Technological Specialization as a Driving Force of Production Specialization

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Summary: The paper analyses the impact of the technological specializations of the EU-15 countries on their production specializations. A neoclassically inspired empirical model is specified and estimated to explain for the considered countries the value added shares of the manufacturing industries in the area of R&D-intensive technology as well as in the area of the remaining technology by technological differences and relative factor endowments. Technological specialization is approximated by the patent stocks in the areas of leading-edge, high-level and the remaining technology, while further technological differences are captured by indices of transferable knowledge and fixed country effects. The empirical results show that the technological specializations of the EU countries are an important driving force of their production specializations.

Zusammenfassung: Dieser Beitrag untersucht die Auswirkungen der technologischen Spezialisierungen der EU-Länder auf ihre Produktionsspezialisierungen. Es wird ein neoklassisch inspiriertes empirisches Modell spezifiziert und geschätzt, um für die betrachteten Länder die Wertschöpfungsanteile des Verarbeitenden Gewerbes im Bereich der FuE-intensiven Technik sowie der restlichen Technik durch die technologischen Differenzen und relativen Faktorausstattungen zu erklären. Dabei wird die technologische Spezialisierung durch die Patentbestände im Bereich der Spitzentechnik, der hochwertigen sowie der restlichen Technik approximiert, während weitere technologische Unterschiede durch Indizes transferierbaren Wissens und fixe Ländereffekte erfaßt werden. Die empirischen Befunde zeigen, daß die technologischen Spezialisierungen der EU-Länder eine wichtige Triebkraft ihrer Produktionsspezialisierungen sind.

1 Introduction

Classical economics already dealt with the question why countries specialize in the production and export of certain goods and the import of others. David Ricardo introduced the concept of comparative advantages, according to which countries should specialize in the production of those goods in which they have at least such a relative advantage. While Ricardo mainly considered technological differences which are reflected in different relative labor productivities to be the source of comparative advantages, technological differences are assumed away in the approach of Heckscher and Ohlin, and different relative factor endowments provide the cause for specialization. Meanwhile, a lot of generalizations of the Heckscher-Ohlin as well as of the Ricardo approach can be found in the theoretical literature. The former includes the so-called neo-endowment trade theory, which extends the two-factor model of trade to include a greater number of additional input factors, including scientific and technological assets, while keeping the assumption of an identical world production function. The latter was extended to include general technological differences, and influences determining varying productivities like returns to scale, R&D expenditures or patents are explicitly taken into account (e.g. Hirsch 1974; Blind and Jungmittag, 2005). Therefore, in demarcation to the original Ricardo approach, these approaches are subsumed under the label "neo-productivity theory".

The standard models as well as the augmented approaches were taken as a basis for some empirical studies to explain the foreign trade specialization of different countries. Especially the transfer of the simple factor endowment approaches to the real world often shows merely modest results (Bernstein and Weinstein, 1998). On the one hand, this experience and the observation that technical progress brings about changes of patterns of specialization, reductions of trade costs and hence larger trade volumes, has lead to the call that a more technologically oriented trade theory – and a corresponding empirical research – is needed, which emphasizes structural dynamics and enables conclusions to be drawn with regard to economic change (Helpman, 1998, 587).[1] On the other hand, some authors rightly point out that a large part of the approaches in the Heckscher-Ohlin tradition aims at explaining internationally different production specializations. Most of these approaches combine a sophisticated production model with a very simple model of consumption (cf. Harrigan, 1995, 1997; Bernstein andWeinstein, 1998; Harrigan and Zakrajšek, 2000; Schott, 2001). Therefore, in the opinion of these authors, it would be more revealing to empirically analyze the patterns of production specialization directly and not of foreign trade specialization.

However, the empirical content of explanation in those studies, which solely fall back on differences in factor endowments to explain production specializa-

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[1]Similarly, however more strongly tied to traditional trade theory, Krugman and Obstfeld (1991), 83, also suggest "... to return to the Ricardian idea that trade is largely driven by international differences in technology rather than ressources".

tion, is also rather low (Harrigan, 1995; Bernstein and Weinstein, 1998; Schott, 2001). Besides differences in factor endowments, Reeve (2006) uses some further industry-specific factors (like the degree of unionization, regulations and trade policies) to explain industry structures and shows that the aggregate factor endowments, independently of industry idiosyncrasies, clearly contribute to the explanation of the structures of production. With regard to economic policy, he concludes from his results that investment in physical capital and education may have as great an impact on production patterns as sector-specific trade and industrial policies.

However, the attempts at explanations become more successful in all, if it is assumed – as done by Harrigan (1997) as well as Harrigan and Zakrajšek (2000) – that differences in relative factor endowments and technologies together determine comparative advantages. In these two studies the specification of a neoclassically inspired empirical model is based on the so-called gross domestic product function approach, which is described in depth within a time series context by Kohli (1991), but is now adapted to panel data. Harrigan (1997) uses sectoral total factor productivities as residuals based on the index number approach of Caves et al. (1982) to measure technological differences, while Harrigan and Zakrajšek (2000) capture the developments of technological levels solely by fixed country and time effects. Here the approach of Harrigan (1997) and Harrigan and Zakrajšek (2000) is taken up to explain the production specializations of the EU countries in the area of R&D-intensive technology as well as in the area of the remaining technology – measured by the value added shares in each case – for the period from 1970 to 1996. However, with regard to the consideration of the technological level, I will differentiate, unlike the aforementioned authors, between accumulated innovations (the patent stocks in the area of leading-edge, high-level and the remaining technology) and other components (transferable knowledge and the unexplained residual). As a result, the empirical findings show that the technological specializations of EU countries are an important driving force of their production specializations.

This paper proceeds in four parts. The description of the theoretical approach and the derivation of the empirical model follows in section 2. The database is discussed in section 3. In this context, especially issues with regard to the definitions of leading-edge, high-level and remaining technology as well as with regard to the calculation of patent stocks are addressed. Section 4 contains the empirical results and finally, a summary and some conclusions are presented in section 5.

2   Theoretical Approach and Empirical Modeling

The theoretical approach, which forms the basis for the empirical model used to analyze the production specialization, follows the standard derivation of income or revenue functions according to Dixit and Norman (1980). Only some of the

usual neoclassical assumptions are needed. Production takes place with constant returns to scale, so that the individual production factors have decreasing marginal returns. Furthermore, market clearing takes place at competition.[2] Finally, the factor supplies are fixed and exogenously given. The same applies to the prices, what implies that a small open economy is taken as a basis for this approach. Under these assumptions the value of final production (of the GDP) is maximized in a general equilibrium. This maximization problem can be written as

$$\mathbf{p}'\mathbf{y} \longrightarrow \max \ \text{subject to } \mathbf{y} \in Y\left(\mathbf{v}\right) \tag{1}$$
$$\mathbf{p}, \mathbf{y} \in \mathbb{R}^{M}, \ \mathbf{v} \in \mathbb{R}^{K},$$

where $\mathbf{y}$ is the vector of the final products and $\mathbf{p}$ is the vector of their prices. Furthermore, $Y\left(\mathbf{v}\right)$ is the concave volume of production, which depends on the factor endowments $\mathbf{v}$. In a macroeconomic view the elements of $\mathbf{y}$ represent the value added of the individual industries of the economy. In the following empirical analysis the value added shares of the manufacturing industry, on the one hand, in the area of R&D-intensive technology and, on the other hand, in the area of the remaining technology in GDP are explained.[3] Thus the definition of specialization resulting from this model differs due to its connection to GDP from the definition usually used, according to which total value added of the manufacturing industry (more or less the tradeable goods) serves as a standard of comparison.[4]

The solution of this problem gives the income function for the maximized value of GDP as

$$Y = r\left(\mathbf{p}, \mathbf{v}\right). \tag{2}$$

This function is homogeneous of degree 1 in $\mathbf{p}$ and $\mathbf{v}$. If it is assumed that it is twice differentiable, which requires complete substitutability among input factors and at least as many factors as goods $(K \geq M)$, Hotelling's Lemma can be used to determine a vector of net output supply functions as the gradient of $r\left(\mathbf{p}, \mathbf{v}\right)$ with respect to the output prices:

$$\mathbf{y} = r_{p}\left(\mathbf{p}, \mathbf{v}\right). \tag{3}$$

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[2] Although this assumption is often found in the literature, it is not unproblematic. In the case of a strong specialization in R&D-intensive goods Schumpeterian innovation processes, which are particularly characterized by departures from perfect competition, might be relevant to a considerable extent. Therefore, at least for some of the considered product groups, it would be more appropriate to assume monopolistic competition. However, then the theoretical approach could not be derived in this comfortable and clear way.

[3] A further division of the area of R&D-intensive technology in the areas of leading-edge and high-level technology would certainly be desirable, but due to the available value added data in the OECD STAN database, such a differentiation is only possible for a much smaller group of EU countries for different subperiods.

[4] To this definition of specialization differing from the usual definition, cf. also Harrigan and Zakrajšek (2000), 10.

If there are more produced goods than factors, the output vector maximizing GDP is not unique and the gradient $r_p(\mathbf{p}, \mathbf{v})$ must be be reinterpreted as a set of subgradient vectors (Harrigan, 1997, 477). The potential indeterminacy of the output, however, is an empirical issue in the framework of the analysis carried out here, and differentiability of $r(\mathbf{p}, \mathbf{v})$ is only assumed for a more convenient exposition of the theoretical approach (cf. Harrigan and Zakrajšek, 2000, 5).

For the derivation of the theoretical approach it has been assumed thus far that the same technology is used across countries, so that output internationally differs depending only on $\mathbf{p}$ and $\mathbf{v}$. If it would be assumed that technologies differ arbitrarily across countries, equation (3) would be unsuited for cross-country analyses. However, things look differently if the usual restricting differentiation between different kinds of technical progress is applied. Then, augmented versions of equation (3) can be used to analyze variations of the output and its composition across countries and over time.

A first possibility is to suppose Hicks-neutral technological differences across countries and over time. Now let a sectoral production function for good $j = 1, ..., M$ be

$$\breve{y}_j = A_j \cdot f^j\left(\mathbf{v}^j\right) = A_j y_j, \tag{4}$$

where A_j is an efficiency scalar for industry j in country n in year t, relative to a numéraire country and a base period.[5] The resulting output supply functions are then

$$\mathbf{y} = r_p\left(\mathbf{A}\mathbf{p}, \mathbf{v}\right), \tag{5}$$

where $\mathbf{A} = \mathrm{diag}\{A_j\}$ is a diagonal matrix of Hicks-neutral technological differences. Thus, industry-specific Hicks-neutral technological differences lead to good-specific price differences, and a change in technology has the same effect on income as a price change (Dixit and Norman, 1980, 138).

Secondly, it can be assumed that technical progress is factor augmenting. In this case the supply functions are given by

$$\mathbf{y} = r_p\left(\mathbf{p}, \mathbf{A}\mathbf{v}\right). \tag{6}$$

Now $\mathbf{A} = \mathrm{diag}\{A_i\}$, $i = 1, ..., K$, is a diagonal matrix of factor augmenting technological differences, and a change in the efficiency parameter has the same effect as a change in factor endowments (Dixit and Norman, 1980, 139).

We get the output shares of the interesting sectors in GDP by multiplying both sides of the equations (3), (5) or (6) by a matrix $\mathbf{P} = \mathrm{diag}\{p_j\}$ and dividing by nominal GDP Y. In the case of equation (3), we obtain

$$\mathbf{s} = \frac{1}{Y}\mathbf{P} \cdot \mathbf{y}(\mathbf{p}, \mathbf{v}), \quad \mathbf{s} \in S^{M-1}, \tag{7}$$

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[5]For the sake of a simpler notation, the country and time indices are dropped in the further derivation of the theoretical approach.

where $\mathbf{s}$ is the vector of output shares and S^{M-1} is the unit simplex. These share equations are homogeneous of degree 0 in $\mathbf{p}$ and $\mathbf{v}$, so that the shares will remain constant in the case of a proportional change of all output prices or factor endowments.

To convert the theoretical approach into an empirical model, it is assumed that the revenue function can be approximated by a transcendental logarithmic – or shortly translog – function. This very flexible function, which was already used by Kmenta (1967) as well as Christensen et al. (1971) and formally introduced by Berndt and Christensen (1973) as well as Christensen et al. (1973), is a second-order Taylor approximation to any logarithmic function. Thus, the logarithmic revenue function without technical progress can be written as

$$\ln r\left(\mathbf{p}, \mathbf{v}\right) = a_{00} + \sum_{j=1}^{M} a_{0j} \ln p_j + \frac{1}{2} \sum_{j=1}^{M} \sum_{m=1}^{M} a_{jm} \ln p_j \ln p_m$$

$$+ \sum_{i=1}^{K} b_{0i} \ln v_i + \frac{1}{2} \sum_{i=1}^{K} \sum_{k=1}^{K} b_{ik} \ln v_i \ln v_k$$

$$+ \sum_{j=1}^{M} \sum_{i=1}^{K} c_{ji} \ln p_j \ln v_i \qquad (8)$$

From a theoretical view, symmetry of the cross effects requires that $a_{jm} = a_{mj}$ and $b_{ik} = b_{ki}$, and linear homogeneity requires: $\sum_{j=1}^{M} a_{0j} = 1$, $\sum_{i=1}^{K} b_{0i} = 1$, $\sum_{j=1}^{M} a_{jm} = 0$, $\sum_{i=1}^{K} b_{ik} = 0$ and $\sum_{i=1}^{K} c_{ji} = 0$.

Differentiating equation (8) with respect to each $\ln p_j$ gives the the shares $s_j = p_j \cdot y_j / Y$ of each sector j in GDP as a function of goods prices and factor supplies, namely by incorporation of the country and time indices n and t:

$$s_{jnt} = a_{0j} + \sum_{m=1}^{M} a_{jm} \ln p_{mnt} + \sum_{i=1}^{K} c_{ji} \ln v_{int}. \qquad (9)$$

If the share equations are homogeneous of degree 0 in $\mathbf{p}$ and $\mathbf{v}$, the restrictions $\sum_{m=1}^{M} a_{jm} = \sum_{i=1}^{K} c_{ji} = 0$ must be valid, so that the system of equations (9) can be rewritten as

$$s_{jnt} = a_{0j} + \sum_{m=2}^{M} a_{jm} \ln \frac{p_{mnt}}{p_{1nt}} + \sum_{i=2}^{K} c_{ji} \ln \frac{v_{int}}{v_{1nt}}. \qquad (10)$$

Whether these restrictions are actually valid must be tested in the course of the estimation.

If it is supposed that the technological differences across countries are Hicks-neutral, it follows for the unrestricted share equations system

$$s_{jnt} = a_{0j} + \sum_{m=1}^{M} a_{jm} \ln p_{mnt} + \sum_{m=1}^{M} a_{jm} \ln A_{mnt} + \sum_{i=1}^{K} c_{ji} \ln v_{int}. \qquad (11)$$

Analogously, we have in the case of factor-augmenting technological differences

$$s_{jnt} = a_{0j} + \sum_{m=1}^{M} a_{jm} \ln p_{mnt} + \sum_{i=1}^{K} c_{ji} \ln v_{int} + \sum_{i=1}^{K} c_{ji} \ln A_{int}. \qquad (12)$$

For the empirical implementation it should be assumed that part of the technological differences can be approximated, on the one hand, by the patent stocks in the area of leading-edge technology (P^{LE}), high-level technology (P^{HL}) as well as the remaining technology (P^{RT}), and, on the other hand, by transferable knowledge (T).[6] For the remaining technological differences it is supposed that they are constant over time but otherwise unrestricted, so that they can be approximated by fixed country effects. Furthermore, due to the different possible impact channels no a priori decision is made whether the technological differences are Hicks-neutral or factor-augmenting. Thus, the system of share equations can be rewritten as

$$s_{jnt} = a_{0j} + r_{jn} + \sum_{m=1}^{M} a_{jm} \ln p_{mnt} + \sum_{i=1}^{K} c_{ji} \ln v_{int}$$
$$+ d_{j1} \ln P_{nt}^{LE} + d_{j2} \ln P_{nt}^{HL} + d_{j3} \ln P_{nt}^{RT} + d_{j4} \ln T_{nt}. \qquad (13)$$

A further problem on the way to a feasible empirical model is that internationally comparable goods prices are not available. Therefore, following Harrigan (1997) as well as Harrigan and Zakrajšek (2000), it is assumed that free trade leads to international goods prices equalization, so that the country index for the prices can be dropped, and thus $\sum_{m=1}^{M} a_{jm} \ln p_{mt}$ can be depicted by fixed time effects τ_{jt}. The system of share equations now becomes:

$$s_{jnt} = a_{0j} + r_{jn} + \tau_{jt} + \sum_{i=1}^{K} c_{ji} \ln v_{int}$$
$$+ d_{j1} \ln P_{nt}^{LE} + d_{j2} \ln P_{nt}^{HL} + d_{j3} \ln P_{nt}^{RT} + d_{j4} \ln T_{nt}. \qquad (14)$$

However, such a model would only be justified if all goods were internationally tradeable. Actually, each country produces internationally nontraded goods and above all services as well. Therefore, let the total vector of the goods prices $\mathbf{p}$ be partitioned into

$$\mathbf{p} = \left[\mathbf{p}^T \ \mathbf{p}^N \right], \qquad (15)$$

where $\mathbf{p}^T$ is a $(M_1 \times 1)$-vector of the prices of traded goods and $\mathbf{p}^N$ is a $(M_2 \times 1)$-vector of the prices of nontraded goods. Accordingly, the system of share equa-

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[6]The transferable knowledge is captured – as it will be explained in detail below – by an index calculated on the basis of the estimation results in Jungmittag (2004).

tions would become

$$
s_{jnt} = a_{0j} + r_{jn} + \tau_{jt} + \sum_{m=M_1+1}^{M} a_{jm} \ln p_{mnt}^{N} + \sum_{i=1}^{K} c_{ji} \ln v_{int}
$$
$$
+ d_{j1} \ln P_{nt}^{LE} + d_{j2} \ln P_{nt}^{HL} + d_{j3} \ln P_{nt}^{RT} + d_{j4} \ln T_{nt}. \qquad (16)
$$

Since prices for nontraded goods are also unavailable, among other things because these variables hardly can be measured in an internationally comparable manner and are therefore for practical purposes unobservable, it is assumed that their effects can be captured by a random variable ε_{jnt} with fixed country effects η_{jn}, fixed time effects μ_{jt} and a random component e_{jnt} with constant variance σ_j^2, thus

$$
\varepsilon_{jnt} = \sum_{m=M_1+1}^{M} a_{jm} \ln p_{mnt}^{N} = \eta_{jn} + \mu_{jt} + e_{jnt}. \qquad (17)
$$

Summarizing the fixed country and time effects from the equation systems (16) and (17) yields the estimable empirical model as

$$
s_{jnt} = a_{0j} + \gamma_{jn} + \delta_{jt} + \sum_{i=1}^{K} c_{ji} \ln v_{int}
$$
$$
+ d_{j1} \ln P_{nt}^{LE} + d_{j2} \ln P_{nt}^{HL} + d_{j3} \ln P_{nt}^{RT} + d_{j4} \ln T_{nt} + e_{jnt}, \qquad (18)
$$

with $\gamma_{jn} = r_{jn} + \eta_{jn}$ and $\delta_{jt} = \tau_{jt} + \mu_{jt}$. If no restrictions are imposed on the model, it can be estimated as a multivariate linear regression model by using simple OLS. However, if some or all restrictions derived from the theoretical approach are valid, which cause cross-equation restrictions among the system of output share equations, the SURE estimator can be used, which is in this case an asymptotically efficient GLS estimator (cf. e.g. Greene, 2003, 366 - 369).

3 Data Issues

Before the results of the econometric estimations are presented, some issues with regard to data used should be discussed. Nominal value added data for the industries of the manufacturing sector are taken from the OECD STAN database, and its differentiation into R&D-intensive and remaining technology was carried out – with reference to ISIC2 – according to the high-technology list jointly developed at the Fraunhofer Institute for Systems and Innovation Research and the Lower Saxonian Institute for Economic Research (cf. Grupp et al., 2000). According to the criteria of this list, all industries with an R&D intensity above 3.5% are categorized as R&D-intensive. This group is further subdivided into industries in the area of high-level technology with a R&D intensity between 3.5% and 8.5% and industries in the area of leading-edge technology with a R&D intensity above 8.5% (see table 1). The value added data obtained in this manner

Table 1: Concordance between ISIC2 and SIC for the R&D-intensive industries

ISIC2	Description	SIC (USPTO sequence number)
	Leading-edge technology	
3522	Drugs and medicines	14
3825	Office and computing machinery	27
3832	Radio, TV and communication equipment	42+43
3845 (and partly 3829)	Aircraft, guided missiles and space vehicles	47, 54
	High-level technology	
351+352 (without 3522)	Chemicals ex. drugs	6-9, 11-13
382 (without 3825)	Non-electrical machinery (ex. office and computing machinery)	23-26, 29-32
383 (without 3832)	Electrical machinery (ex. radio, TV, communication equipment)	35+36, 38-40
3843	Motor vehicles	46
3841+3842+3844+3849	Other transport equipment	49-53
385	Professional goods	55

were divided by nominal GDPs of the countries considered, which come from the national accounts statistics of the OECD. These output share data are available for 13 EU countries (excluding Ireland and Luxemburg), normally from 1970 until 1996.

Capital stock data are taken from the AMECO database of the DG ECFIN of the European Commission. The employment numbers, which also come from this source, are used, on the one hand, as a homogeneous input factor. On the other hand, they are alternatively subdivided into workers with low, medium and high qualifications. Low-skilled workers have no secondary education, however in most cases a primary education. Medium-skilled workers have a certain secondary education but no higher education, and high-skilled workers are at least equipped with a certain higher education. The shares required for this subdivision were calculated on the basis of the data on educational attainment from Barro and Lee (2000), which can be downloaded from www.cid.harvard.edu/ciddata/ciddata.html. This data set contains estimates of the shares of these three educational attainment groups for the population aged 15 and over at five-year intervals between 1960 and 2000. Therefore, the intervening values for the considered period from 1970 until 1996 were interpolated. The application of the shares for the popula-

tion to employment is surely not unproblematic, but it is the only possibility to obtain internationally comparable data for such a long period.[7] Furthermore, as a third production factor the areas of agricultural land, which come from World Development Indicators of the Worldbank, are taken into account.

The patent stocks for the areas of leading-edge, high-level and remaining technology were calculated from the patents granted to the considered EU countries at the US Patent and Trademark Office. For assigning the patents granted, which are originally classified according to the US SIC from 1972, to the grouping of the R&D-intensive industries, which is based on ISIC2, I developed a commensurate concordance (see also table 1). Afterwards, the patent stocks for the three areas of technology were calculated.

With regard to the calculation of patent stocks from patents granted, two opposite opinions predominate in the literature. In the one vein of literature, the view is taken that the economically relevant life time of a patent is much longer than its legal life. Thus, for example, Cantwell and Anderson (1996) as well as Cantwell and Piscitello (2000) calculate patent stocks by accumulating patents over a thirty-year period and assuming thereby a linear depreciation function as in vintage capital models, i.e. the current number of patents is weighted with 1, those of the previous periods with factors from 29/30 to 1/30. They justify their assumption with the hint that new technical knowledge is partly embodied in new equipment or devices, which have an average life span of 30 years. Zachariadis (2000), who calculates patent stocks using the perpetual inventory method with a depreciation rate of 7 per cent, puts forward a similar argument by pointing out that his rate would correspond with this century's average annual rate of technological obsolescence estimated by Caballero and Jaffe (1993).

In the other vein of literature, the opinion is held that the economically relevant life span of a patent is much shorter than its legally possible life. As evidence for it, among other things, the analysis of Mansfield et al. (1981) is quoted, which shows that 60 per cent of all patents are invented at most 4 years ago. Therefore many authors use a depreciation rate of 15 per cent in their calculations of patent stocks by means of the perpetual inventory method, which implies a average life of $6.\bar{6}$ years (e.g., Lach, 1995; Hall et al., 2001). Other authors use even higher depreciation rates of 20 per cent (e.g., Henderson and Cockburn, 1996; Agrawal and Henderson, 2001) or 30 per cent (e.g., Cockburn and Griliches, 1988; Blundell et al., 1998).

I also assume a depreciation rate $\mu = 0.15$ for the calculation of patent stocks, but the problem of calculating a initial stock is avoided by following the suggestion of Heeley et al. (2000) to confine the depreciation of the patent stock to a period lasting only several years.[8] Here, a six year period is used, such that the patent

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[7]This approach was also chosen in Harrigan (1997) and Harrigan and Zakrajšek (2000). A justification for the choice of this approach in contrast to a occupation-based classification of workers is given in Harrigan (1997), 481.

[8]Assuming that the number of annual patents granted evolved in the past with the

stock P_{nt} is given by

$$P_{nt} = \sum_{\tau=t-5}^{t} (1 - \mu)^{(t-\tau)} P_{n\tau}^{gr}, \tag{19}$$

where P_{nt}^{gr} is the number of US patents granted to EU country n in year t.

Furthermore, the contributions of transferable knowledge to growth from the decomposition results calculated in Jungmittag (2004) on the basis of an econometric growth model for the EU15-countries were linked – starting with 1 in 1968 – to form an index of the level of transferable knowledge. Altogether, 337 observations are available for the panel data estimation.

4   Results of Empirical Analysis

The estimation results for the production specialization – measured as the percentage share of manufacturing's value added in the whole R&D-intensive area or in the area of the remaining technology in GDP – subject to a homogeneous factor labor are displayed in table 2. The individual estimates of the coefficients could be interpreted to indicate how many percentage points the shares will change if the value of the corresponding explanatory variable were to increase by one per cent.

The second and third column of the table contain the estimation results for the unrestricted model, where it is not assumed a priori that the factor supply effects are homogeneous of degree zero. The value added shares of the R&D-intensive industries are positively influenced by the patent stocks in the area of leading-edge technologies, while the patent stocks in the area of high-level technology do not show a significant impact. Furthermore, there are no spillover effects from the patent stocks in the area of the remaining technology. At the same time, the indices of transferable technical knowledge exert a positive proportional influence, because the squared logs of the indices are not statistically significant and are thus excluded from the estimated equation. With regard to the factor supplies, the capital stocks do not have a significant influence on the value added shares of the R&D-intensive industries, while the effect of the factor labor is highly significantly negative. Moreover, the impact of the factor arable land is at least at a significance level of ten per cent different from zero.

Inversely related to the value added shares of the R&D-intensive industries, the patent stocks in the area of the remaining technology contribute highly significantly to the explanation of the value added shares of the industries in this area. By contrast, there are no positive spillover effects from the patent stocks in the areas of leading-edge and high-level technology. Furthermore, the transferable

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same average rate g as in the observation period, an initial stock may be calculated as $P_{n0} = P_{n0}^{gr} \left[(1 + g) / (\mu + g) \right]$; for several EU countries, however, the number of patents granted is zero in the first available year 1963, especially when patents granted in the area of leading-edge or high-level technology are considered.

Table 2: SURE estimates of the GDP share equations with homogeneous labor endowments

Variable	Unrestricted model		Restricted model	
	R&D-intensive industries	Remaining industries	R&D-intensive industries	Remaining industries
Patent stock				
leading-edge	0.521	-0.355	0.542	-0.303
	$(3.37)^{a)}$	(-1.40)	(3.67)	(-1.25)
high-level	-0.316	-0.506	-0.476	-0.597
	(-1.25)	(-1.23)	(-2.25)	(-1.73)
remaining	0.046	0.970	-0.066	0.900
	(0.25)	(3.22)	(-0.43)	(3.65)
Transferable	5.509	47.795	6.319	49.608
knowledge	(3.18)	(7.15)	(4.37)	(7.88)
Transferable		-62.847		-64.184
knowledge squared		(-6.59)		(-7.54)
Capital	0.216	-0.797	0.461	-0.386
	(0.28)	(-0.63)	(0.69)	(-0.34)
Labor	-2.323	-3.907	-2.263	-3.651
	(-2.59)	(-2.52)	(-2.76)	(-2.60)
Land	1.662	3.467	1.802	4.037
	(1.91)	(2.46)	(2.83)	(3.90)
$R^2_{adj.}$	0.936	0.905	0.936	0.906
Wald tests				
Homogeneity of	$1.374^{b)}$	0.085		
patent stocks	$(0.241)^{c)}$	(0.771)		
Homogeneity of	0.117	0.341		
factor stocks	(0.732)	(0.560)		
Simultaneous test	1.822			
of homogeneity	(0.769)			
Country effects	1046.86	974.83	4272.32	1657.06
	(0.000)	(0.000)	(0.000)	(0.000)
Time effects	99.17	93.45	136.14	124.98
	(0.000)	(0.000)	(0.000)	(0.000)
Turning point transferable knowledge		1.463		1.472

$^{a)}$ t-values in parentheses

$^{b)}$ χ^2-value

$^{c)}$ Significance levels in parentheses

knowledge shows for the values observed within the sample, which range from 1.015 to 1.676 with a mean of 1.238 and a median of 1.219, a highly significant positive effect. However, this impact grows initially only underproportionately

with the transferable knowledge and from 1.463 upwards the impact decreases, as the additional significance of the coefficient for the squared logarithmic indices shows. With regard to the influence of the factor endowments, a similar picture to the production specialization in the area of R&D-intensive technologies emerges, but the negative effect of the factor labor and the positive effect of arable land are clearly stronger.

Altogether, the model shows a good fitting with adjusted R^2's of 0.936 and 0.905. Moreover, the null hypotheses of the Wald tests that the patent stocks and factor endowments are homogeneous of degree zero cannot be rejected in all four cases. This also applies to the simultaneous test of the four degrees of homogeneity. Thus, with regard to these variables only the relative factor endowments and patent stocks are relevant for the value added shares of the R&D-intensive and remaining industries. Furthermore, the fixed country and time effects are highly significantly different from zero. The time effects show in both equations a distinct negative trend, which, however, is far stronger for the value added shares of the remaining industries.

The columns 4 and 5 of table 2 display the estimates of the model explicitly taking into account the permissible homogeneity restrictions. Only one essential difference arises. It must be assumed at a significance level of five per cent that the influence of the patent stocks in the area of high-level technology is negative in both equations. In the case of the share equation for the remaining industries, this result indicates that innovations in the areas of high-level and the remaining technology compete with each other. For the R&D-intensive industries, on the other hand, it appears that increases of the value added shares are mainly the result of innovations in the area of leading-edge technology, while a strong orientation on innovations in the area of high-level technology more likely threatens them.

Alternatively to the just presented estimates, table 3 shows the models with labor endowments differentiated by three levels of qualifications. The unrestricted estimates, which are again displayed in the second and third column, indicate that the impact of the patent stocks in the share equation for the R&D-intensive industries remains for the most part unchanged, while the share equation for the remaining industries already confirms here the competitive relation between the patent stocks in the areas of high-level and the remaining technology. The effects of the transferable technical knowledge also remain nearly unchanged, only the turning point of the influence on the value added shares of the remaining industries is already reached at 1.406. However, a marked difference occurs with regard to the capital stocks, which now affect the value added shares of the R&D-intensive industries significantly positively and the value added shares of the remaining industries significantly negatively.

At first glance, the estimated effects of the differentiated labor endowments on the value added shares of the R&D-intensive industries do not seem very plausible. According to them low-skilled labor has no effect, while medium- and high-skilled

Table 3: SURE estimates of the GDP share equations with differentiated labor endowments

Variable	Unrestricted model		Restricted model I		Restricted model II	
	R&D-int. industries	Remaining industries	R&D-int. industries	Remaining industries	R&D-int. industries	Remaining industries
Patent stock						
leading-edge	0.415	-0.230	0.438	-0.166	0.358	-0.282
	$(2.61)^{a)}$	(-0.94)	(2.78)	(-0.70)	(2.31)	(-1.18)
high-level	-0.239	-0.920	-0.221	-0.867	-0.177	-0.848
	(-0.94)	(-2.38)	(-0.92)	(-2.68)	(-0.74)	(-2.63)
remaining	0.244	1.040	0.236	1.033	0.328	1.130
	(1.30)	(3.54)	(1.33)	(4.46)	(1.90)	(4.83)
Transferable	6.831	42.454	7.212	44.512	5.719	41.646
knowledge	(3.89)	(6.68)	(4.29)	(7.21)		(6.67)
Transferable		-62.347		-63.948		-62.726
knowledge squared		(-7.71)		(-7.71)		(-7.57)
Capital	2.203	-8.032	2.719	-6.620	1.248	-8.868
	(1.99)	(-4.698)	(2.62)	(-4.84)	(1.40)	(-5.52)
Labor						
low-skilled	-0.329	0.989	-0.310	0.998	-0.344	0.969
	(-0.90)	(1.65)	(-0.85)	(1.66)	(-0.94)	(1.62)
medium-skilled	-0.996	4.268	-1.095	3.994	-0.855	4.382
	(-2.32)	(6.50)	(-2.59)	(6.38)	(-2.05)	(6.83)
high-skilled	-0.762	-0.898	-0.802	-1.011	-0.734	-0.883
	(-2.96)	(-2.28)	(-3.15)	(-2.68)	(-2.88)	(-2.33)
Land	1.686	1.27	2.202	2.638	0.686	0.378
	(1.93)	(0.96)	(2.83)	(3.22)	(1.27)	(0.32)
$R^2_{adj.}$	0.936	0.917	0.936	0.917	0.936	0.917
Wald-tests						
Homogeneity of	$3.575^{b)}$	0.093	5.934		7.680	
patent stocks	$(0.059)^{c)}$	(0.760)	(0.015)		(0.006)	
Homogeneity of	2.109	1.614	7.189			7.031
factor stocks	(0.146)	(0.204)	(0.007)			(0.008)
Simultaneous test	18.927					
of homogeneity	(0.001)					
Country effects	1114.54	602.40	1116.86	661.53	1209.91	609.73
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time effects	104.97	68.62	114.23	78.83	107.52	66.95
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Turning point trans-ferable knowledge		1.406		1.416		1.394

$^{a)}$ t-values in parentheses

$^{b)}$ χ^2-value

$^{c)}$ Significance levels in parentheses

labor shows a negative impact. Firstly, however, it must be taken into account that the measurement carried out here is without any choice rather rough, and, secondly, that there are in all EU countries – more or less strong – opposite developments of, on the one hand, the increasing population and employment shares with medium and high skills, and, on the other hand, the decreasing value added shares of R&D-intensive manufacturing industries. Thus, it can be expected that the increase in the shares of skilled labor is closely associated with the expansion of the service sectors.[9] The results for the share equation of value

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[9]Harrigan (1997) presents similar findings with regard to the impact of high-skilled labor and interprets them analogously. Assuming that high-skilled labor is relatively intensively used in

added of the remaining industries are intuitively more convincing. The numbers of low-skilled workers have a positive impact at a significance level of five per cent for a one-sided hypothesis, and the positive effect of the medium-skilled workers is statistically significant far below a level of one per cent. On the other hand, high-skilled workers clearly affect the value added shares negatively. This finding also supports the just formulated hypothesis with regard to the link between the development of the employment shares with high qualifications and the expansion of the service sectors. The positive effect of arable land on the value added shares of the R&D-intensive industries is also confirmed in this case, while its impact in the second share equation is no longer significantly different from zero.

The goodness of fit increased only slightly for the share equation for the remaining industries to $R^2_{adj.} = 0.917$, when differentiated labor endowments are included, while it remains unchanged for the share equation for the R&D-intensive industries. Furthermore, the null hypotheses that the fixed country and time effects are zero, must once again be rejected. The test results with regard to the degrees of homogeneity look slightly more heterogeneous. The null hypothesis that the patent stocks are homogeneous of degree zero cannot be rejected convincingly only for the remaining industries, while the significance level of 5.9 per cent is at the borderline for the R&D-intensive industries. On the other hand, this null hypothesis cannot be rejected for the factor endowments at the usual levels of significance if both share equations are considered separately. This is not the case, however, when all four restrictions are tested simultaneously. Then the null hypothesis must be rejected very clearly. To take this fact into account, a sequential procedure was chosen. Firstly, the restriction which was most convincingly not rejected was imposed, and afterwards it was tested stepwise to see which further restrictions are now permissible.[10]

In the first step, the restriction with the highest probability of an α-error – the patent stocks in the share equation for the remaining industries are homogeneous of degree zero ($\alpha = 0,760$) – was imposed. This leads to a model, in which the individual tests of the hypothesis that the patent stocks in the share equation for the R&D-intensive industries are homogeneous of degree zero can be rejected at a significance level of $\alpha = 0,014$, while the homogeneity restrictions cannot be rejected for the factor endowments with $\alpha = 0,154$ (R&D-intensive industries) and $\alpha = 0,171$ (remaining industries) at the usual levels of significance. Therefore, in the next step, two further models were estimated, with each additionally

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the service sector, the Rybczynski theorem supports such an interpretation from the viewpoint of traditional trade theory. However, a confirmation of this explanation would require data on direct factor shares, which are not easily available in internationally comparable form (Harrigan, 1997, 486-487).

[10]This procedure seems more convincing from a methodological point of view than the one chosen in Harrigan (1997), where only a completely restricted model was estimated and afterwards the tests show that some of the restrictions are statistically inadmissible, but no consequences were taken.

including one of the two latter restrictions.

The restricted model I, which additionally includes the homogeneity restriction for the factor endowments in the share equation for the remaining industries, is displayed in the columns 4 and 5 of table 3. This model is very similar to the unrestricted estimates, with the exception of the impact of arable land, which is now highly significantly positive in both equations. Furthermore, the significance of the positive effect of the capital stocks increases considerably. As can be seen from the remaining two Wald tests concerning the homogeneity restrictions, no further homogeneity restriction can be imposed from a statistical point of view. Alternatively, the fixing of the degree of homogeneity of the factor endowments in the share equation for the R&D-intensive industries to zero can be imposed as a second restriction. The estimates for this restricted model are shown in the columns 6 and 7 of table 3. Here, some more fundamental changes occur in the share equation for the R&D-intensive industries. The impact of the patent stocks in the area of the remaining technology is now positive in a one-sided test at a significance level of five per cent, which implies that there would be positive spillover effects from the stocks of innovations in this area to the value added shares of the R&D-intensive industries. Moreover, the effects of the capital stocks and arable land are no longer different from zero at the usual levels of significance. In comparison, no major changes can be observed in the share equation for the remaining industries. Imposing a further restriction is also inadmissible for this model, as the remaining Wald tests show.

From a statistical point of view, both the restricted model I and II are permissible, and no decision can be made as to which of both models is superior, since both have approximately the same goodness of fit. However, intuitively and from a theoretical point of view, model I seems to be more convincing. Altogether, the estimates show that a neoclassically inspired model – originally only emphasizing relative factor endowments – augmented by technological differences is well-suited to explain the different production specializations of the EU countries in the area of R&D-intensive technology as well as in the area of the remaining technology.

5 Conclusions

The paper analyses whether technological specializations – besides factor endowments and transferable knowledge – affect the production specializations of the EU countries. A neoclassically inspired empirical model was specified and estimated to explain for the considered countries the value added shares of the manufacturing industries in the area of R&D intensive technology as well as in the area of the remaining technology by technological differences and relative factor endowments. Altogether, the different variants of the model show a high goodness of fit. Thereby, the results with regard to the impact of technological differences seem to be more robust than those with regard to the factor endowments, namely:

1. The patent stocks in the area of leading-edge technology have a clearly positive effect on the value shares of the R&D-intensive industries, while the patent stocks in the area of high-level technology have no impact here, and in one case even a negative impact.

2. The value added shares of the remaining industries are positively influenced by the stocks of innovations in this area, while the cumulated innovation successes in the area of high-level technology have a negative impact. This points to a competitive relationship between the innovation efforts in these two areas, and – taking it one step further – to a ladder model, where in the course of a development process innovation efforts and higher value added shares of the remaining industries are most likely taken over by corresponding activities in the area of high-level technology.

3. Transferable technical knowledge has a proportional positive effect on the value added shares of the R&D-intensive industries, while it is also certainly positive for the remaining industries; yet it increases less than proportionally and decreases again from a certain threshold value.

The lower robustness of the results concerning the factor endowments might be caused to a certain degree by the data quality. Here, it would be desirable to get more reliable, internationally comparable data on labor endowments with different levels of qualifications.

With regard to economic policy, the results provide evidence that a sole orientation towards relative factor endowments can lead to incorrect implications. Therefore, adequate policy measures for influencing production patterns – and thus trade patterns – could only be developed, if, at least to the same extent, the technological specializations are taken into account.

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