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Technology and Trade - an analysis of technology specialization and export flows

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Keywords: exports, technology, knowledge, specialization, quality, patents

Technology and Trade

- an analysis of technology specialization and export flows[1]

Martin Andersson[2] and Olof Ejermo[3]

Abstract

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JEL Codes: F14, O33, O52, R12
Keywords: exports, technology, knowledge, specialization, quality, patents

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1 INTRODUCTION

The role of technology and innovation in trade has been recognized at least since the work by Posner (1961), Vernon (1966) and Hirsch (1967). These authors were early proponents of the view that comparative advantages can be created and maintained by investments in technology and knowledge. Today, many authors often refer to *dynamic* comparative advantages, i.e. comparative advantages that develop over time through knowledge accumulation processes associated with R&D, learning by doing and other measures.[4] This view, of course, differs from the assumptions in the classic model of factor proportions which imply that comparative advantages arise from a given uneven allocation of (immobile) production factors between countries and are thus given by nature (Fagerberg, 1996).

Posner maintained that 'technology capacity', *created* via investments in e.g. R&D, is an important predictor of a region's export specialization.[5] Vernon (1966) and Hirsch (1967) based their research on the realistic assumption that the nature of competition in different sectors changes over time. As a consequence, the factors important for competitiveness changes over time as well. The essence of this framework is the product cycle model, in which the demand for different types of knowledge, skills and other inputs changes in a systematic way during the life of a product (Andersson & Johansson 1984,1998). Countries and regions with superior access to R&D, human capital and technologies then specialize on the early stages of the product cycle where R&D and innovations are most important.

[4] An associated assumption in this framework is that technology and knowledge do not diffuse instantly.
[5] See also Kaldor (1981).

With reference to this type of theoretical framework, a large set of studies has been devoted to analyses of the relationship between technology and trade performance, as well as the relationship between technology specialization and trade specialization. There is no room here for a complete review of all these works but examples of such studies can be found *inter alia* in Soete (1981, 1987), Wolff (1995), Amable & Verspagen (1995), Verspagen (1991), Wakelin (1997, 1998), Sanyal (2004), Fagerberg *et al.* (1997), Dosi, Pavitt & Soete (1990) and Archibugi & Mitchie (1998).[6] Many of these studies relate the Revealed Comparative Advantage (RCA) index after Balassa (1965) or export market shares to different types of technology-related variables, (see e.g. Sanyal, 2004; Amable & Verspagen, 1995; Grupp & Münt, 1998 and Amendola, Guerrieri & Padoan, 1998). Typical technology variables employed are R&D and patents.

The present paper bears upon the abovementioned literature and examines the relationship between technology specialization and trade. Specifically, using citations-weighted patent and export data, the paper analyzes; (i) the relationship between technology specialization and export specialization across regions and (ii) how the technology specialization of origin and destination affect the size and structure of link-specific export flows. The paper analyses (i) and (ii) using data on Swedish regions' exports to European countries. Link-specific export flows thus refers to the exports by firms in a sector in one region to one specific country.

A basic presumption in the paper is that knowledge is necessary not only to create, but also to maintain comparative advantages in a dynamic market economy. As the knowledge specialization of a region is determined by the technology field or domain of the knowledge-creating activities in the region, the export specialization of a region is

[6] See Dosi & Soete (1988) and Fagerberg (1996) for reviews of related literature.

expected to correspond to its technology specialization. Moreover, there are strong theoretical arguments in favor of that technology specialization in origin and destination shapes the size and composition of export flows. From a strict Ricardian perspective, a country that is specialized in a specific technology would import fewer commodities related to that technology. However, scale economies in production is a pervasive phenomenon and scale economies combined with limited domestic resources implies that a single region cannot produce all possible goods (or varieties of a good) itself. Therefore, one should expect to observe trade flows between regions with similar technology specialization(s).[7] A main conjecture in this paper is that the structure and composition of export flows from a region to destinations with similar technology specialization(s) differ from the trade flows to destinations with dissimilar specialization(s). Specifically, trade flows to destinations with similar technology specialization as the origin regions are expected to consist of highly specialized high-quality products within the sector associated with that technology, i.e. goods in the upper segment of the ‘quality-ladder’. The production of such goods typically requires a specialization in the technology associated with that sector. Standard consumer theory suggests that such a relationship should manifest itself in higher prices of the export flows to destinations with similar technology specialization as the origin regions. A one-sided open gravity model, which includes the technology specialization in destination and origin, is estimated to assess how export values and export prices varies across destinations with different technology specialization(s).

There are a number of novelties in the analysis. Firstly, the literature has somewhat uncritically used patent counts as the bearer of information about strength of countries as

[7] Cross-hauling within sectors is indeed a well documented phenomenon.

regards technology in the measures of technology specialization. This paper employs citation-weighted measures. There is by now a mounting literature on the usefulness of citations as a relevant ‘quality-adjuster’ (e.g. Trajtenberg, 1990; Harhoff, et al. 2003, Lanjouw and Schankerman, 2004 and Hall, et al. 2005). Secondly, the paper makes use of export data which enables us to study the export flows from individual well-defined regions in Sweden to European countries. This allows for an assessment of how the technology specialization in origin *and* destination affects the export flows. Thirdly, we take advantage of a newly established concordance scheme between technologies and industries. The problem of how to ‘translate’ patent technologies using the international patent classification (IPC) to industry data is a recurring one. The concordance table developed by Schmoch *et al* (2003) in a project for the European Commission (EC) has, for the purpose of this paper, the advantage that it is based on European patent data – rather than US or Canadian – to examine the correspondences between industry and technology. The present analysis is conducted at the European level and has European Patent Office (EPO) data as its basis.[8]

The remainder of the paper is organized as follows: Section 2 presents the theoretical framework and formulates the hypotheses. Section 3 describes the measures applied. Section 4 describes the data and Section 5 presents the results of the empirical analysis. Section 6 concludes.

[8] Advocates of the use of USPTO data often put forward the argument that the U.S. is the world’s single largest economic market and any technological advantage sought here should therefore best reflect technological leadership. On the other hand, European firms are more familiar with the European market. There is a home bias effect in patenting (Criscuolo, 2006).

2 THEORETICAL FRAMEWORK

The relationship between technology specialization and export specialization

Ricardo's classic analysis implies that regions will specialize according to their comparative advantages, i.e. their relative productivity advantages. Against this background, analyses of regions' specialization across sectors frequently rest upon a specification of a vector of factors related to productivity in each sector and an assessment of the relative endowments of such factors across regions. An analytical weakness of many of the archetypal models within this framework – such as the Hecksher-Ohlin model of factor proportions – is that they focus on (immobile) factors given by nature, which means that relative productivity differentials are exogenously pre-determined.

With few exceptions, however, productivity is endogenous. Productivity advantages can be created and maintained by knowledge expansion and creation, for instance through R&D investments and 'learning-by-doing' effects over time. R&D refers to investments in the production of new knowledge, both scientific knowledge and knowledge directed towards blueprints, practical applications and commercial objectives (c.f. OECD, 1980). Learning-by-doing (LBD) refers to new knowledge and skills acquired over time through repeated production experience. At the same time as knowledge is the fundamental output from R&D activities and LBD processes, the knowledge acquired in the past is an important input in present and future knowledge-expansion activities. Knowledge is thus intrinsically of a cumulative character. In this perspective the accumulated knowledge is a generic factor pertinent to retain and improve productivity levels.

Both R&D and LBD potentially raise productivity, for instance through new and more advanced technologies. Product and process R&D, in particular, are undertaken in order to develop new products and/or more efficient methods of producing existing goods. Product and process innovations raise productivity via:

- higher output price due to product innovations (temporary monopoly).
- improved production technologies (lower production costs) due to process innovations.

In a dynamic market economy knowledge expanding and creating activities are necessary, not only to create but also to maintain comparative advantages. This is a core element of the general analysis of product cycles, which dates back to the seminal works by Vernon (1966) and Hirsch (1967). In these kinds of models, comparative advantages are dynamic and can be lost over time through imitation, product obsolescence and product standardization. In such an environment, retaining and improving productivity advantages require initiation of new product cycles, i.e. innovation activities, in which the accumulated knowledge is an important input. Recent contributions in this vein include the product cycle model in Grossman & Helpman (1991) where North needs to 'climb the quality ladder' to retain its advantages relative to South.

Even though productivity advantages are dynamic and depend on the accumulated knowledge acquired through e.g. R&D and LBD, the standard Ricardian framework is still applicable to explain the specialization pattern in each time period. This is easily illustrated with a simple dynamic version of a basic Ricardian model. Assume there is a continuum of goods defined on the interval $x \in [0,1]$. Each good, *x*, is produced according to the following production technology in each time period:

(1) $$q_x(t) = A_x(t) l_x(t)$$

where $A_x(t)$ denotes (labor) productivity in period *t* and $l_x(t)$ denotes the amount of labor employed in production. The full-employment condition for a region in each time period can thus be expressed as:

(2) $$L = \int_0^1 l_x(t)dx = \int_0^1 a_x(t)q_x(t)dx, \qquad a_x(t) \equiv \frac{l_x(t)}{q_x(t)} = \frac{1}{A_x(t)}$$

Dynamic comparative advantages can be introduced by assuming that the productivity in producing *x* a given time period *T* depends on the accumulated knowledge of *x* production up to time *T*, $K_x(T)$:

(3) $$A_x(T) = f\left(K_x(T)\right)$$

where the knowledge evolves in a 'learning-by-doing' process, such that the accumulated knowledge in time *T* is given by:

(4) $$K_x(T) = \int_{-\infty}^{T} \lambda q_x(t)dt, \qquad 0 < \lambda < 1$$

The relative productivities in time *T* for each good between 2 regions (foreign region denoted by *) are:

(5) $$\frac{A_x(T)}{A_x^*(T)} = \frac{a_x^*(T)}{a_x(T)}$$

In each time period then, the model is exactly the 'standard' Ricardian model. Conditional on wages, trade between two regions is determined by relative productivities.[9]

According to this framework a region will be specialized and hence export goods in sectors in which it have relative knowledge advantages. Specifically, it implies that the export specialization of a region corresponds to the knowledge specialization of the region. The knowledge specialization of a region manifests itself in the region's technology specialization, because the knowledge specialization is determined by the technology field or domain of the knowledge-creating activities. Against this background, the following hypothesis is formulated:

> H1 = In a given period of time the export specialization of a region is positively associated with the technology specialization of the region.

Composition of export flows and technology specialization in destination and origin

A region typically exports to a set of destination markets with different technology specializations. There are two basic aspects on how the size of the export flows to a given destination market is affected by the technology specialization in the destination market. On the one hand, the classic models of interregional and international trade provide no rationale for the existence of export flows from one region to another if both regions have similar technology specialization(s), i.e. similar endowment(s) of knowledge. In this perspective the export flows from an origin to a destination market with similar technology specialization would be lower than the export flows to destination markets

[9] By ranking all goods such that lower values of x corresponds to higher home relative productivity, the home region will specialize and export those goods whose index is lower than a threshold value $\tilde{x}$. Home exports all goods for which $x < \tilde{x}$. At the threshold, $\tilde{x}$, where $wa(\tilde{x}) = w^* a^*(\tilde{x})$, trade is indeterminate.

with dissimilar technology specialization. On the other hand, the general Burenstam-Linder hypothesis (1961), suggests that trade is most intense between countries with similar economic structures because of preference similarities. A vast amount of empirical observations also show that a considerable share of bilateral trade flows is indeed constituted by intra-industry trade (IIT).[10] One should thus expect to observe trade flows from a region to destination markets with similar technology specialization(s) as the origin region, but whether a similar technology specialization in the destination market tends to increase or decrease the size of the export flows (in terms of export values) is an open question.

Notwithstanding the ambiguities regarding the effects of technology specialization on export flows, there are strong theoretical arguments suggesting that the composition and structure of the export flows from a region varies with the destinations' technology specialization. For instance, bilateral IIT is generally explained by adhering to either vertical or horizontal product differentiation. The former refers to products that differ in quality and hence price (e.g. Flam & Helpman 1987, Falvey & Kierzowski 1987), whereas the latter refers to differentiated products of the same price and quality (e.g. Krugman 1980).[11] Horizontal product differentiation rests on preference for variety among consumers and vertical product differentiation on heterogeneous consumers as regards preferences for product qualities.

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[10] See e.g. Greenaway *et al* (1998).

[11] Despite a clear analytical distinction between the two, it is hard to distinguish between the alternative forms of differentiation in practice. The extent of observed pure cross-hauling, for instance, which would count as horizontal IIT, certainly depends on the level of classification, e.g. 4-digit contra 6-digit, etc. In empirical studies, vertical IIT is often identified by examining price differentials between export and imports in a given industry.

Consider now a country specialized in a specific sector, whose consumers are heterogeneous in terms of preferences for product qualities. If there are scale economies in production – which is a pervasive phenomenon across sectors – and the country has limited (domestic) resources, it can neither produce all possible goods nor all varieties of a good by itself. Therefore, it can be expected that there is a demand for foreign goods in both the upper and the lower segments of the 'quality-ladder' in the specific sector. The upper segments of the 'quality-ladder' in a sector are usually associated with highly specialized and complex high-quality goods, of which the production requires a specialization in the technology associated with that sector.

From the above discussion it follows that the export flows of a region to destination markets with similar technology specialization(s) can be expected to consist of highly specialized and complex high-quality commodities. What characterizes such type of commodities? Standard consumer theory suggests that higher quality is associated with higher willingness-to-pay, as higher willingness-to-pay necessitates that the attributes of the products in question are superior to other products. Therefore, the price of export products is a legitimate indicator of the quality of the products within a specific technology. Against this background the following hypothesis is formulated:

> H2: The export flows to destination markets with similar technology specialization as the region of origin are characterized by highly specialized high-quality products. This is manifested in higher export prices to destinations with similar technology specialization as the origin.

In what follows, hypotheses 1 and 2 are tested empirically by analyzing Swedish regions' trade with destination countries in Europe. The next section described the data and the measures of technology and export specialization.

3 DATA AND MEASURES OF TECHNOLOGY AND EXPORT SPECIALIZATION

3.1 Data sources

The patent data are obtained from the European Patent Office (EPO). Inventors' addresses[12] are used to allocate the patents to different countries using fractional counting. The following countries are included in the sample: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Switzerland and the United Kingdom. Citations to these patents has been added from material provided by Colin Webb at the OECD, and is documented in OECD (2005). As discussed in that document, only using EPO-patents' citations could bias results for certain patents, and the citations therefore comprise those from non-EPO sources as documented in World Intellectual Property Organization (WIPO) files. This practice differs compared to the widely used NBER patent data set on citations, which only covers US patent citations. OECD (2005) only recommends using data from 1982-1999 in their material.[13] This study employs EPO-patents from 1993-1999.

The export data is provided by Statistics Sweden (SCB). These data report exports in value (SEK) and volume in kilogram, for each exporting firm, product and destination. The structure of these data thus makes it possible to study the export flow from a region in Sweden to a given destination in terms of (i) export value, (ii) export volume and (iii) export prices (value per kilogram). As stated in the introduction, (i) and (iii) are used in the analysis. Exports can be regionalized because each exporting firm is assigned to a

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[12] We thank Bart Verspagen for providing EPO data divided by country. The material originates from Maurseth and Verspagen (2002).

[13] EPO was started in the late 70's, so using the first few years may bias counts downward. Also, using data after 1999 is likely to lead to truncation biases, since most patents issued after that date have not yet received many citations.

municipality in Sweden according to the location of its establishment. A region's total export is thus the sum of the exports of all firms located in that region. Regions are defined as integrated Local Labor Market (LLM) regions, of which there are 81 in Sweden (see NUTEK, 1998). The exports are registered by product according to the Combined Nomenclature (CN) classification system.

As described above, a concordance table has been used to 'translate' the technology class (the so-called IPC-code of each patent) into industrial sectors using the NACE-code system. The division in this paper is by 43 sectors. The sectors are listed in Appendix A. A concordance table between CN and NACE is used to couple the export data to the same industrial sectors.[14]

3.2 Measures of technology specialization and export specialization

The Technology Specialization Index (TSI) applied here measures how the share of patenting in a sector *s*, in a country *i* relates to the same share measured for all countries.[15] We use *P* to denote "patents" and use the following abbreviations: $P_{is} = \sum_j P_{isj}$, i.e. the sum of individual patents *j* belonging to *i*, *s*, $P_i = \sum_s P_{is}$ is therefore all patents in country *i*, $P_s = \sum_i P_{is}$ is all countries' patenting in sector *s*, and $P = \sum_s P_s$ is the sum of all patenting. The TSI index for country *i* in technology *s* is hence written:

(6) $$TSI_{is}^{I} = \frac{P_{is} / P_i}{P_s / P}$$

[14] This concordance can be found on Eurostat's Ramon project homepage: http://europa.eu.int/comm/eurostat/ramon/index.cfm?TargetUrl=DSP_PUB_WELC

[15] Some studies normalize the specialization indices used in this study through a monotonic transformation, such that the specialization indices are bounded between -1 and 1 (e.g. Malerba & Montobbio, 2003). The analyses presented in subsequent sections do not apply this transformation. However, results with transformed specialization indices are identical to the ones reported in the paper. These results are available from the authors upon request.

The technology specialization of regions is calculated in an analoguous manner. However, we use two different levels of comparison. The first employs European sectoral patenting as reference in the denominator, whereas the second uses Swedish sectoral patenting as its reference point.[16] In the first case, for a Swedish region *r* we specify:

(7) $$TSI_{rs}^{II} = \frac{P_{rs} / P_r}{P_s / P}$$

so that $P_{rs} = \sum_j P_{rsj}$ are all the patents in Swedish region *r*, sector *s* and $P_r = \sum_s P_{rs}$ region *r*'s total number of patents. Using Sweden as reference point, the technology specialization is:

(8) $$TSI_{rs}^{III} = \frac{P_{rs} / P_r}{P_{s(swe)} / P_{swe}}$$

To construct citations-weighted measures of technology specialization, we use the following abbreviations: $P_{is}^w = \sum_j w_j P_{isj}$, with w_j being the number of citations that patent *j* receives. The citations-weighted measures then follow analogous to before, where $P_i^w = \sum_s P_{is}^w$, $P_s^w = \sum_i P_{is}^w$ $P^w = \sum_s P_s^w$:

(9) $$TSI_{is}^{Iw} = \frac{P_{is}^w / P_i^w}{P_s^w / P^w}$$

Similarly, we define:

(10) $$TSI_{rs}^{IIw} = \frac{P_{rs}^w / P_r^w}{P_s^w / P^w}$$

[16] The second variant is equivalent to the location quotient.

and:

(11) $$TSI_{rs}^{IIIw} = \frac{P_{rs}^{w} / P_{r}^{w}}{P_{s(swe)}^{w} / P_{swe}^{w}}$$

The export specialization of a region *r* in sector *s* is measure equivalently and is given by:

(12) $$ESI_{rs} = \frac{x_{rs} / x_{r}}{x_{s(swe)} / x_{swe}}$$

where x_{rs} denotes region *r*'s exports in sector *s* and x_r the region's total exports.

4 TECHNOLOGY SPECIALIZATION OF COUNTRIES AND REGIONS

4.1 Technology specialization of countries

Table 1 shows descriptive statistics of the data on technology specialization in European countries across sectors. The information about which country has the most patenting is given by the means for P_i, since all countries have patenting.[17] The five countries with the highest patenting in 1993-1999 are in descending order: Germany, France, United Kingdom, Italy, and Switzerland. However, by weighing patents by the number of citations, Italy and the UK switch places. Sweden falls from 7th to 10th place.

Examining the variation in specialization can be done in two ways from Table 1 both by the coefficient of variation[18] and by the chi-square of sectoral specialization also used by Laursen (2000) and Archibugi and Pianta (1992, 1994). The coefficient of variation is generally higher for small countries. Notably Finland has an exceptionally high coefficient of variation, followed by Portugal and Luxembourg. Italy, Austria and Spain are the least specialized by this measure.

[17] Max (P_i) for instance describes how much patenting occurs in the most patent-intensive sector.

[18] Since the CV-measures are rather similar across variables, we only present the coefficient of variation for weighted patenting in order to conserve space.

>> TABLE 1 ABOUT HERE <<

The measure, given in (13), takes the difference between a country's share in a sector *s* and the corresponding share for our group of countries and squares this difference (the numerator), relates this to the share for our group of countries (denominator) and then sums for all sectors.

(13) $$\chi_i^2 = \sum_s \left(\left[\left(X_{si} \Big/ \sum_s X_{si} \right) - \left(\sum_i X_{si} \Big/ \sum_s \sum_i X_{si} \right) \right]^2 \Big/ \left(\sum_i X_{si} \Big/ \sum_s \sum_i X_{si} \right) \right)$$

The result in Table 1, χ_P^2 for non-weighed patents and $\chi_{P^w}^2$ for weighed ones, shows that the small countries have the highest specialization (Greece, Luxembourg, and Finland when we use χ_P^2, and Finland, Portugal and Luxembourg when we use $\chi_{P^w}^2$) and the large countries have the least specialization (France, Germany and Italy using χ_P^2 and France, Germany and Spain for $\chi_{P^w}^2$). This suggests a clear tendency for the amount of patenting and country size to be inversely related to specialization.[19]

4.2 Technology specialization of Swedish regions

We restrict our attention here to the main features of regional technology specialization. Patent data has been allocated to 81 local labor market regions (LLM). Counts of unweighted patent fractions show that the Stockholm region has the highest amount of patenting, followed by the Gothenburg and Malmö regions. This matches closely population size. Stockholm (~ 2104 patent fractions) has around twice the patenting of Gothenburg (~ 1043) and three times that of Malmö (~ 679) for the full period 1993-1999. This order is unchanged if we consider weighted values. However, Stockholm

[19] We ran a few simple linear regressions between amount of patenting and specialization which confirmed a statistically significant negative association between the two.

patents are on average more highly cited than the other two. Moreover, patenting becomes more unevenly distributed when we study weighted counts. This result is akin to what is generally found in the literature when citation-weighted counts are compared to unweighted ones, except that our results here refer to the distribution across regions.[20] Does the variation in the regional data follow or deviate from the variation in the county data? To answer this question we modify the notation in (13) to:

$$\chi_r^2 = \sum_s \left(\left[\left(X_{sr} / \sum_s X_{sr} \right) - \left(\sum_r X_{sr} / \sum_s \sum_r X_{sr} \right) \right]^2 / \left(\sum_r X_{sr} / \sum_s \sum_r X_{sr} \right) \right) \tag{14}$$

The important question is how we can compare regions with countries in terms of variation, since the measures we have considered calculates values for each country/region respectively. We here examine the standard deviation of patenting a, minimum and maximum across countries/regions of χ_P^2 and $\chi_{P^w}^2$, as an approximation, and also consider the standard deviation of all patenting, unweighted and citation-weighted across countries/regions. The results are given in Table 2.

>> TABLE 2 ABOUT HERE <<

Judging from coefficient of variation measures, Table 2 indicates that patenting specializing patterns are clearly more varied across regions than they are across countries. In other words, countries tend to embody a more diverse pattern of patenting. Swedish regions are in general more specialized.

With respect to absolute amounts of patenting (whether unweighted or weighted), regions also show a higher coefficient of variation than countries. In other words, certain

[20] A separate paper (under preparation) describes the Swedish regional distribution of unadjusted and quality-adjusted patenting (Ejermo, 2006).

regions are patenting hubs. This pattern is not as marked among countries. The differences are more pronounced for both countries and regions when we use weighted specialization rather than unweighted.

5 TECHNOLOGY SPECIALIZATION AND EXPORT FLOWS

As stated in the introduction, the purpose of the paper is to analyze (i) the relationship between technology specialization and export specialization across regions and (ii) how the technology specialization of origin and destination affect the size and structure of link-specific export flows. This section presents empirical analyses of these two issues.

5.1 Technology specialization and export specialization

This section tests the first hypothesis of Section 2: in a given time period, the export specialization of a region is positively associated with the technology specialization of the region. This hypothesis is tested by relating export specialization (*ESI*) to technology specialization (*TSI*) presented. Given that citations-weighted patents are interpreted as 'quality-adjusted' patents, we should expect a stronger correlation between the export specialization and the technology specialization based on citations-weighted patents.

The first question is if there is any difference in the technology specialization across regions whether we use Sweden or the group of European countries as point of reference. The correlation coefficient between TSI_{rs}^{II} and TSI_{rs}^{III} amounts to 0.98 and is significant at the 0.01 level. Similarly, the correlation between TSI_{rs}^{IIw} and TSI_{rs}^{IIIw} is 0.94 and is also significant at the 0.01 level. Thus, it matters little if we use Sweden or the European countries as point of reference. In what follows, we stick to using European countries as reference point.

In order to test for a relationship between technological specialization and export specialization the export specialization variable, ESI_{rs}, and the technology specialization variables, TSI_{rs}^{II} and TSI_{rs}^{IIw}, are categorized individually into three categories, according to equal percentiles. Category 1 refers to a low value (specialization) and category 3 refers to a high values (specialization). Table 3 and 4 presents contingency matrices of categories based ESI_{rs} and TSI_{rs}^{II} as well as ESI_{rs} and TSI_{rs}^{IIw}, respectively. There are 81 regions and 43 sectors so there are 3 483 observations in total.

The χ^2 associated with Table 3 and 4 is 371.61 and 300.51 respectively and significant at the 0.01 level. Thus, the null hypothesis of no association between export specialization and the two measures of technology specialization can be rejected. From the ratios between the observed and expected number of observations, it is evident that the relationships are diagonal, i.e. high technology specialization in a given sector corresponds to a high value for export specialization in the same sector.

>> TABLE 3 ABOUT HERE <<

>> TABLE 4 ABOUT HERE <<

As a further test we regress ESI_{rs} on TSI_{rs}^{II} and TSI_{rs}^{IIw}, respectively, and include dummies for each sector to control for heterogeneity among sectors. The results of this undertaking are presented in Table 5.

>> TABLE 5 ABOUT HERE <<

The coefficient estimate of each measure of technology specialization is statistically significant. The results thus clearly confirm a positive relationship between export and technology specialization. Moreoever, the R^2 and the *t*-value of the estimated coefficients both increase when using citations-weighted specialization measures. This point towards that citations-weighted patents are more appropriate to use than raw patent counts, as confirmed in previous literature (both empirically and theoretically). In the subsequent analysis, we focus only on citations-weighted measures of specialization.

5.2 Technology specialization in destination and origin and the size and composition of export flows

This section analyzes the effect of technology specialization in destination and origin on the size of export flows. The general structure of the unconstrained open gravity model is applied in the analysis.

Gravity models are associated with empirical success in trade analyses and provide an intuitive general modeling structure for assessments of how attributes in origins and destinations as well as of links affect trade flows. Early motivations for gravity models rested upon an economic analog to Newton's gravitational forces. The use of gravity models in trade analyses dates back to Tinbergen (1962), Pöyhönen (1963), Leontief & Strout (1963) and Linnemann (1966). Theoretical foundations for the gravity model came with Anderson (1979) and Bergstrand (1985) who derived gravity models by adhering to product differentiation.

(15) provides a general formulation of the open gravity model:

$$X_{rs} = A\prod_{i\in M} O_{r,i}^{\alpha_i} \prod_{j\in N} D_{s,j}^{\beta_j} f(r,s) \tag{15}$$

where X_{rs} denotes export flows from region r to s and A is a constant. The set $M = \{1,...i...,m\}$ contains pertinent attributes of origin r and $O_{r,i}$ denotes r's value (or size) as regards attribute $i \in M$. $N = \{1,...j...,n\}$ and $D_{s,j}$ are defined analogously. $f(r,s)$ is a function describing the attributes of the link between region *r* and *i*. The typical attribute in origin and destination is GDP, which is assumed to reflect the supply capacity and potential demand, respectively.

The specification applied in the subsequent analysis builds on the general formulation in (15) and includes the technology specialization as a pertinent attribute of both origin and destination. Specifically, the size of the export flows from region *r* to country *i*, measured in export values, in sector *s*, $X_{ri,s}$, is specified as a function of:

- The export capacity of origin *r* in sector *s*, proxied by the number of export firms in sector *s* in the region, $N_{r,s}$
- Origin *r*'s technology specialization in sector *s*, $TS_{r,s}$
- The size of the potential demand (GDP) in the destination country, Y_i
- Destination country *i*'s technology specialization in sector *s* $TS_{i,s}$
- The distance between origin and destination, d_{ri}, in kilometers[21]

The model described above is formulated in (16) below:

$$X_{ri,s} = AY_i^{\alpha} N_{r,s}^{\beta} TS_{i,s}^{\varphi} TS_{r,s}^{\gamma} e^{\{-\lambda d_{ri}\}} \qquad (16)$$

which assumes an exponential distance-decay function. Such a non-linear function is motivated by the unambiguous observation that transport costs per kilometer are more often than not lower for long-distance haulages compared to short-distance ones.

Taking natural logs, denoted by small letters, the model to be estimated takes the following form:

$$x_{ri,s} = a + \alpha y_i + \beta n_{r,s} + \varphi ts_{i,s} + \gamma ts_{r,s} \ldots$$
$$\ldots - \lambda d_{ri} + \sum_{\sigma=1}^{43} \theta_{\sigma} D_{\sigma} + \sum_{\delta=1}^{81} \rho_{\delta} D_{\delta} + \varepsilon_{ri,s} \qquad (17)$$

[21] Appendix B shows the formula for calculating the distance using latitude and longitudinal data.

where D_σ is a sector dummy to control for heterogeneity across sectors, with $D_\sigma = 1$ when $\sigma = s$ and $D_\sigma = 0$ otherwise. Moreover, D_δ is a region dummy with $D_\delta = 1$ if $\delta = r$ and $D_\delta = 0$ otherwise. The difference between the model in (17) and a standard one-sided[22] open gravity specification is the inclusion of the technology specialization of the origin (region) and destination (country). The model above allows for an estimation of the effect of the technology specialization in origin and destination on the size of the export flows.

The model in (17) explains the size of the export flows, but the same model is used to analyze how the prices of the export flows vary with the technology specialization in origin and destination. Thus, exactly the same model is used to test the second hypothesis in the paper, where the size of the export flows is substituted for the average prices of the export flows on the left-hand-side. This way of altering the specification can be motivated by observing that $\ln X_{ri,s} = \ln \overline{P}_{ri,s} + \ln V_{ri,s}$, where $\overline{P}_{ri,s}$ is the average price (per volume unit) and $V_{ri,s}$ the total volume of the export flows from *r* to *i* in sector *s*. Thus, $\overline{p}_{ri,s} \equiv \ln \overline{P}_{ri,s}$ is regressed on the right-hand-side of (17).

The model is estimated on cross-section data by means of a fixed effects model with sector and region dummies. Correlations between all variables in (17), excluding dummies, is presented in Appendix C.[23] The results of the estimations are presented in Table 6. Models I and II use export values as the dependent variable and models III and IV use export prices. The table also reports the results when we use raw counts of citations-weighted patents instead of technology specialization measures.

[22]The model is one-sided since it only includes export from regions and their respective imports.
[23] The Variance Inflation Factors (VIF) associated with the variables indicates that multicollinearity is not a problem for any of the variables in the model.

First, for export values the parameter estimates of the potential demand (GDP) in the destination country is highly significant and has the expected sign. The elasticity varies from 0.45 in model I to 0.91 in model II. Similarly, the parameter estimate of the supply capacity in the origin region (number of export firms) is positive and significant. Distance has as expected a negative parameter estimate. As can be seen (model I), the size of the export flows (in terms of export value) from an origin region tend to be lower if the destination country has a high specialization in the same sector as the origin region. The same result emerges when using counts of citations-weighted patents. However, regions' with a high specialization in a given sector tend to export more in that sector. The parameter estimates of both TSI^{IIw} and citations-weighted patents in origin regions are significant and positive. The results thus suggest that technology specialization affect export performance.

>> TABLE 6 ABOUT HERE <<

When we examine the effects on export prices, we notice that GDP has an irregular effect. It only enters significantly in model IV with a negative sign, which is partly counter-intuitive. However, the partial correlation between GDP and prices is positive. Citations-weighted patent counts and GDP in destinations countries are correlated – the correlation coefficient amounts to 0.69 (see Appendix C) – so the results cannot unambiguously be interpreted as that prices are lower to destination countries with large GDP. The citations-weighted patent variable, however, dominates which supports hypothesis 2 and can thus be theoretically motivated. In addition, the parameter estimate for the technology specialization in the destination country is also positive and significant which lends further support for hypothesis 2. Hence, export flows from an origin region to destination countries with high specialization in a similar sector as the origin region is specialized in are characterized by flows of commodities in a higher segment of the quality ladder. Note here that the parameter estimates of technology specialization and number of citations-weighted patents in the origin region are significant and positive in the estimations with price as the dependent variable.

Moreover, the parameter estimate of distance is significant and positive in the estimations with price as the dependent variable. This indicates clearly that only high-value products can be shipped over longer distances, as the share of transport costs in the delivered prices of such goods remain low even over long distances. This is a classic result in location-theoretic models, (see e.g. Weber's (1909) location model in McCann, 2002). It can also be observed that the parameter estimate of the number of firms is significantly negative (-0.12). Thus, prices tend to be lower from regions with a large number of firms.

In summary, the results in Table 6 show that technology specialization affects both the size and the structure of export flows. The parameter estimates of the technology specialization variables of both origin regions and destination countries are significant in all specifications. Specifically, export flows to destination countries with similar technological specialization as the origin regions consist of commodities in a higher quality segment in the specific technology, as indicated by the prices of the export flows. Moreover, regions that have a high specialization in a given technology export more (in terms of export value) and charge higher prices of export commodities that correspond to the given technology.

6 SUMMARY AND CONCLUSIONS

This paper has studied the relationship between technology and exports, by using export and citations-weighted patent data. Two distinct hypotheses regarding technology and exports were deduced and tested. The first hypothesis was that technology is necessary not only to create, but also to maintain comparative advantages. As the technology specialization of a region is determined by the technology field or domain of the knowledge-creating activities in the region, the export specialization of a region should correspond to its technology specialization. The second hypothesis stated that technology specialization shapes the structure and composition of export flows. Specifically, trade flows from regions to destinations with similar technology specialization as the origin regions were expected to consist of highly specialized high-quality products within the sector associated with the pertinent technology, i.e. goods in a higher segment of the 'quality-ladder'.

The paper finds a strong correlation between technology specialization and export specialization across regions. It thus verifies that the endowment of knowledge is an important factor that needs to be considered in trade analyses. This also demonstrates that comparative advantages are dynamic in the sense that they can be 'upgraded' through investments in knowledge-building capabilities.

Moreover, the paper documents that the technology specialization in origin regions and destination countries affects the size and structure of trade flows. Export flows from regions to destination countries with similar technological specialization consist of commodities in a higher segment of the quality-ladder, as indicated by the prices of the export flows. Specialization in a technology associated with a sector brings about an ability meet the demand for high-quality products in the sector. Both export prices and the size of export flows (in terms of export value) in a sector are larger from regions with higher specialization in the technology associated with the sector. However, controlling for the size of potential demand in the destination country and the supply capacity of the origin region, export volumes are lower to destination countries with similar technology specialization(s) as the origin region.

The major conclusion from the study is that technology and knowledge shape export specialization patterns as well as the structure and composition of export flows. The study lends strong support for spatial product cycle models which explicitly includes endowments of knowledge and technology as determinants for trade patterns and recognizes quality as a pertinent attribute of export flows. The results of the paper thus imply that an understanding of trade ultimately requires an understanding of the spatial pattern of investments in (and creation of) technology and knowledge, as such investments (at least partly) shape specialization patterns and compositions of export flows in space.

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Appendix A. The NACE sectors.

The 43 NACE sectors in the study.

No.	Sector	No.	Sector
01	Food	23	Agro mach.
02	Tobacco	24	Machine-tools
03	Textiles	25	Special mach.
04	Wearing	26	Weapons
05	Leather	27	Domestic appl.
06	Wood products	28	Computers
07	Paper	29	Electr. motors
08	Publishing	30	Electr. distrib.
09	Petroleum	31	Accumulators
10	Basic chem.	32	Lightening
11	Pesticides	33	Other electr.
12	Paint	34	Electronic comp.
13	Pharma	35	Telecom
14	Soaps	36	Television
15	Other chem	37	Medical equip.
16	Man-m. fibres	38	Measuring instr.
17	Plastic prod.	39	Optics
18	Mineral prod.	40	Watches
19	Basic metals	41	Mot. Vehicles
20	Metal prod.	42	Other transp.
21	Energy mach.	43	Consumer goods
22	Non-sp. mach.		

Appendix B. Method for calculating distance using latitude and longitudinal data.

Set A = latitude of the first point, e.g. a Swedish region *r*, B = longitude of first point, C = latitude of second point, e.g. the location of a capital in a European country *i*, D = longitude of second point, where the numbers are given in decimal terms (not in minutes). If the longitude is east of the Greenwich meridian (true for most cases) a negative sign is put in front of the number before insertion into the formula that yields the distance between the two points:

$$d_{ri} = 6370 \cdot \arccos(\cos(\mathrm{rad}(90 - \mathrm{A})) \cdot \cos(\mathrm{rad}(90 - \mathrm{C})) + \sin(\mathrm{rad}(90 - \mathrm{A})) \cdot \sin(\mathrm{rad}(90 - \mathrm{C})) \cdot \cos(\mathrm{rad}(\mathrm{B} - \mathrm{D})))$$

, where 6370 is the approximate radius of earth in kilometers.

Appendix C. Correlations between variables in (17), excluding dummies.

	Export value	Export price	GDP	Patw origin	TSI^{IIw}	Patw destination	TSI^{Iw}	Distance	Number of firms
Export value	1	-	-	-	-	-	-	-	-
Export price	-0.236*	1	-	-	-	-	-	-	-
GDP	0.095*	0.020*	1	-	-	-	-	-	-
Patw origin	0.229*	0.086*	-0.003	1	-	-	-	-	-
TSI^{IIw}	0.156*	0.082*	0.007	0.945*	1	-	-	-	-
Patw destination	0.116*	0.051*	0.690*	0.110*	0.043*	1	-	-	-
TSI^{Iw}	-0.015*	0.046*	0.169*	0.033*	0.028*	0.285*	1	-	-
Distance	-0.155*	0.064*	0.114*	0.059*	0.055*	-0.080*	0.111*	1	-
Number of firms	0.453*	-0.061*	-0.008	0.542*	0.415*	0.044*	0.051*	0.100*	1

a) * denotes that correlation is significant at the 0.05 level (2-tailed).

Table 1. *Descriptive statistics for technology variables across sectors in investigated countries. SD – Standard Deviation, CV – coefficient of variation.*

	P_i				P_i^w					TSI_{is}^{I}				TSI_{is}^{Iw}				χ_P^2	$\chi_{P^w}^2$
	mean	SD	min	max	Mean	SD	min	max	CV	mean	SD	Min	max	mean	SD	min	max		
Austria	119.28	123.86	4.53	498.98	35.47	38.89	1.41	149.99	109.65	1.09	0.30	0.70	2.09	1.08	0.33	0.60	2.03	0.07	0.10
Belgium	142.22	178.16	2.64	743.15	71.72	93.69	1.47	364.49	130.63	0.97	0.40	0.46	1.95	0.96	0.57	0.34	2.69	0.15	0.29
Denmark	83.27	114.52	2.96	651.74	10.76	13.39	0.30	51.33	124.47	0.99	0.38	0.47	2.05	1.02	0.68	0.39	4.35	0.17	0.30
Finland	120.80	188.45	3.35	1 027.81	49.19	114.75	0.87	683.35	233.30	0.90	0.35	0.48	2.54	0.81	0.63	0.16	3.64	0.26	0.94
France	858.39	1 019.53	35.82	3 852.57	353.65	451.40	11.88	1 845.22	127.64	0.99	0.10	0.75	1.19	0.98	0.13	0.77	1.31	0.01	0.02
Germany	2 237.61	2 644.78	83.73	11 489.65	677.37	867.34	22.79	3 717.20	128.04	0.99	0.11	0.76	1.23	1.00	0.16	0.68	1.33	0.01	0.03
Greece	3.03	3.88	0.05	20.52	0.37	0.60	0.01	3.27	159.29	1.23	1.23	0.27	8.20	1.05	0.68	0.13	3.05	0.28	0.38
Ireland	16.68	19.94	0.41	83.59	3.74	4.53	0.11	20.45	121.18	1.01	0.37	0.61	2.52	1.04	0.42	0.41	2.40	0.11	0.18
Italy	425.73	449.65	15.67	1 719.67	205.78	219.05	8.32	825.27	106.45	1.07	0.28	0.73	2.39	1.11	0.38	0.70	2.81	0.04	0.07
Luxembourg	6.28	6.87	0.22	26.82	2.65	4.26	0.09	25.32	160.73	1.10	0.54	0.35	3.14	1.01	0.65	0.08	2.88	0.27	0.48
Netherlands	297.64	375.33	9.36	1 705.53	104.95	132.49	2.49	592.58	126.24	0.96	0.33	0.54	2.32	0.97	0.42	0.42	3.07	0.10	0.11
Norway	36.95	40.56	1.03	162.95	2.61	3.44	0.03	17.22	131.95	1.02	0.35	0.60	2.46	0.95	0.46	0.32	1.97	0.09	0.21
Portugal	3.07	4.10	0.08	21.48	0.61	1.02	0.01	5.75	167.13	1.09	0.52	0.44	3.16	0.95	0.81	0.02	5.19	0.15	0.54
Spain	70.42	76.16	1.97	321.53	26.08	29.78	1.00	118.99	114.19	1.05	0.26	0.69	2.01	1.01	0.23	0.64	1.81	0.05	0.05
Sweden	242.10	294.72	6.63	1 226.27	30.62	42.96	0.69	199.27	140.30	0.97	0.24	0.62	1.95	0.94	0.53	0.17	3.72	0.07	0.33
Switzerland	302.37	321.80	11.26	1 275.48	123.44	144.64	4.74	666.66	117.18	1.12	0.60	0.74	4.88	1.12	0.51	0.66	3.99	0.07	0.08
United Kingdom	625.97	802.82	21.02	3 623.72	199.34	271.71	4.86	1 153.73	136.30	0.96	0.21	0.64	1.60	0.93	0.24	0.46	1.52	0.04	0.07

Table 2. *Variation in specialization across countries and regions.*[a]

Measure	*Mean*	*SD*	*CV*	*min*	*Max*	*obs*
P_i (countries)	328.93	546.51	1.66	3.03	2 237.61	17
P_i (regions)	1.78	6.10	3.42	0.00	47.83	81
P_i^w (countries)	111.67	175.15	1.57	0.37	677.37	17
P_i^w (regions)	0.29	1.25	4.28	0.00	10.30	81
χ_P^2 (countries)	0.12	0.09	0.77	0.01	0.28	17
χ_P^2 (regions)	1.54	4.05	2.62	0.07	33.66	81
$\chi_{P^w}^2$ (countries)	0.25	0.24	0.98	0.02	0.94	17
$\chi_{P^w}^2$ (regions)	2.74	3.53	1.29	0.08	19.56	81

a) *CV* (coefficient of variation) defined as *SD* (std. dev) divided by the mean.

Table 3. *Contingency matrix between categories based on ESI and TSI*^{II}*. Categories constructed according to equal percentiles; 1=low 3=high).*[a,b]

		TSI_{rs}^{II}			
	Category	**1**	**2**	**3**	***No. obs***
ESI_{rs}	**1**	O/E = 1.54	O/E = 0.86	O/E = 0.59	**1 161**
	2	O/E = 0.92	O/E = 1.15	O/E = 0.93	**1 161**
	3	O/E = 0.53	O/E = 0.73	O/E = 1.48	**1 161**
	No. obs	**1 161**	**1 161**	**1 161**	**3 483**

a) O = actual observations in cell
b) E = expected number of observations in cell based on a random distribution.

Table 4. *Contingency matrix between categories based on ESI and TSI*^{IIw}*. Categories constructed according to equal percentiles; 1=low 3=high).*[a,b]

		TSI_{rs}^{IIw}			
	Category	**1**	**2**	**3**	***No. obs***
ESI_{rs}	**1**	O/E = 1.34	O/E = 1.19	O/E = 0.47	**1 161**
	2	O/E = 0.89	O/E = 1.04	O/E = 1.07	**1 161**
	3	O/E = 0.76	O/E = 0.77	O/E = 1.47	**1 161**
	No. obs	**1 161**	**1 161**	**1 161**	**3 483**

a) O = actual observations in cell
b) E = expected number of observations in cell based on a random distribution.

Table 5. *Regression coefficients for technology specialization variables (ESI dependent variable, significance at the 0.05 level indicated by a star)*[a,b].

	TSI_{rs}^{II}	TSI_{rs}^{IIw}
ESI_{rs}	0.28* (5.60)	0.30* (8.79)
No. obs	3 483	3 483
R^2	0.03	0.04

a) *t*-values within brackets.
b) Sector dummies not reported

Table 6. *Estimates of parameters in (17).* [a,b,c,d]

Variable	*Dependent variable: Export values*		*Dependent variable: Export prices*	
	I	II	III	IV
GDP (destination)	0.4507 (0.0205)***	0.9123 (0.0354)***	0.011 (0.0097)	-0.1014 (0.0173)***
Number of firms (origin)	1.7028 (0.0503)***	1.6973 (0.0506)***	-0.1156 (0.0260)***	-0.1244 (0.0262)***
Distance	-0.0011 (0.0000)***	-0.0013 (0.0000)***	0.0002 (0.0000)***	0.0003 (0.0000)***
TSI1W (destination)	-0.3269 (0.0432)***		0.0448 (0.0214)**	
TSI2W (origin)	0.1045 (0.0114)***		0.0116 (0.0057)**	
Patents weighted (destination)		-0.2727 (0.0154)***		0.0652 (0.0079)***
Patents weigthed (origin)		0.156 (0.0142)***		0.0134 (0.0072)*
No. obs	19 067	19 067	19 067	19 067
R^2	0.30	0.31	0.48	0.48

a) *** significance at the 1 % level, ** significance at the 5 % level, * significance at the 10 % level.
b) Sector and region dummies not shown.
c) Standard errors calculated according to White's (1980) heteroscedasticity-consistent covariance matrix.
d) Standard errors presented within brackets.

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