TECHNOLOGY, RESOURCE ENDOWMENTS AND INTERNATIONAL COMPETITIVENESS[1]

By

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Abstract

The paper evaluates the impact of technology together with resource endowments 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 the size of domestic industry as well as economy wide stocks of knowledge, indicating the presence of local externalities. Further results points to the importance of economies of scale in R&D internal to the firm and of investment for introduction of embodied technical progress. Finally, the R&D impact differs between high- and low-tech industries as well as among countries.

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1. Introduction

This paper attempts to evaluate the role of technology in combination with resource 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 changes in trade patterns.

Within the large empirical literature on the determinants of patterns of comparative advantage and specialization (for surveys see Deardorff 1984 and Leamer 1994), 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 & Vernon 1967, Stern & 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 & Wakelin 1996). These studies use different 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 & 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 & 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 (1996) 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 (1996) and Gustavsson, Hansson & Lundberg (1996).

Most of these studies, however, do not explicitly include other potentially important variables such as factor endowments.[2] 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, 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,[3] and if the R&D impact differs between high- and low-tech industries[4] as well as among countries.

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[2] Some studies (e.g. Amable & Verspagen 1995 and Fagerberg 1996) 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.

[3] 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.

[4] The results of Fagerberg (1996) 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. This approach is basically the same as in most studies of the impact of R&D on productivity and meets with the same problems (for a survey see Griliches 1995). Section 3 describes the data, including 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 $\mathbf{N}_{ij}$ firms, $h = 1. . . \mathbf{N}_{ij}$, 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]

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

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 $\mathbf{A}_{hij}$ that corresponds to Hicks-neutral technical change. The elasticities α_{ki} and the scale parameter μ_i are identical across countries.

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

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:

$$\ln \mathbf{c}_{hij} = \phi_i + \left(\frac{1-\mu_i}{\mu_i}\right) \ln q_{hij} - \mu_i^{-1} \ln \mathbf{A}_{hij} + $$

$$+ \sum_{k=1}^{m} \mu_i^{-1} \alpha_{ik} \ln \mathbf{w}_k \qquad (2.1.3)$$

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 ($\ln \mathbf{c}_{ij}$) 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 ith good produced in *j*, relative to the cost and price of the same good produced in the rest of the world, will then be

$$\ln \mathbf{p}_{ij} - \ln \mathbf{p}_{iw} = \left(\frac{1-\mu_i}{\mu_i}\right)(\ln q_{hij} - \ln q_{hiw}) - \mu_i^{-1}(\ln \mathbf{A}_{hij} - \ln \mathbf{A}_{hiw}) + $$

$$+ \sum_{k=1}^{m} \mu_i^{-1} \alpha_{ki} (\ln \mathbf{w}_{kj} - \ln \mathbf{w}_{kw}) \qquad (2.1.4)$$

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 ith 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 ith 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 . . .M**) (Armington 1969). If the products of all firms in the ith industry in country *j* are treated as an aggregate, the S-D-S function gives the utility of the representative consumer as

$$\mathbf{U} = \prod_{i=1}^{n}\left(\sum_{j=1}^{M}\mathbf{C}_{ij}^{b_i}\right)^{\frac{a_i}{b_i}} \qquad \sum_{i=1}^{n}\mathbf{a}_i = 1 \qquad (2.2.1)$$

where $\mathbf{C}_{ij}$ denotes consumption of the "aggregate product" in the ith industry produced in country *j***.**

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

$$\mathbf{C}_{ijg} = \frac{\mathbf{p}_{ij}^{-\sigma_i}}{\sum_{j=1}^{N}\mathbf{p}_{ij}^{1-\sigma_i}}\mathbf{a}_i\mathbf{Y}_g = \left[\frac{\mathbf{p}_{ij}}{\mathbf{p}_{iw}}\right]^{-\sigma_i}\mathbf{a}_i\mathbf{Y}_g \qquad (2.2.2)$$

where $\sigma_i = 1/(1-\mathbf{b}_i)$ is the elasticity of substitution among products in the ith industry, $\mathbf{Y}_g$ aggregate income in **g** and $\mathbf{p}_{iw}$ is an aggregate price index for all products in the ith industry (Varian 1992, p. 112).

2.*3* T*h*e coefficient of speciali*z*ation

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

$$\mathbf{r}_{ij} = \frac{Q_{ij}}{\mathbf{C}_{ij}} = \frac{\mathbf{C}_{ij} + X_{ijw} - X_{iwj}}{\mathbf{C}_{ij}} \qquad (2.3.1)$$

where X_{ijw} is the exports of good **i** from country *j*, X_{iwj} is imports and Q_{ij} is gross production. The **r** measure is thus equivalent with 1+net export ratio.

Inserting (2.2.2) into (2.3.1) we obtain

$$\mathbf{r}_{ij} = \left[\frac{\mathbf{p}_{ij}}{\mathbf{p}_{iw}}\right]^{-\sigma_i} [(\mathbf{Y}_w / \mathbf{Y}_j) + 1] \qquad (2.3.2)$$

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

$$\ln \mathbf{r}_{ij} = \ln F_j + \frac{\sigma_i}{\mu_i}(\ln \mathbf{A}_{hij} - \ln \mathbf{A}_{hiw}) - \frac{\sigma_i(1-\mu_i)}{\mu_i}(\ln q_{hij} - \ln q_{hiw})$$

$$-\frac{\sigma_i}{\mu_i}\sum_{k=1}^{m}\alpha_{ki}(\ln \mathbf{w}_{kj} - \ln \mathbf{w}_{kw}) \qquad (2.3.2a)$$

where the first term is a country-specific constant. Thus the value of the specialization coefficient for a given country in any good/industry is low for goods intensively using the country's expensive (and scarce) factors (i.e. factor intensity α_{ki} and factor price $\mathbf{w}_{kj}$ are both high), where the country has a productivity disadvantage ($\mathbf{A}_{hij}$ is low) and where firms are relatively small. 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 ith 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

$$\ln \mathbf{r}_{ij} = \sum_{i=1}^{n}\gamma_{1i}\mathbf{D}_i + \sum_{j=1}^{M}\gamma_{2j}\mathbf{D}_j + \gamma_3 \ln \mathbf{A}_{hij} + \gamma_4 \ln q_{hij} +$$

$$+\sum_{k=1}^{m}\gamma_{5k}\alpha_{ik}\ln \mathbf{w}_{jk} + \varepsilon_{ij} \qquad (2.3.2.b)$$

2.*4* Sources of knowledge

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 $\mathbf{A}_{hij}$. But what are the causes of international differences in the $\mathbf{A}_{hij}$:**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. that 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, etc. Since technology is a non-rival good, and at least to some extent non-excludable, the innovator usually cannot capture the full commercial value of his invention, so that knowledge can be used at low or zero cost by other firms (Grossman & Helpman 1991). Such spillovers may be local or global; there may be spillovers within as well as among industries. 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, $\mathbf{A}_{hij}$ in (2.1.1), as a function of the different sources of knowledge available to it, namely knowledge acquired by learning (**L**), produced from the firms' own R&D activity ($\mathbf{s}_{hij}$) or obtained by various spillover mechanisms from research in other firms in the domestic industry ($\mathbf{S}_{ij}$), other sectors in the home country ($\mathbf{S}_j$) or the world market ($\mathbf{S}_i$). In addition to these sources of disembodied technical change there may also be technical progress embodied in new capital goods ($\mathbf{s}^{e}_{hij}$):

$$\mathbf{A}_{hij} = F(\mathbf{L}_{hij}, \mathbf{s}_{hij}, \mathbf{S}_{ij}, \mathbf{S}_{j}, \mathbf{S}_{i}, \mathbf{s}^{e}_{hij}) \qquad (2.4.1a)$$

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.[6] If learning is spread locally to all firms in the industry -- e.g. if learning is embodied in the competence of workers that change jobs -- it is the aggregate industry production cumulated over time, $\tilde{q}_{ij}$, that matters:[7]

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

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

[7] A drawback with using $\tilde{q}_{ij}$ is that static and dynamic economies of scale on the industry level will be mixed up.

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. In this study we have no access to firm data; all regressions are estimated on a cross-industry/cross-country basis. If all firms in the ith industry in country *j* were identical, each producing one single product, $\mathbf{s}_{hij}$ 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 ith industry in the jth country by the number of firms:

$$\mathbf{s}_{hij} = \frac{\mathbf{S}_{ij}}{\mathbf{N}_{ij}} \qquad (2.4.2a)$$

This requires that the industry's R&D expenditure is optimally allocated, so that the return from the marginal R&D dollar is the same in all firms. For the case of multi-product firms, size does not matter if there are no economies of scope and the output of each product is assumed to be the same. Then the relevant concept of the stock of knowledge would be the total R&D stock in the industry divided by industry output, i.e. the knowledge stock for the representative product:

$$\mathbf{s}_{hij} = \frac{\mathbf{S}_{ij}}{q_{ij}} \qquad (2.4.2b)$$

We will use (2.4.2a) and (b) as alternative variables in the empirical analysis.

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 & Mairesse (1995) we use the formula

$$\mathbf{S}_{ijt} = (1-\delta_S)\mathbf{S}_{ijt-1} + \mathbf{R}_{ijt-1} \qquad (2.4.3a)$$

where $\mathbf{S}_{ijt}$ the knowledge (R&D) capital stock in industry **i**, country *j*, at the beginning of period **t,** $\mathbf{R}_{ijt-1}$ 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 $\mathbf{S}_1$ is obtained as

$$\mathbf{S}_{ij1} = \frac{\mathbf{R}_{ij1}}{\mathbf{g} + \delta_S} \qquad (2.4.3b)$$

where **g** is the rate of growth of R&D (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 (for the representative product):

$$\ln \mathbf{A}_{hij} = F(\mathbf{L}_{ij}, \mathbf{s}_{hij}) \qquad (2.4.4a)$$

Thus in the regression equation (2.3.2b) we substitute the expression

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

for the technology term $\gamma_3 \ln \mathbf{A}_{hij}$. Additional hypotheses are tested by adding variables to this basic equation.

In (2.4.4b) we simply assume (neglecting learning) that efficiency ($\mathbf{A}_{hij}$) is proportionate to cumulated R&D effort of the firm ($\mathbf{s}_{hij}$). However, it may be more realistic to treat R&D as a fixed cost, i.e. to allow for increasing returns (on the firm level) in the R&D activity. In that case the impact of increased R&D stock per firm (or unit of output) depends positively on firm size.[8] This may be tested by adding the interaction term

$$\gamma_{33} (\ln \mathbf{s}_{hij} \ln q_{hij}) \qquad (2.4.5)$$

to the expression (2.4.4b).

2.5 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

$$\mathbf{s}_{hij} = \mathbf{S}_{ij} \qquad (2.5.1a)$$

The requirement is here that there is no duplication of research effort, and that there is a complete national -- but no global -- spillover of knowledge within an industry.[9]

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

[8] In the single product firm we have economies of scale, in the multi-product case economies of scope.

[9] It is not possible in this paper to evaluate the existence of global within-industry spillovers. To the extent that global spillovers are equally spread among countries, competitiveness and specialization will not be affected (since the increase in productivity is the same).

knowledge, and by the total R&D effort of the industry in the jth country, of which some proportion may be treated as a local common good (Grossman & Helpman 1991). Thus the impact on efficiency of a given increase in 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. Neglecting increasing returns on the firm level, we may test the hypothesis of complementarity of private and public knowledge by adding the interaction variable

$$\gamma_{34}(\ln \mathbf{s}_{hij} \ln \mathbf{S}_{ij}) \qquad (2.5.1b)$$

to the expression (2.4.4b).

2.6 Impact of R&D differing among industries and countries

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 substituting the expression

$$\sum_{gi=1}^{3} \gamma_{34gi} \mathbf{D}_{gi} \ln \mathbf{s}_{hij} \qquad (2.6.1)$$

where the $\mathbf{D}_{gi}$:s are slope dummy variables for high, medium and low R&D intensity industries,[10] for $\gamma_{32} \ln \mathbf{s}_{hij}$ in equation (2.4.4b).

Another possibility is that the impact of the firm’s R&D may differ systematically among countries. There might be several explanations for this. One would be that the capacity to apply technology developed by foreign competitors is higher (i.e. that global spillover inflows are larger in some countries). Another is that it reflects 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 instead substitute the expression

[10] An argument 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.

$$\sum_{gj=1}^{3} \gamma_{34gj} \mathbf{D}_{gj} \ln \mathbf{s}_{hij} \qquad (2.6.2)$$

where the $\mathbf{D}_{gj}$:s are slope dummies for R&D abundant, medium and R&D scarce countries, for $\gamma_{32} \ln \mathbf{s}_{hij}$ in the basic regression equation. The criterion used -- total R&D stock in the manufacturing industry -- introduces a scale effect on the economy level.

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, $\hat{\mathbf{K}}_{ij}$, and the rate of depreciation δ_{Kij} :

$$\frac{\mathbf{I}_{ij}}{q_{ij}} = \frac{\mathbf{dK}_{ij} + \delta_{Kij} \mathbf{K}_{ij}}{q_{ij}} = \frac{\mathbf{dK}_{ij}}{\mathbf{K}_{ij}} \frac{\mathbf{K}_{ij}}{q_{ij}} + \delta_{Kij} \frac{\mathbf{K}_{ij}}{q_{ij}} = \theta_i (\hat{\mathbf{K}}_{ij} + \delta_{Kij}) \qquad (2.7.1)$$

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

$$\mathbf{s}^{e}_{hij} = \frac{1}{\tau} \sum_{v=t-\tau}^{t} \frac{\mathbf{I}_{ijv}}{q_{ijv}} \qquad (2.7.2a)$$

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:

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

3. Data and met*h*ods

According to equation (2.3.2.a) countries will specialize on industries intensively using their cheap resources. Our theoretical model is formulated in terms of cost shares of factors and factor prices, but in our empirical application we replace most cost shares with physical units (e.g. capital stock per worker) and prices with relative endowments (e.g. forest land per capita). A theoretical argument for this is 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. Formally, this holds in autarky for identical and homothetic demand, perfect competition and same technology (Ethier 1984, p. 176). However, it should still hold in a state between autarky and free trade even if goods markets are characterized by monopolistic competition, as long as there is free entry, perfect competition prevails in factor markets and endowments are uncorrelated with technology. A practical argument is that there are no comparative data on factor prices. Moreover, prices (and cost shares) are likely to be more volatile than quantity measures; for instance, profits are more affected by spurious short term variability than capital stocks.

Surveys of empirical work (e.g. Leamer 1994 and Deardorff 1984) conclude that 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, where endowments differ among countries, and requirements differ among industries. In this study, we have included interaction variables measuring country endowments, in combination with industry requirements, of

- forest land per worker/cost share of roundwood
- arable land per capita/food industry (a dummy)
- electrical energy[11]

[11] 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

- physical capital
- human capital or skilled labor, measured by formal education.

All industry characteristics, i.e. capital, energy and roundwood intensities, are measured using Swedish data and assumed to be the same across countries. A complete description of the data -- definitions and sources -- is given in the Appendix.

In (2.3.2a) specialization is affected by relative firm size: the larger the firms, the lower will be costs and prices. We measure q_{ij} in (2.3.2b) by the number of employees per plant.

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 & Mairesse 1995). We also assume that investment in research add to the stock of productive knowledge capital with a lag of three years.[12] We have calculated knowledge capital stocks for 22 manufacturing industries in 13 OECD countries. **Table 1** 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 2** shows total knowledge capital in manufactures in each country both in absolute terms and as a share of value added. **Table 2** also divides the countries into groups with large, medium and small knowledge capital stock.

Table 1 Knowledge capital stock in percent of value added on industry level in 13 OECD countries 1990.

Table 2 Knowledge capital stock in manufactures in 13 OECD countries 1990.

It appears from **table 1** 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.

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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.

Though small countries, such as Sweden and Norway, have the highest knowledge intensity in certain industries, it is evident from **table 2** 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** *3* support the general hypothesis that firms' R&D efforts, by creating technology gaps, improve their competitive position. As shown in column (i), 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 (column (iii)) does not change this conclusion, 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 1996 and Amable & Verspagen 1995).

Table *3* Determinants of international specialization in 22 manufacturing industries and 12 OECD countries

However, R&D is not the only factor influencing competitiveness. First, factor endowments also seem to determine specialization. Countries tend to specialize in industries that are intensive in their abundant resources, thus confirming conventional wisdom. All factor endowment variables -- both natural, such as arable and forest land, and "man-made" -- are positive and strongly significant in columns (i) and (iii), with the exception of human capital.[13] Again, our results are in line with the findings in most of the empirical literature on comparative advantage based on the Heckscher-Ohlin paradigm (for a survey see Deardorff 1984).

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[12] 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.

[13] The measure of human capital -- proportion of workers with post-secondary technical/scientific education -- is strongly positively correlated with the R&D-variables (correlations 0.6 to 0.7). In addition,

Second, the 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 (see equation (2.3.2a)).

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,[14] 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. Column (iv), where all variables but the fixed effects and the R&D stock have been excluded, points to the risk of obtaining seriously biased (in this case overstated) estimates of the impact of technology if other relevant variables, such as factor endowments, are not included in the analysis.

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. A robust regression in column (ii), where such observations are given lower weight, does not in general change neither the coefficients nor the **t** values very much. In particular, the estimated R&D coefficients for the R&D impact remain virtually unchanged. This holds also for the results in **table** *4*, where the robust regression results are not shown.

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the country variation in human capital endowments is rather limited in the sample, where OECD countries with the lowest educational standards are generally excluded because of missing data.

[14] There is likely to be spurious correlation between cumulated production and the ratio of current production to consumption. National data on number of plants do not use the same definitions.

Table *4* Testing additional R&D hypotheses. Estimates of the partial effect of specialization of additional technology variables.

In **table** *4* we report only the coefficients for those variables that have been added to (or substituted into) the basic equations (i) and (iii) in **table** *3* in order to test additional hypotheses. Because the relevant variables are strongly correlated we have not included them all together in the same regression. Thus it is not possible to discriminate between these hypotheses.[15] All other variables, i.e. country and industry dummies, factor endowments and measures of scale and learning effects, are included as in column (i) and (iii) in **table** *3* but not reported; the results for these variables do not differ much from those reported in **table** *3*.

The first row tests for the existence of economies of scale in R&D (as distinct from general effects of firm size) by including an R&D-firm size interaction variable (expression 2.4.5). This variable is positive and significant,[16] thus supporting the hypothesis that the impact of a given proportional increase in R&D stock per firm (per unit of output) may be higher for 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** *4* supports the idea of local within-industry spillovers. A positive and significant coefficient for interaction variable $\ln \mathbf{s}_{hij} \ln \mathbf{S}_{ij}$ implies that the total domestic knowledge stock in an industry increases the impact of firms' own research on competitiveness.[17]

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[15] Thus we cannot 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. Thus we cannot discriminate between alternative "models" as expressed in regression equations containing different R&D variables. Consequently, we present no single "preferred equation".

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

[17] Assuming spillovers to follow trade flows, Fagerberg (1996) found national spillovers to be more important than global.

The next section in **table** *4* indicates that the impact of technology on competitiveness differs among high-tech, medium and low-tech industries.[18] 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.

From **table** *4* it is evident that the impact of R&D also seems to differ among countries. These differences are related to the size of the total stock of R&D induced knowledge in the manufacturing sector. This is consistent with the idea that part of this stock constitutes common knowledge -- i.e. that there may be economy-wide local externalities -- which increases the output of a given R&D input of a particular firm. This is in line with the findings of Bernstein & Nadiri (1989) that local spillover effects on productivity may extend over industry boundaries.

The last two rows of **table** *4* 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** *4* shows both components 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 & 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

[18] The classification is based on average R&D stock in per cent of value added as shown in table 3.

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 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 technical 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 level. In addition there seems to be scale effects on the industry as well as on the national level, which are caused by local externalities/spillovers. It appears that R&D as a factor shaping competitiveness is really crucial mainly for high and medium technology sectors. Finally, technical 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.

References

Amable, B. & Verspagen B. (1995), The Role of Technology in Market Share Dynamics. **Applied Economics**, 27, 197-204.

Armington, P. (1969), A Theory of Demand for Products Distinguished by Place of Production. **IMF Staff Papers**, 16, 159-178.

Berndt, E.R. (1991), **The Practice of Econometrics. Classic and Contemporary**. New York: Addison-Wesley.

Bernstein, J. & Nadiri, M. (1989), Research and Development and Intra-Industry Spillovers: an Empirical Application of Dynamic Duality. **Review of Economic Studies** 56, 249-269.

Deardorff, A.V. (1984), 'Testing Trade Theories and Predicting Trade Flows' in Jones R.V. & Kenen, P.B. (eds), **Handbook of International Economics Volume I.** Amsterdam: North-Holland.

Dosi, G., Pavitt, K. & Soete, L. (1990), **The Economics of Technical Change and International Trade**. London: Harvester/Wheatsheaf.

Ethier, W. (1984), 'Higher Dimensional Issues in Trade Theory', in Jones R.W. & Kenen P. (eds), **Handbook of International Trade Theory. Volume I.** Amsterdam: North Holland.

Fagerberg, J. (1988), International Competitiveness. **Economic Journal**, 98, 355-374.

Fagerberg, J. (1996), Competitiveness, Scale and R&D, in Fagerberg, J. et al. (eds) **Technology and International Trade**. Cheltenham: Edward Elgar (forthcoming).

Finger, J.M. (1975), A New View of the Product Cycle Theory. **Weltwirtschaftliches Archiv,** 111, 79-99.

Griliches, Z. (1995), 'R&D and Productivity: Econometric Results and Measurement Issues', in Stoneman, P. (ed.) **Handbook of the Economics of Innovation and Technological Change.** Oxford: Basil Blackwell.

Grossman, G.M. & Helpman, E. (1991) **Innovation and Growth in the Global Economy.** Cambridge: MIT Press.

Gruber, W., Metha D. & Vernon R. (1967), The R&D Factor in International Trade and International Investment of United States Industries. **Journal of Political Economy,** 75, 20-37.

Gustavsson, P., Hansson, P. & Lundberg, L. (1996), 'Technical Progress, Capital Accumulation and Changing International Competitiveness', in Fagerberg, J. et al. (eds) **Technology and International Trade**. Cheltenham: Edward Elgar (forthcoming).

Hall, B.H., & Mairesse, J. (1995), Exploring the Relationship between R&D and Productivity in French Manufacturing Firms. **Journal of Econometrics**, 65, 263-293.

Helpman, E. & Krugman, P.R. (1985), **Market Structure and Foreign Trade.** Cambridge: MIT Press.

Hufbauer, G.C. (1970), The Impact of National Characteristics and Technology on the Commodity Composition of Trade in Manufactured Goods. In Vernon R (ed.), **The Technology Factor in International Trade.** New York: Columbia University Press.

Irwin, D.A. & Klenow, P.J. (1994), Learning-by-Doing Spillovers in the Semiconductor Industry. **Journal of Political Economy**, 102, 1200-1227.

Leamer, E.E. (1994), 'Testing Trade Theories', in Greenaway, D. & Winters, L.A. (eds), **Surveys in International Trade**. Oxford: Blackwell.

MacDougall, G.D.A. (1951), British and American Exports: A Study Suggested by the Theory of Comparative Costs. Part I. **Economic Journal,** 61, 697-724.

MacDougall, G.D.A. (1952), British and American Exports: A Study Suggested by the Theory of Comparative Costs. Part II. **Economic Journal,** 62, 487-521.

Mansfield, E., Rapoport, J., Romeo, A. & Beardsley G. (1977), Social and Private Rates of Return from Industrial Innovations. **Quarterly Journal of Economics**, 91, 221-240.

Posner, M.V. (1961), International Trade and Technical Change. **Oxford Economic Papers**, 13, 323-341.

Scherer, F.M. (1982), Interindustry Technology Flows and Productivity Growth. **Review of Economics and Statistics**, 627-634.

Stern, R.M. & Maskus K.E. (1981), Determinants of the Structure of US Foreign Trade 1958-76. **Journal of International Economics,** 11, 207-224.

US Bureau of Labor Statistics (1989), **The Impact of Research andDevelopment and Productivity Growth.** Bullentin 2331, Washington DC.

Varian, H. (1992), **Microeconomic Analysis.** Third Edition. London: W.W. Norton.

Verspagen, B. & Wakelin, K. (1996), 'Technology, Employment and Trade: Perspectives on European Integration', in Fagerberg, J. et al. (eds) **Technology and International Trade**. Cheltenham: Edward Elgar (forthcoming).

Wells, L.T., Jr (1969), Test of a Product Cycle Model of International Trade: US Exports of Consumer Durables. **Quarterly Journal of Economics**, 82, 152-162.

White, H. (1980), A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. **Econometrica**, 48, 817-838.

Wolff, E. (1996), 'Productivity Growth and Shifting Comparative Advantage on the Industry Level', in Fagerberg, J. et al. (eds) **Technology and International Trade**. Cheltenham: Edward Elgar (forthcoming).

Appendix Variables: definitions, measurement and sources

Coefficient of specialization

$$\mathbf{r}_{ij} = \frac{Q_{ij}}{\mathbf{C}_{ij}} = \frac{Q_{ij}}{Q_{ij} + X_{iwj} - X_{ijw}}$$

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

$\mathbf{C}_{ij}$ 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 [19]

$$\mathbf{S}_{ijt} = (1-\delta_S)\mathbf{S}_{ijt-1} + \mathbf{R}_{ijt-1}$$

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

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

δ_S depreciation rate of knowledge.

Firm specific knowledge stock: $\mathbf{s}_{hij} = \mathbf{S}_{ij} / \mathbf{N}_{ij}$ or $\mathbf{s}_{hij} = \mathbf{S}_{ij} / q_{ij}$

$\mathbf{S}_{ij}$ see above.

$\mathbf{N}_{ij}$ 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).

Plant size: $q_{hij} = \mathbf{L}_{ij} / \mathbf{N}_{ij}$

$\mathbf{L}_{ij}$ number of employees, industry **i**, country *j*, 1990. Source: OECD (1994b).

$\mathbf{N}_{ij}$ see above.

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: $\mathbf{k}_i \ln \mathbf{k}_j$

$$\mathbf{k}_i = \mathbf{K}_{i85} / \mathbf{L}_{i85}$$

$$\mathbf{k}_j = \left[\sum_{t=87}^{89} \mathbf{K}^*_{jt} / \sum_{t=87}^{89} \mathbf{L}_{jt}\right]$$

$\mathbf{K}_{i85}$ capital stock, industry **i**, Sweden, 1985, 1985 prices. Source: SCB (1992) and SCB, Unpublished data on capital stocks.

$\mathbf{L}_{i85}$ number of employees, industry **i**, Sweden, 1985. Source: SOS Manufacturing 1985.

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[19] 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).

$\mathbf{K}^*_{jt}$ capital stock in manufactures, country *j*, time **t**, US dollar 1985 PPP, 1985 prices. Source: OECD (1993).

$\mathbf{L}_{jt}$ total employment in manufactures, country *j*, time **t**. Source: OECD (1993).

Human capital: $h_i \ln h_j$

h_i proportion of employees in industry **i** with a university degree in engineering (3 years or more), Sweden, 1990. Source: SCB Regional Labor Statistics.

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

Energy: $\mathbf{e}_i \ln \mathbf{e}_j$

$\mathbf{e}_i$ cost of electrical power SEK per employee, industry **i**, Sweden, 1989. Source: SOS Manufacturing 1989.

$\mathbf{e}_j$ production of electrical power kWh per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Forest land: $\mathbf{t}_i \ln \mathbf{t}_j$

$\mathbf{t}_i$ input of roundwood SEK per 10 000 SEK output, industry **i**, Sweden, 1985. Source: SCB Input-output table for Sweden 1985.

$\mathbf{t}_j$ hectare forest land per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Arable land: $\mathbf{a}_i \ln \mathbf{a}_j$

$\mathbf{a}_i$ dummy variable for industry 31 (food)

$\mathbf{a}_j$ hectare arable land per worker, country *j*, 1990. Source: SCB (1993) and OECD (1995a).

Embodied technology:[20] $\mathbf{s}^e_{hij} = \frac{1}{\tau}\sum_{v=t-\tau}^{t} \frac{\mathbf{I}_{ijv}}{q^*_{ijv}}$ or $\mathbf{s}^e_{hij} = \sum_{v=t-\tau}^{t} \left(1-\delta^K_i\right)^{t-v} \frac{\mathbf{I}_{ijv}}{q^*_{ijv}}$

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

$\mathbf{I}_{ijv}$ 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

Data sources

Hansson, B. (1991), **Measuring and Modelling Technical Change**. Department of Economics, Uppsala University.

OECD (1993), **International Sectoral Database (ISDB).**

OECD (1994a), **Education at a Glance**. Paris: OECD.

OECD (1994b), **The STAN Database 1970-93**. December.

OECD (1995a), **National Accounts Volume II.** Paris: OECD.

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

OECD (1995b), **Industrial Structure Statistics**. Paris: OECD.

OECD (1996), **DSTI(STAN/ANBERD Database).**

SCB (1992), **National Wealth and Stocks of Fixed Assets 1980-1990.**

SCB (1993), **Statistical Yearbook of Sweden 1994.**

SCB (1995), **National Accounts 1980-1993. Stocks of Fixed Assets. Appendix** 3.

SCB, **SOS Manufacturing 1985. Part I.**

SCB, **SOS Manufacturing 1989. Part I.**

SCB, **Input-Output Table for Sweden 1985.**

SCB Regional Labor Statistics, Unpublished data on employees by industry and level of education.

SCB, Unpublished data on capital stocks. The data were kindly provided by Nils-Olov Stålhammar.

Table 1 Knowledge capital stock in percent of value added on industry level in 13 OECD countries 1990.

ISIC	Industry	Technology level	Mean	Coeff. of variation	Highest	Lowest
31	Food	Low	5.49	0.54	11.40 Sweden	0.83 Italy
32	Textiles & clothing	Low	3.89	0.59	7.90 Italy	0.26 Japan
33	Wood & furniture	Low	1.97	0.71	4.46 Norway	0.12 Italy
34	Paper & printing	Low	3.03	0.88	9.71 Sweden	0.18 Italy
351+352 –3522	Chemicals	Medium	36.20	0.46	60.56 Germany	12.95 Australia
3522	Pharmaceutical	High	85.22	0.44	161.63 Netherlands	26.15 Canada
353+354	Refineries	Medium	22.49	1.05	79.77 USA	4.20 Sweden
355+356	Plastic & rubber	Medium	12.39	0.55	22.25 Finland	3.71 Australia
36	Stone, clay & glass	Low	8.89	0.62	18.60 Japan	0.59 Italy
371	Ferrous metals	Medium	13.09	0.61	32.25 Norway	5.17 Canada
372	Non-ferrous metals	Medium	16.22	0.75	48.55 Finland	2.21 Denmark
381	Metal products	Low	6.68	0.58	15.41 Sweden	2.68 Italy
382–3825	Other machinery	Medium	20.85	0.50	42.49 Sweden	6.11 Italy
3825	Computers	High	81.88	0.69	229.97 Norway	19.85 Australia
383–3832	Electrical machinery	High	44.78	0.83	146.80 Sweden	11.61 Australia
3832	Electronics	High	97.94	0.47	209.07 Norway	40.18 Japan
3841	Shipyards	Medium	12.85	0.75	31.90 Norway	0.24 Canada

Table 1 (continued)

ISIC	Industry	Technology level	Mean	Coeff. of variation	Highest	Lowest
3843	Motor vehicles	High	39.97	0.71	95.46 USA	3.98 Canada
3845	Aircraft	High	117.42	0.74	245.36 Germany	0.78 Norway
3842+3844 +3849	Other transport	Medium	28.04	1.17	119.77 USA	4.15 UK
385	Instruments	High	48.99	1.11	205.65 Norge	4.46 Italy
39	Other manufacturing	Low	7.24	0.56	15.65 USA	2.61 Italy

Table 2 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 *3* Determinants of international specialization in 22 manufacturing industries and 12 OECD countries 1989-91.

Variable	(i) OLS	(ii) Robust	(iii) OLS	(iv) OLS
$\ln \mathbf{s}_{hij}$ R&D/plant	0.046 (2.48) [2.63]	0.042 (2.41)	-	0.133 (6.61) [6.12]
$\ln \mathbf{s}_{hij}$ R&D/output	-	-	0.039 (2.12) [2.32]	-
$\ln \tilde{q}_{ij}$ Learning	0.197 (7.26) [6.61]	0.196 (7.64)	0.209 (7.76) [7.14]	-
$\ln q_{hij}$ Plant size	0.128 (3.30) [2.80]	0.123 (3.35)	0.167 (4.81) [4.09]	-
$\mathbf{k}_i \ln \mathbf{k}_j$ Physical capital	2.33×10^{-4} (2.46) [3.04]	2.13×10^{-4} (2.37)	2.21×10^{-4} (2.32) [2.95]	-
$h_i \ln h_j$ Human capital	1.21×10^{-2} (1.26) [1.18]	0.76×10^{-2} (0.83)	1.16×10^{-2} (1.20) [1.11]	-
$\mathbf{e}_i \ln \mathbf{e}_j$ Energy	9.47×10^{-6} (5.26) [5.78]	8.48×10^{-6} (4.99)	9.64×10^{-6} (5.35) [5.91]	-
$\mathbf{t}_i \ln \mathbf{t}_j$ Forest land	2.73×10^{-5} (2.85) [3.43]	2.81×10^{-5} (3.11)	2.77×10^{-5} (2.89) [3.47]	-
$\mathbf{a}_i \ln \mathbf{a}_j$ Arable land	0.092 (1.84) [3.28]	0.082 (1.74)	0.093 (1.88) [3.30]	-
F(country effects)	15.86 /0.00/	16.39 /0.00/	15.68 /0.00/	5.45 /0.00/
F(industry effects)	9.81 /0.00/	9.05 /0.00/	9.74 /0.00/	5.95 /0.00/
Constant	−18.37	−16.92	−17.72	−1.98
$\bar{\mathbf{R}}^2$	0.651		0.648	0.390
F	12.47	12.34	12.33	5.77
Observations	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.

Table *4* Testing additional R&D hypotheses. Estimates of the partial effect on specialization of additional technology variables

Row	Hypothesis/variable	Coefficient ($\mathbf{s}_{hij} = \mathbf{S}_{ij} / \mathbf{N}_{ij}$)	$\overline{\mathbf{R}}^2$	Coefficient ($\mathbf{s}_{hij} = \mathbf{S}_{ij} / q_{ij}$)	$\overline{\mathbf{R}}^2$
1	Scale economies in R&D $\ln \mathbf{s}_{hij}\ \ln q_{hij}$	0.012 (1.68) [1.80]	0.654	0.035 (2.97) [2.76]	0.661
2	Local R&D externality $\ln \mathbf{s}_{hij}\ \ln \mathbf{S}_{ij}$	0.008 (3.24) [3.82]	0.666	0.010 (2.18) [2.81]	0.654
3	Industry specific R&D impact				
	$\ln \mathbf{s}_{hij}$ high	0.061 (2.74) [2.85]	0.657	0.050 (1.89) [1.92]	0.645
	$\ln \mathbf{s}_{hij}$ medium	0.049 (2.10) [2.10]		0.034 (1.21) [1.24]	
	$\ln \mathbf{s}_{hij}$ low	–0.013 (–0.42) [–0.48]		0.026 (0.74) [0.96]	
4	Country specific R&D impact				
	$\ln \mathbf{s}_{hij}$ large	0.070 (3.16) [3.49]	0.654	0.090 (3.41) [3.95]	0.657
	$\ln \mathbf{s}_{hij}$ medium	0.035 (1.75) [1.92]		0.028 (1.24) [1.48]	
	$\ln \mathbf{s}_{hij}$ small	0.042 (1.81) [1.63]		0.020 (0.80) [0.70]	

Table *4* (continued)

Row	Hypothesis/variable	Coefficient ($\mathbf{s}_{hij} = \mathbf{S}_{ij} / \mathbf{N}_{ij}$)	$\overline{\mathbf{R}}^2$	Coefficient ($\mathbf{s}_{hij} = \mathbf{S}_{ij} / q_{ij}$)	$\overline{\mathbf{R}}^2$
5a	Embodied and disembodied knowledge				
	$\ln \mathbf{s}^{e}_{hij}$ (2.7.2a)	0.165	0.663	0.158	0.660
		(3.33)		(3.14)	
		[3.86]		[3.63]	
	$\ln \mathbf{s}_{hij}$	0.040		0.031	
		(2.15)		(1.62)	
		[2.47]		[1.95]	
5b	$\ln \mathbf{s}^{e}_{hij}$ (2.7.2b)	0.149	0.661	0.141	0.657
		(3.08)		(2.87)	
		[3.45]		[3.20]	
	$\ln \mathbf{s}_{hij}$	0.042		0.033	
		(2.26)		(1.76)	
		[2.64]		[2.14]	

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.