of the specialization coefficient for a given country in any good/industry will be low for goods intensively using the country's expensive (and scarce) factors (i.e. factor intensity α_{ki} and factor price w_{kj} are both high), where the country has a productivity disadvantage (A_{hij} is low) and where firms are relatively small (reflecting increasing returns to scale). These mechanisms work through the relative unit cost and price. Moreover, the effect of a given cost difference is larger the higher the elasticity of substitution among products σ_i and the lower the scale elasticity μ_i in the *i*:th industry.

Assuming σ and μ to be constant across industries, and noting that all terms in (2.3.3) with index *w*, i.e. world averages, will appear as industry or country fixed effects (intercept dummies) we may write the corresponding regression equation

$$\ln r_{ij} = \sum_{i=1}^{n} \gamma_{1i} D_i + \sum_{j=1}^{M} \gamma_{2j} D_j + \gamma_3 \ln A_{hij} + \gamma_4 \ln q_{hij} +$$

$$+ \sum_{k=1}^{m} \gamma_{5k} \alpha_{ik} \ln w_{jk} + \varepsilon_{ij} \qquad (2.3.4)$$

where we expect $\gamma_3 > 0$, $\gamma_4 > 0$ and $\gamma_{5k} < 0$ for all factors $k = 1. . .m$.

2.4 Sources of knowledge

2.4.1 The general framework

Superior technology or know-how available to firms in a certain industry in a particular country is introduced in the model in the previous section as a Hicks-neutral shift in the production function, represented in (2.1.1) by A_{hij}. But what are the causes of international differences in the $A_{hij}:s$? How does new knowledge develop and spread? How is international competitiveness affected?

New, economically relevant knowledge available to a firm may come from learning by doing, i.e. efficiency increases over time with experience of production, or it may require that resources are used for R&D within the firm. In addition, knowledge may spread from other firms, either through sales of licenses or in the form of spillover effects through imitation. Since technology is a non-rival good, and at least to some extent non-excludable, the innovator often cannot capture the full value of his invention, and new knowledge will be available to other users. However, utilization of knowledge spillovers is not costless. Studies show that costs of copying technology may be substantial (Cohen and Levinthal 1989, Mowery and Rosenberg 1989). Moreover, own research and skilled personnel may be a necessary condition for receiver capacity.

Technology spillovers may be local or global. There may be spillovers within as well as among industries. The absorption of global spillovers may be positively related to the degree of openness, measured by international trade as proportion of GDP (Coe and Helpman 1995). Finally, some technical progress may be achieved only through investment in new capital goods.

Let us write the level of technology in firm *h* in industry *i*, country *j*, A_{hij} in (2.1.1), as a function of the different sources of knowledge available. Knowledge may be acquired by learning (L_{hij}), produced from the firm's own R&D activity (s_{hij}), or obtained by various spillover mechanisms from research in other firms in the domestic industry (S_{ij}), other sectors in the home country (S_j) or the world market (S_i)[6]. In addition to these sources of disembodied technical change there may also be technical progress embodied in new capital goods (s^e_{hij}):

$$A_{hij} = F(L_{hij}, s_{hij}, S_{ij}, S_j, S_i, s^e_{hij}) \qquad (2.4.1a)$$

Learning by experience from production is usually thought of as proportional to the learning period or to cumulated production of the firm over time (Berndt 1991), thus creating dynamic economies of scale.[7] If learning is spread locally to all firms in the industry -- e.g. if all learning is embodied in the competence of workers that frequently change jobs -- it is the aggregate industry production cumulated over time, $\tilde{q}_{ij}$, that matters:

$$\tilde{q}_{ij} = \sum_{s=t-\tau}^{t} q_{ijs} \qquad (2.4.1b)$$

[6] Note that the impact on A_{hij} of global spillovers may depend on firms' own research as well as the degree of openness of the home economy.

[7] In a study of the semiconductor Irwin and Klenow (1994) discerned significant learning effects. Firms learn most from their own production but learning also spills over between firms in the same country as well as between firms in different countries.

2.4.2 R&D stock per firm or per unit of output?

Let us for the moment neglect spillovers and assume that knowledge generated by R&D is a private good which is totally firm specific and cannot be used elsewhere. Following the standard production function approach (Griliches 1995) we assume that total factor productivity of a firm is determined by the firm's available stock of knowledge (s_{hij}), obtained by cumulating the firm's R&D expenditure over a relevant period of time, and deducting for obsolecence.

In this study, however, we have no access to firm data; all data are industry totals. Thus we have to work with averages for the "representative" firm or product. A commonly used technology indicator (cf. OECD 1986, Griliches 1995) is the R&D intensity, i.e. R&D expenditure as a proportion of value added. We use here the cumulated R&D *stock* of the industry relative to industry value added:

$$s_{hij}^{q} = \frac{S_{ij}}{q_{ij}} \qquad (2.4.2a)$$

This may be appropriate if we think of multi-product firms where R&D expenditure are fixed costs pertaining to individual products, and where output of each product is the same. The relevant concept will then be total industry R&D stock per unit of output in industry *i* in the *j*:th country.

In (2.4.2a), firm size does not matter. However, if the knowledge stock of the firm was equally applicable to all its products, or if we assume single-product firms, R&D expenditure will be a fixed cost at the firm level. If all firms in the *i*:th industry in country *j* were identical, each producing one single product, s_{hij} for the representative firm may be approximated by dividing the cumulated series of aggregated R&D expenditure, i.e. the stock of knowledge, for the *i*:th industry in the *j*:th country by the number of firms:

$$s_{hij}^{N} = \frac{S_{ij}}{N_{ij}} \qquad (2.4.2b)$$

(2.4.2b) implies that if industry R&D stock and output are the same in two countries, the country with fewer and larger firms is expected to have a competitive advantage.

Another way of introducing economies of scale in R&D at the firm level is to add an interaction term to (2.4.2a):

$$\gamma_{32} \ln s_{hij}^{q} + \gamma_{33} (\ln s_{hij}^{q} \ln q_{hij}) \qquad (2.4.2c)$$

The impact on efficiency of increasing industry R&D intensity will then depend on average firm size; we expect $\gamma_{33} > 0$. We will use (2.4.2a) and (b) as alternative variables in the empirical analysis.

2.4.3 Measuring R&D stocks

Stocks of knowledge by industry and country may be calculated from time series of R&D expenditure. Let us assume that technical progress is purely disembodied. Following Hall and Mairesse (1995) we use the formula

$$S_{ijt} = (1 - \delta_S) S_{ijt-1} + R_{ijt-1} \qquad (2.4.3a)$$

where S_{ijt} is the knowledge (R&D) capital stock in industry *i*, country *j*, at the beginning of period *t*, R_{ijt-1} is expenditure on R&D, industry *i*, country *j*, time *t-1* in constant prices and δ_S the rate of depreciation of knowledge, i.e. the rate at which knowledge becomes obsolete. A benchmark S_1 is obtained as

$$S_{ij1} = \frac{R_{ij1}}{g + \delta_S} \qquad (2.4.3b)$$

where *g* is the rate of growth of R&D in the pre-sample period, i.e. up to $t = 1$ (assumed constant over time).

Our first and simplest hypothesis is that competitiveness is determined by learning and the stock of knowledge in the representative firm or per unit of output in the industry:

$$A_{hij} = F(L_{ij}, s_{hij}) \qquad (2.4.4a)$$

Thus in the regression equation (2.3.4) we substitute the expression

$$\gamma_{31} \ln \tilde{q}_{ij} + \gamma_{32} \ln s_{hij} \qquad (2.4.4b)$$

for the technology term $\gamma_3 \ln A_{hij}$, where s_{hij} is measured alternatively by (2.4.2a) or (b), or $\gamma_{32} \ln s_{hij}$ is replaced by (2.4.2c). Additional hypotheses are tested by adding variables to this basic equation.

2.5 Technology spillovers

2.5.1 Knowledge as a local public good: local externalities from R&D

Let us now assume that there is no firm specific, excludable knowledge at all, and that the national stock of knowledge generated by R&D in the industry is shared freely by all domestic firms, i.e. that knowledge is a local public good. This means that there is a positive scale effect of the common R&D effort on the industry level. Then

$$s_{hij} = S_{ij} \qquad (2.5.1a)$$

This requires that there is no duplication of research effort, and that there is a complete national -- but no global -- spillover of knowledge within an industry.

A less extreme case would be obtained by assuming that the stock of knowledge of the firm, and thus its level of technology, may be influenced both by the R&D activity of the firm itself, producing firm specific (excludable) as well as some non-excludable knowledge, and by the total R&D effort of the industry in the *j*:th country, of which some proportion may be treated as a local common good (Grossman and Helpman 1991). Thus the impact on efficiency of a given level of R&D effort of the individual firm may depend on the level of common knowledge, which in turn will be proportional to cumulated R&D expenditure of the industry. We may test the hypothesis of complementarity of private and public knowledge by adding

$$\sum_{g=1}^{2} \gamma_{34g} G_g \ln s_{hij} \qquad (2.5.1b)$$

to the expression (2.4.4b), where the G_g :s are slope dummy variables indicating if the domestic R&D stock in the *i*:th industry is large, medium or small in an international comparison.

Another possibility is that the impact of firms' R&D on competitiveness may reflect differences in the size of the domestic, economy-wide knowledge base, which may be important for the output of the R&D of the firm. To test for this we define the G_g :s in (2.5.1b) as slope dummies for R&D abundant, medium and R&D scarce countries. The criterion used -- total R&D stock in the manufacturing industry -- introduces a scale effect on the economy level.

2.5.2 Global spillovers

There may also be international spillovers of new knowledge, i.e. that firms in a country may make use of knowledge developed by R&D in foreign firms. In the extreme case of perfect global spillovers, competitiveness and specialization would not be affected at all, since the resulting increase in productivity would be the same in all countries. However, countries may differ in their ability to absorb such spillovers. Following Coe and Helpman (1995), we add a variable OP_j, the trade ratio in country *j* -- exports plus imports of goods and services as a proportion of GDP -- to equation (2.4.4b) in order to test the hypothesis that the capacity to absorb a given stock of international common knowledge, and to use it to improve competitiveness, increases with the degree of openness.[8]

2.6 Impact of R&D differing among industries

It is possible that the relative R&D effort of the firm is more important for competitiveness in some sectors than in others. In particular, this might be true for firms competing in "new" product groups -- in the product cycle sense -- where products and processes are continuously changing, compared to more mature industries. Since the former industries should be more R&D intensive than the latter, this hypothesis may be tested by adding

$$\sum_{r=1}^{2} \gamma_{36r} R_r \ln s_{hij} \qquad (2.6.1)$$

[8] The degree of openness may affect a country's capacity to utilize global spillovers in various ways. First, trade is a mechanism through which technological knowledge is transmitted internationally. International trade increases the availability of differentiated intermediate products. New technology is embodied in imported capital goods. Second, international competition forces domestic producers to be informed about and use the internationally best known technology to stay competitive. However, in this study we cannot quantify the relative importance of these factors. Moreover, the trade ratio is an imperfect measure of the capacity to absorb new knowledge, since some technology flows may be unrelated to the exchange of goods and services.

where the R_r :s are slope dummy variables for high, medium and low R&D intensity industries,[9] to equation (2.4.4b).

2.7 *Embodied technical change*

If the level of technology for a given vintage of capital does not change over time, and if machines of later vintages are more efficient than older ones, the average level of technology at a given point in time will depend not only on the knowledge frontier, i.e. the efficiency of the most recent vintages, but also on the age composition of the capital stock, which in turn depends on the time path of gross investment. We will assume here that such technical progress is potentially available globally to all producers, since it is embodied in internationally tradable machinery. Differences among producers with respect to average level of technology will then depend only on the rate of investment.

If the capital/output ratio θ_i in an industry is constant across countries we may write the investment ratio (i.e. investment to value added, neglecting the time index) as a linear function of the rate of growth of the capital stock, $\hat{K}_{ij}$, and the rate of depreciation δ_{Kij} :

$$\frac{I_{ij}}{q_{ij}} = \frac{dK_{ij} + \delta_{Kij} K_{ij}}{q_{ij}} = \frac{dK_{ij}}{K_{ij}} \frac{K_{ij}}{q_{ij}} + \delta_{Kij} \frac{K_{ij}}{q_{ij}} = \theta_i (\hat{K}_{ij} + \delta_{Kij}) \qquad (2.7.1)$$

Thus a high investment ratio indicates either a high rate of growth of the capital stock or a high depreciation rate and thus a short life length of capital. In both cases this implies a low average age of the capital stock, i.e. a high proportion of the most recent vintages and thus a high average level of efficiency. To test this possibility we include the average investment ratio in firm h , industry i, country j , calculated as

$$s^e_{hij} = \frac{1}{\tau} \sum_{v=t-\tau}^{t} \frac{I_{ijv}}{q_{ijv}} \qquad (2.7.2a)$$

This takes account of the differences in average level of investment ratio but not of the time profile of investment. This may be done by introducing capital depreciation:

[9] An explanation for this in terms of our model would be to allow elasticities of substitution and economies of scale to differ among industries (cf. equations 2.3.2a and b), which could be introduced as industry specific slope variables. However, we have not explored the possibilities that the impact of other variables than R&D may also differ among industries.

$$s^{e}_{hij} = \sum_{v=t-\tau}^{t} \frac{I_{ijv}}{q_{ijv}} (1-\delta_{Ki})^{t-v} \qquad (2.7.2b)$$

3. Data and methods

According to equation (2.3.3) countries will specialize on industries intensively using their cheap resources. Our theoretical model is formulated in terms of cost shares of factors and national factor prices. We use factor prices except for natural resources -- arable and forest land -- where only quantities are available. However, some prices (e.g. relative wage for skilled labor) are available only for a limited number of countries. In order to expand the sample we have estimated a second set of equations where we replace prices with factor endowments. It can be shown that in a multi-sector economy in autarky, a country's abundant factors tend to be cheap, i.e. factor prices and endowments are negatively correlated.[10] As shown in *table 1* , factor prices and factor endowments in our sample are in fact negatively correlated.

Table 1 Correlations between factor prices and factor endowments

Surveys of empirical work (e.g. Leamer and Levinsohn 1995 and Deardorff 1984) conclude that supplies of natural resources affect industrial localization, not only of extractive industries but also of processing industries. In addition, both human and physical capital have been found to be important. In principle, one should include resources which are internationally immobile,[11] where endowments and/or prices differ among countries, and requirements (cost shares) differ among industries. In this study, we have included interaction variables measuring *national* prices or quantities, in combination with *industry* requirements, of

- forest land per worker/cost share of roundwood
- arable land per capita/food industry (a dummy)

[10] Formally, this is derived for identical and homothetic demand, perfect competition and identical technology (Ethier 1984, p. 176).

[11] By definition, arable and forest land are perfectly immobile; international trade in roundwood and electrical energy is very low relative to production. International mobility of skilled labor is still rather low, even within the European Single Market. Since financial capital as well as machinery both are highly mobile across countries it may be argued that capital should not be included in a country's (exogeneously given) factor endowments (cf. Wood 1994); we have, however, kept the capital variable.

- relative price of electrical energy or production of electrical energy per worker[12]/cost of electrical energy per employee
- return to capital/capital cost share of value added
- relative earnings of skilled labor or proportion of labor force with post-secondary education/wage costs accruing to workers with post-secondary education as share of value added.

According to our model, cost shares, α_{ki}, will be identical across countries. For some industry characteristics where national data are available we have calculated averages for the countries in the sample. For others - - especially human capital - - only Swedish data were available. A complete description of the data -- definitions and sources -- is given in the Appendix.

In (2.3.3) specialization is affected by relative firm size: the larger the firms, the lower will be costs and prices. We measure representative plant size, q_{hij} in (2.3.4), by the average number of employees per plant.[13]

To calculate knowledge capital stocks we use (2.4.3a) and (2.4.3b). We assume a depreciation rate of knowledge δ_S of 15 percent and a presample growth in R&D expenditure *g* of 6 percent (cf. Hall and Mairesse 1995). We also assume that investment in research add to the stock of productive knowledge capital with a lag of three years.[14] We have calculated knowledge capital stocks for 22 manufacturing industries in 13 OECD countries. *Table 2* reports average knowledge stocks as a share of value added (knowledge intensity) on industry level and classify industries into high, medium and low technology industries. *Table 3* shows total knowledge capital in manufactures in each country both in absolute terms and as a share of value added.

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[12] A country's production of electrical energy may be treated as a "natural" resource to the extent that it is based on hydroelectric power. However, energy-intensive production, while historically based on cost advantages of abundant and cheap hydroelectric capacity, may over time acquire a technological advantage that creates the base for future competitiveness. This may lead to investment in "non-natural" energy production capacity such as nuclear power. Thus the causal interpretation of a correlation between energy production and the size of the energy-intensive industry sector may be ambiguous.

[13] Measuring size with output per plant or employees per plant is a matter of definition. The equations have been re-estimated with the former definition, giving basically the same results.

[14] According to a study by the U.S. Bureau of Labor Statistics (1989) the mean lag for basic research appears to be five years and two years for applied research.

Table 3 also divides the countries into groups with large, medium and small knowledge capital stock.

Table 2 Knowledge capital stock in percent of value added by industry in 13 OECD countries 1990.

Table 3 Knowledge capital stock in manufacturing in 13 OECD countries 1990.

It appears from *table 2* that there are significant variations in technology levels among manufacturing industries. The average knowledge intensity is only about 2 percent of value added in Wood & furniture, whereas it is more than 100 percent in Aircraft. Though small countries, such as Sweden and Norway, have the highest knowledge intensity in certain industries, it is evident from *table 3* that the bulk, in absolute terms, of OECD's knowledge stock in manufacturing -- almost 80 percent -- is concentrated to the US, Japan and Germany. The US also tops the ranking in relative terms, i.e. in percent of value added in manufactures.

4. Results

The econometric results in *table 4* support the general hypothesis that firms' R&D efforts, by creating technology gaps, improve their competitive position. As shown in columns (i) and (v), average R&D stock per plant is positive and significant, even if complications such as scale economies or externalities in R&D, as well as differences in the importance of technology among industries, are neglected. Substituting the variable R&D stock per unit of output for R&D stock per plant (columns (iii) and (vii)) does not change this conclusion, [15] though the R&D effect appears to be slightly less significant. Our results thus are in line with numerous studies of the impact of R&D on productivity and growth (for a survey see Griliches 1995) as well as with earlier studies of R&D and competitiveness (Fagerberg 1997, Amable and Verspagen 1995).

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[15] This indicates that the measurement problems with the variable number of plants (cf. below), and thus the potential errors in measuring R&D stock per plant, may not be important enough to affect the main conclusions.

Table 4 Determinants of international specialization in 22 manufacturing industries and 12 OECD countries

However, R&D is not the only factor influencing competitiveness. First, factor prices affect specialization, thus confirming the predictions from our model. Columns (i) to (iii) in *table 4* show that countries where energy and capital are cheap tend to specialize on industries using these factors intensively. For skilled labor the coefficient has the right sign but is not significant. [16]

In columns (v) to (vii) we have replaced national prices of skilled labor and electrical energy with the corresponding endowment quantities (cf. section 3 and Appendix), thereby extending the sample. The expected sign of the factor requirements/endowments interaction variables is positive. The coefficients for arable and forest land as well as for energy and capital[17] are strongly significant[18], whereas the coefficient for skilled labor becomes weakly significant, all with the ”right” sign. Our results are thus broadly in line with the findings in most of the empirical literature explaining international specialization based on the Heckscher-Ohlin paradigm (for surveys see Deardorff 1984 and Leamer and Levinsohn 1995), namely that countries tend to specialize on industries intensively using their cheap and/or abundant factors of production.

The conclusion that factor prices/endowments should be included in a comprehensive model of international specialization is stressed by the results in columns (iv) and (viii), where these variables have been left out. The coefficient for the R&D variable increases, and the explanatory value of the regression falls by 10 to 15 percentage points. Thus the importance of R&D might be overstated if factor prices/endowments are not included in the analysis.

[16] One possible explanation is that the measure of skilled labor -- proportion of workers with post-secondary technical/scientific education -- is positively correlated with the R&D-variables (correlations 0.6 to 0.7). Moreover, the country variation in human capital endowments is rather limited in the sample, since OECD countries with the lowest educational standards are generally excluded because of missing data.

[17] Note that the capital variable is still calculated using capital price, as in (i)-(iv), so the expected coefficient is negative.

[18] The difference between column (v) where arable land is strongly significant and column (i) where it is not is that in the latter Australia and Denmark had to be excluded because of missing data. The variables measuring arable and forest land as well as capital are the same in all regressions in table 4.

Second, fixed country and industry effects are strongly significant. Thus competitiveness depends in addition on a number of country and/or industry characteristics not captured by our variables. One source of such fixed effects are the existence of trade surpluses/deficits in manufacturing in some countries, as well as surpluses/deficits of the country group as a whole in some products. Moreover, according to our theoretical model in section 2 fixed country and industry effects should influence the result (cf. 2.3.3).

Third, there is evidence for the existence of (static) economies of scale on the plant level in production, as well as of dynamic scale effects (on the industry level) from learning. However, since these variables -- firm size and cumulated production -- are likely to be less reliable measures of the corresponding theoretical concepts than other data,[19] one should not overstress these findings. We have re-estimated all equations without these two variables; this increases the significance of the other variables in general, and of R&D in particular, but does not upset the conclusions.

Tests indicate that heteroskedasticity is likely to be present in most of the equations; thus we report *t* statistics estimated both by OLS and by White's heteroskedasticity consistent method. These *t* values differ somewhat, but the main conclusions remain. Nor are the results strongly dependent on a limited number of observations with extreme values of the variables. In most cases, robust regressions in columns (ii) and (vi), where such observations are given lower weight, do not change the coefficients nor the *t* values very much. The estimated R&D coefficients for the R&D impact remain virtually unchanged. This holds also for the results in *table 5*, where the robust regression results are not shown.

Table 5 Testing additional R&D hypotheses. Estimates of the partial effect of specialization of additional technology variables.

Having estimated the "basic" equations in *table 4*, we examine a number of additional hypotheses discussed in section 2 by adding new variables. In *table 5* we report only the

[19] National data on number of plants do not use the same definitions. While e.g. Canada surveys all plants, Sweden includes only plants with more than five employees and Germany plants belonging to firms with

coefficients for those variables that have been *added* to the basic equations (v) and (vii) in *table 4* in order to test additional hypotheses.[20] Since the relevant variables are strongly correlated we do not include them all together in the same regression.[21] All other variables, i.e. country and industry dummies, factor endowments and measures of scale and learning effects, are included as in columns (v) and (vii) in *table 4* but not reported; the results for these variables do not differ much from those reported in *table 4*.

The first row tests for the existence of economies of scale in R&D on the firm/plant level (as distinct from general effects of firm or plant size) by including an interaction variable combining the effect of industry R&D intensity (R&D stock relative to value added) with average plant size (expression 2.4.2c). The coefficient for this variable is positive and significant,[22] thus supporting the hypothesis that the impact of a given R&D stock per unit of output may be higher for countries with large firms. Our interpretation is that this highlights the role of R&D as a fixed cost at the firm level.

Mansfield et al. (1977), Scherer (1982) and others have shown that social returns on R&D strongly exceeded private returns, which implies that spillovers may be important for productivity growth. Such spillovers may be local or global. The second row in *table 5* supports the idea of domestic within-industry spillovers. The impact of firms' own research on competitiveness seems to increase with the size of the total domestic knowledge stock in the industry.[23] This holds when s_{hij} is defined as R&D stock relative to value added, but not for R&D per plant.

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more than 20 workers. This introduces measurement errors in the variables plant size (workers per plant) and R&D stock per representative firm (industry R&D stock divided by the number of firms).

[20] Since the choice between factor prices or factor quantities does not seem to matter much for the basic results, we have used the latter version, in order to increase the sample size (cf. above).

[21] We do not test simultaneously for industry and country slope dummies, interaction effects, etc. In other words we do not test for, e.g. the presence of externalities, taking account of economies of scale and varying R&D impact. Since we do not discriminate between alternative "models" as expressed in regression equations containing different R&D variables, we present no single "preferred equation".

[22] Note that the variables R&D stock per firm and firm size remain in the equation.

[23] Assuming spillovers to follow input flows, Fagerberg (1997) found national spillovers to be more important than global.

The absolute importance of global spillovers cannot be estimated in this paper.[24] However, the results in rows 2 and 3 of *table 5* indicate that - - given the amount of globally available common knowledge - - a country's capacity to absorb such knowledge and to use it to improve its competitiveness may increase with the degree of openness, thus confirming the results of Coe and Helpman (1995).

Local spillovers may be economy-wide rather than within-industry. Row 3 in *table 5* shows the results of a regression where the R&D slope dummy is based on the size of the total national R&D stock in manufacturing, rather than the stock in each industry. The results are basically the same: the impact of a given R&D stock per plant, as well as of a given R&D intensity in the industry, seems to be larger in countries with a large common stock of locally available knowledge. This is in line with the findings of Bernstein and Nadiri (1989) that local spillover effects on productivity may extend over industry boundaries. In fact, data give a slightly stronger support for the the economy-wide rather than the intra-industry effects. However, the results also indicate that this implicit handicap for small countries may be mitigated by openness.

Row 4 in *table 5* indicates that the impact of technology on competitiveness differs among high-tech, medium and low-tech industries.[25] The coefficient for R&D stock per firm is positive and significant for high and medium technology industries, but very low and insignificant for the low-technology sector, where competitiveness more may be a matter of factors such as wage costs. Still, the group for which "technology matters" covers more than the "traditional high-tech" group.

The last two rows of *table 5* support the hypothesis that technical progress influencing competitiveness may be both disembodied and embodied in new capital goods. The first component depends (disregarding spillovers) only on average R&D stock per plant or per unit of output. If the "frontier" technology is embodied in new machinery which is internationally freely traded, the average efficiency of a producer's capital stock relative to competitors depends only on the investment ratio in the previous period (and possibly also on the time path of investment during that period). *Table 5* shows both components

[24] Since commonly shared spillovers do not affect competitiveness.
[25] The classification is based on average R&D stock in per cent of value added as shown in *table 2*.

of technical progress -- disembodied and embodied -- to have positive and significant effects on competitiveness.

5. Limitations of the analysis

In our model, R&D activity is exogenously given. Thus we neglect a basic issue in modern growth theory, namely intentional (endogeneous) innovation in response to profit opportunities (Grossman and Helpman 1991). It is therefore important to be careful when making causal interpretations of the results. A related econometric point is the issue of simultaneity bias, i.e. if competitiveness also affects R&D. Unfortunately, good instruments are lacking. However, since competitiveness in 1990 in the model depends on cumulated R&D expenditure during a previous 15 year period, simultaneity should not present a serious problem.

Moreover, factor endowments are also assumed to be given. In a more realistic model, endowments of e.g. capital -- both human and physical -- are the results of investment decisions determined by expected rates of return. Since these accumulation processes may be interrelated (if e.g. some factors are strongly complementary), caution in causal interpretation is again required.

In section 2 we attempt to model the impact of what is basically process innovations via costs on competitiveness. The model does not explicitly treat product innovations. Nevertheless, it seems obvious that new and improved products, by shifting consumer demand among firms, increases competitiveness and therefore should be captured by the R&D variables in the empirical analysis.

Our analysis of e.g. economies of scale in R&D is limited by the lack of firm data on R&D and sales; we can only work with industry averages. Moreover, we do not explicitly take account of differences among industries in elasticities of substitution among products or the extent of economies of scale. Finally we avoid the complications involved in modelling the dynamic interactions between R&D activity, operating technology and market shares that becomes necessary in a pooled time series cross-section analysis using annual data.

6. Conclusions: a choice among paradigms?

The results in this paper show that technology has a significant effect on international competitiveness. But so have factor prices and endowments. Our conclusion is thus that in order to explain countries' comparative advantages and patterns of international specialization it is necessary to combine elements from both competing paradigms -- the factor endowments or Heckscher-Ohlin and the technology or Ricardian -- rather than to substitute one for the other.

Firms' R&D activity is important for international competitiveness. However, the process of acquiring a technological advantage seems to be rather complicated, and involve other factors than the firm's own R&D intensity. Our results indicate that R&D may be treated as a fixed cost, and thus that there are economies of scale in research on the firm (plant) level. In addition there seems to be scale effects on the domestic industry as well as on the national level, which are caused by local externalities/spillovers. This means that size matters on all levels. To some extent, this size handicap for small countries might be mitigated by openness to trade. It appears that R&D as a factor shaping competitiveness is really crucial mainly for high and medium technology sectors. Finally, technological progress seems to be both embodied and disembodied, which means that acquiring technical leadership requires not only intensive research activity but also a high rate of investment.

Appendix Variables: definitions, measurement and sources

Coefficient of specialization:

$$r_{ij} = \frac{Q_{ij}}{C_{ij}} = \frac{Q_{ij}}{Q_{ij} + X_{iwj} - X_{ijw}}$$

Q_{ij} production (gross output), industry *i*, country *j*, average 1989-91.

C_{ij} consumption, industry *i*, country *j*, average 1989-91.

X_{iwj} import, industry *i*, from the whole world *w* to country *j*, average 1989-91.

X_{ijw} export, industry *i*, from country *j* to the whole world *w*, average 1989-91. Source: OECD (1994b).

Knowledge capital stock:[26]

$$S_{ijt} = (1 - \delta_S) S_{ijt-1} + R_{ijt-1}$$

S_{ij} knowledge capital (R&D) stock, industry *i*, country *j*, 1990, US dollar 1985 PPP, 1985 prices.

R_{ijt} expenditure on R&D, industry *i*, country *j*, 1973-87, US dollar 1985 PPP, 1985 prices. R&D expenditures R_{ijt} are deflated by the manufacturing sector value added deflator. Source: OECD (1996a) and OECD (1994b).

δ_S depreciation rate of knowledge.

Firm specific knowledge stock: $s^N_{hij} = S_{ij} / N_{ij}$ or $s^q_{hij} = S_{ij} / q_{ij}$

N_{ij} number of establishments, industry *i*, country *j*, 1990. Source: OECD (1995b).

q_{ij} value added, industry *i*, country *j*, 1990, US dollar 1985 PPP, 1985 prices. Source: OECD (1994b).

Embodied technology:[27]

$$s^e_{hij} = \frac{1}{\tau} \sum_{v=t-\tau}^{t} \frac{I_{ijv}}{q^*_{ijv}} \text{ or } s^e_{hij} = \sum_{v=t-\tau}^{t} \left(1 - \delta^K_i\right)^{t-v} \frac{I_{ijv}}{q^*_{ijv}}$$

δ_{Ki} rate of depreciation of physical capital, industry *i*. Source: Hansson (1991).

I_{ijv} gross fixed capital formation, current prices, industry *i*, country *j*, 1976-90. Source: OECD (1994b)

q^*_{ijv} value added, current prices, industry *i*, country *j*, 1976-90. Source: OECD (1994b)

τ 15 years

Plant size: $q_{hij} = L_{ij} / N_{ij}$

L_{ij} number of employees, industry *i*, country *j*, 1990. Source: OECD (1994b).

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[26] Three observations were deleted because calculated R&D expenditure as a share of value added were extremely high (close to or larger than one), namely Australia (ISIC 3832), Denmark (ISIC 39), and the Netherlands (ISIC 383–3832).

[27] The extreme value of refineries (ISIC 353+354) in Norway has been excluded.

Cumulated production: $\tilde{q}_{ij} = \sum_{s=t-\tau}^{t} q_{ijs}$

q_{ijs} value added, industry *i*, country *j*, 1970-89, US dollar 1985 PPP, 1985 prices. Source: OECD (1994b).

Physical capital: $\alpha_{Ki} \ln w_{Kj}$

α_{Ki} share of operating surplus in value added , industry *i*, average for all countries *j* in the period 1980-90. Source: OECD (1994b).

w_{Kj} return to physical capital calculated as average operating surplus in manufacturing 1980-90 relative to the manufacturing capital stock 1985.

$$w_{kj} = \frac{\sum_{t=1980}^{1990} (Y_{jt} - W_{jt}) / 11}{K_{j85}}$$

Y_{jt} value added in manufacturing, country *j*, 1985 prices. Source: OECD (1994b).

W_{jt} labor compensation in manufacturing, country *j*, 1985 prices. Source: OECD (1994b).

K_{j85} capital stock in manufacturing, country *j*, 1985 prices. Source: OECD (1993).

Skilled labor: $\alpha_{Hi} \ln w_{Hj}$ and $\alpha_{Hi} \ln h_j$

$$\alpha_{Hi} = \sum_{j=1}^{12} \left(\alpha_{Lij} \left(W_i^S / W_i \right) \right) / 12$$

α_{Hi} share of skilled labor compensation in value added , industry *i*, average for 12 countries in the period 1980-90.

α_{Lij} share of wages in value added, industry *i*, country *j*, average 1980-90. Source: OECD (1994b).

W_i^s compensation to employees with post-secondary education, industry *i*, Sweden, 1990. Source: SCB Regional Labor Statistics.

W_i total labor compensation, industry *i*, Sweden, 1990. Source: SCB Regional Labor Statistics.

w_{Hj} relative wage of skilled labor: ratio of mean annual earnings by educational qualifications (level B/ level E), country *j*, middle of the 1980s. Source: OECD (1996b)

h_j number of graduates in science and engineering per 100,000 of population aged 25-35, country *j*, 1991. Source: OECD (1994a).

Energy: $\alpha_{Ei} \ln w_{Ej}$ and $\alpha_{Ei} \ln e_j$

α_{Ei} cost of electrical energy SEK per employee, industry *i*, Sweden, 1989. Source: SOS Manufacturing 1989.

w_{Ej} relative price of electrical energy, country *j*. Price of electrical energy for industrial users. Source: National Utility Services. Labor costs per hour in manufacturing. Source: Swedish Employers Federation (SAF).

e_j production of electrical energy kWh per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Forest land: $\alpha_{Ti} \ln t_j$

α_{Ti} input of roundwood SEK per 10 000 SEK output, industry *i*, Sweden, 1985. Source: SCB (1992).

t_j hectare forest land per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Arable land: $\alpha_{Ai} \ln a_j$

α_{Ai} dummy variable for industry 31 (food)

a_j hectare arable land per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Openness:

$$OP_j = \left(\frac{X + M}{Y}\right)_j \quad \text{(average 1980-89)}$$

X_j export of goods and services from country *j*

M_j import of goods and services to country *j*

Y_j GDP in country *j*

Source: OECD (1995c)

Factor prices, country coverage:

Data were available for return to capital for all 13 countries in table 3, for relative earnings of skilled labor for all except Finland, and for energy prices for all except Australia, Denmark and Japan.

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Table 1 Correlations between factor prices and factor endowments

Factor of production	Correlation
Physical capital	–0.63 (0.02)
Human capital	–0.54 (0.10)
Electrical energy	–0.64 (0.03)

Parentheses ( ) give the significance level of correlation

Table 2 Knowledge capital stock in percent of value added on industry level in 13 OECD countries 1990

ISIC	Industry	Technology level	Mean	Coefficient of variation
31	Food	Low	5.49	0.54
32	Textiles and clothing	Low	3.89	0.59
33	Wood and furniture	Low	1.97	0.71
34	Paper and printing	Low	3.03	0.88
351+352–3522	Chemicals	Medium	36.20	0.46
3522	Pharmaceutical	High	85.22	0.44
353+354	Refineries	Medium	22.49	1.05
355+356	Plastic and rubber	Medium	12.39	0.55
36	Stone, clay and glass	Low	8.89	0.62
371	Ferrous metals	Medium	13.09	0.61
372	Non-ferrous metals	Medium	16.22	0.75
381	Metal products	Low	6.68	0.58
382–3825	Other machinery	Medium	20.85	0.50
3825	Computers	High	81.88	0.69
383–3832	Electrical machinery	High	44.78	0.83
3832	Electronics	High	97.94	0.47
3841	Shipyards	Medium	12.85	0.75
3843	Motor vehicles	High	39.97	0.71
3845	Aircraft	High	117.42	0.74
3842+3844+3849	Other transport	Medium	28.04	1.17
385	Instruments	High	48.99	1.11
39	Other manufacturing	Low	7.24	0.56

Table 3 Knowledge capital stock in manufactures in 13 OECD countries 1990

Country	Knowledge capital stock		
	Value (Billion USD PPP 1985 prices)		Share of value added (Percent)
Australia	3.47	Small	9.17
Canada	10.47	Medium	15.04
Denmark	1.97	Small	17.67
Finland	2.39	Small	16.24
France[1]	48.78	Large/Medium	28.34
Germany	85.11	Large	28.85
Italy	19.98	Medium	10.17
Japan	126.73	Large	22.60
The Netherlands	10.35	Medium	29.76
Norway	1.77	Small	25.27
Sweden	9.65	Medium	39.59
United Kingdom	50.38	Large	30.01
United States	420.79	Large	47.00

[1] France is not included in the regression analysis

Table 4 Determinants of international specialization in 22 manufacturing industries and 7 or 12 OECD countries 1989-91

Variable	Factor prices 7 countries*				Factor endowments 12 countries**			
	(i) OLS	(ii) Robust	(iii) OLS	(iv) OLS	(v) OLS	(vi) Robust	(vii) OLS	(viii) OLS
$\ln s^N_{hij}$ R&D/plant	0.03 (1.75) [2.29]	0.03 (1.60)	-	0.05 (1.99) [2.22]	0.04 (2.45) [2.46]	0.04 (2.25)		0.06 (2.88) [3.04]
$\ln s^q_{hij}$ R&D/output	-	-	0.03 (1.59) [2.11]	-	-	-	0.04 (2.31) [2.38]	-
$\ln \tilde{q}_{ij}$ Learning	0.21 (6.06) [5.95]	0.21 (6.04)	0.22 (6.54) [6.39]	0.21 (5.45) [4.60]	0.21 (7.71) [7.05]	0.20 (7.91)	0.22 (8.24) [7.66]	0.24 (7.93) [6.72]
$\ln q_{hij}$ Plant size	0.11 (2.52) [3.36]	0.09 (2.14)	0.13 (3.58) [4.60]	0.12 (2.31) [2.91]	0.12 (3.25) [2.73]	0.12 (3.32)	0.16 (4.75) [4.02]	0.13 (3.07) [2.78]
$\alpha_{Ki} \ln w_{Kj}$ Capital	−12.13 (−3.38) [−4.30]	−13.01 (−3.60)	−12.17 (−3.38) [−4.49]	-	−6.32 (−2.85) [−2.70]	−4.96 (−2.36)	−6.49 (−2.92) [−2.79]	-
$\alpha_{Hi} \ln w_{Hj}$ $\alpha_{Hi} \ln h_j$ Skilled labor†	−1.97 (−1.29) [−1.41]	−1.89 (−1.23)	−2.05 (−1.34) [−1.45]	-	0.86 (1.73) [1.64]	0.47 (1.00)	0.85 (1.70) [1.60]	-
$\alpha_{Ei} \ln w_{Ej}$ $\alpha_{Ei} \ln e_j$ Energy†	-1.59×10^{-6} (−4.68) [−5.58]	-1.65×10^{-6} (−4.83)	-1.63×10^{-6} (−4.77) [−5.67]	-	9.82×10^{-6} (5.65) [6.31]	8.91×10^{-6} (5.43)	9.87×10^{-6} (5.67) [6.41]	-
$\alpha_{Ti} \ln t_j$ Forest land	3.92×10^{-6} (3.99) [6.46]	3.75×10^{-6} (3.80)	3.91×10^{-6} (3.97) [6.33]	-	2.83×10^{-6} (2.98) [3.56]	2.97×10^{-6} (3.32)	2.84×10^{-6} (2.99) [3.56]	-
$\alpha_{Ai} \ln a_j$ Arable land	0.05 (0.75) [0.95]	0.01 (0.23)	0.05 (0.73) [0.95]	-	0.09 (1.74) [3.30]	0.07 (1.58)	0.09 (1.77) [3.43]	-
Constant	−6.27	−6.14	−6.14	−6.70	−7.43	−6.54	−7.16	−6.97
F Country effects	16.39 /0.00/	9.08 /0.00/	16.60 /0.00/	6.81 /0.00/	16.20 /0.00/	16.59 /0.00/	16.01 /0.00/	9.86 /0.00/
F Industry effects	13.19 /0.00/	6.64 /0.00/	13.32 /0.00/	11.16 /0.00/	13.63 /0.00/	9.38 /0.00/	13.66 /0.00/	11.89 /0.00/
$\bar{R}^2$	0.74		0.74	0.59	0.66		0.66	0.56
F	12.52	12.19	12.44	7.92	12.76	12.62	12.71	9.82
Observations	144	144	144	144	247	247	247	247

Parentheses ( ) give OLS *t* statistics, square brackets [ ] White's (1980) heteroskedasticity-consistent *t* statistics and slashes / / the significance level of the F-test.

* The 7 countries are Canada, Germany, the Netherlands, Norway, Sweden, the United Kingdom and the United States.

** The 12 countries are Australia, Canada, Denmark, Finland, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom and the United States.

† In specification (i)-(iv) we use national prices, i.e. $\alpha_{Hi} \ln w_{Hj}$ and $\alpha_{Ei} \ln w_{Ej}$, and in (v) - (vii) national endowments, i.e. $\alpha_{Hi} \ln h_j$ and $\alpha_{Ei} \ln e_j$, for skilled labor and energy.

Table 5 Testing additional R&D hypotheses. Estimates of the partial effect on specialization of additional technology variables

Row	Hypothesis/variable	s_{hij}^{N}	$\overline{R}^2$	s_{hij}^{q}	$\overline{R}^2$
1	Scale economies in R&D $\ln s_{hij}^{q} \ln q_{hij}$	-	-	0.036 (3.02) [2.75]	0.669
2	Domestic R&D spillovers within industries				
	$\ln s_{hij}$ (S_{ij} large)	0.046 (2.46) [2.50]	0.656	0.087 (3.32) [3.70]	0.662
	$\ln s_{hij}$ (S_{ij} medium)	0.042 (2.16) [2.17]		0.052 (2.45) [2.70]	
	$\ln s_{hij}$ (S_{ij} small)	0.045 (2.16) [2.19]		0.037 (1.96) [1.98]	
	International R&D spillovers				
	$\ln OP_j$	0.009 (5.08) [5.62]		0.008 (4.61) [4.87]	
3	Domestic R&D spillovers				
	$\ln s_{hij}$ (S_j large)	0.065 (3.02) [3.27]	0.659	0.093 (3.63) [4.26]	0.666
	$\ln s_{hij}$ (S_j medium)	0.037 (1.84) [1.93]		0.032 (1.41) [1.62]	
	$\ln s_{hij}$ (S_j small)	0.039 (1.68) [1.49]		0.021 (0.86) [0.74]	
	International R&D spillovers				
	$\ln OP_j$	0.011 (4.10) [5.36]		0.006 (3.32) [3.32]	

Table 5 (continued)

Row	Hypothesis/variable	s^N_{hij}	$\bar{R}^2$	s^q_{hij}	$\bar{R}^2$
4	Industry specific R&D impact				
	$\ln s_{hij}$ high	0.059	0.662	0.047	0.652
		(2.64)		(1.79)	
		[2.54]		[1.67]	
	$\ln s_{hij}$ medium	0.049		0.044	
		(2.14)		(1.54)	
		[2.14]		[1.54]	
	$\ln s_{hij}$ low	–0.012		0.031	
		(–0.40)		(0.89)	
		[–0.45]		[1.16]	
5a	Embodied and disembodied knowledge				
	$\ln s^e_{hij}$ (2.7.2a)	0.171	0.674	0.162	0.672
		(3.58)		(3.36)	
		[4.17]		[3.90]	
	$\ln s_{hij}$	0.037		0.031	
		(2.01)		(1.64)	
		[2.23]		[1.90]	
5b	$\ln s^e_{hij}$ (2.7.2b)	0.155	0.671	0.146	0.669
		(3.34)		(3.11)	
		[3.78]		[3.50]	
	$\ln s_{hij}$	0.039		0.033	
		(2.12)		(1.78)	
		[2.39]		[2.09]	

Parentheses ( ) give OLS *t* statistics and square brackets [ ] White's (1980) heteroskedasticity-consistent *t* statistics. The number of observations is 247 except in row 5a and 5b where it is 233.