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The Structure of the German Economy

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Abstract

Exploiting the information contained in an economy's input-output matrix and using the novel approach developed by Fisher and Marshall (2011), we calculate Rybczynski effects and Stolper-Samuelson effects for Germany in 2007. We show how sectoral output and factor remuneration react to exogenous changes of factor endowments and product prices, respectively. These calculations are implemented using two different models comprising one with labor and capital as the classical production factors and one where we introduce patent stock as an additional factor of production. In the former, we further differentiate between a scenario where all production factors are mobile and one with sector-specific capital. In the latter analysis we measure the impact of innovation-targeting policy action for sectoral output. Positive Rybczynski effects of patents and high-skilled workers are strongest in knowledge-intensive sectors, while other sectors contract. The introduction of patents as a further production factor has only minor influence on the Rybczynski effects of other factors.

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Keywords: Rybczynski effect, Stolper-Samuelson effect, input-output, Germany.

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1 Introduction

In this paper we use German sector-level data to calculate changes in output and factor rewards induced by various types of exogenous shocks to the economy. Based on the Rybczynski theorem, our analysis shows that some sectors expand and others contract in response to changes in factor endowments. Based on the Stolper-Samuelson theorem, we find that price changes in one sector induce an increase in payments to owners of some production factors while the owners of other production factors may lose out. We use a novel approach developed by Fisher and Marshall (2011) who show that each of these shocks can be decomposed into an orthogonal outward shift of the production possibility frontier or the zero-profit condition, respectively, and a movement on these curves. Only the first part is relevant to output or factor price changes.

Our analysis can be applied across a range of policy initiatives. For example, in areas such as cluster-developments, investments in infrastructure and education as well as export-promotion policies, knowledge of how different sectors and skill-levels of workers interact is required. Additionally, the economy's global position needs to be taken into consideration. Bilateral trade data for the German economy reveals that it has a comparative advantage reflected by large net exports in machinery, cars and metal products while natural resources, agriculture and fishery are sectors where Germany is a large net importer.¹ Hence, policies have to be judged in the context of whether or not they strengthen the comparative advantages of Germany. Viable long-term development will only be achieved in Germany if strategies are implemented that lead to structural changes strengthening sectors that are internationally competitive.

In the second part of this paper we include patents as a production factor to facilitate the analysis of innovation policy. This key objective of economic policy is stated in the European Union's Lisbon Strategy, which is aimed at making the EU *"the most dynamic and competitive knowledge-based economy in the world by 2010."* Similarly, the OECD's

¹The data for trade flows are taken from the German Statistical Office (<https://www.destatis.de/DE/ZahlenFakten/GesamtwirtschaftUmwelt/Aussenhandel/Handelswaren/Tabellen/EinfuhrAusfuhrGueterabteilungen.html>).

publication on regions and innovation policy (OECD 2011) opens with: “Sustainable growth at regional level is now, more than ever, predicated on the capacity to innovate. (...) For many decades now, economists have known that long-term, sustainable economic growth cannot simply be explained by increases in physical capital, natural resources or population. (...) Ultimately, long-term sustainable growth will depend on knowledge accumulation, either embodied, in smarter capital, a more efficient use of natural resources and a better-educated labor force, or disembodied, for example, as codified in patents, copyrights or trademarks.”

Our analysis allows us to derive sectorally decomposed output effects from innovation. This enables us to highlight positive output effects in some sectors and quantify potentially negative sectoral spillovers. These negative spillovers result from competition for scarce resources. In an innovative economy these resources will be attracted by innovative sectors and thus impose a negative effect on those that are less innovative. Innovation probably benefits the economy as a whole, but for the evaluation of policies stimulating innovation it is indispensable to know how these benefits are distributed across sectors and between workers with different skills.

As mentioned above, this analysis is based on the Rybczynski theorem. The textbook formulation is based on a model in which two factors are used to produce two goods. Since factors are employed with different factor intensities, an increase in the endowment of one factor will increase the output of the good which uses this factor intensively and decrease the output of the other good when full employment of factors as well as incomplete specialization is assumed. A Rybczynski matrix comprises the marginal effects of endowment changes on sectoral output. Each row of this matrix stands for one sector of the economy and each column stands for one factor of production. The relative number of sectors and factors is of crucial importance. Official statistics usually report a lower number of production factors than sectors. When all factors are assumed to be mobile between sectors, this implies that the typical Rybczynski matrix has more rows than columns. For a long time it was argued that this feature impeded the estimation of Rybczynski effects. This was because when there are fewer factors than sectors that all differ in their factor input coefficients, there are many possible combinations to accommodate additional factor endowments under the condition of

full employment.

Only recently, Fisher and Marshall (2011) showed that in this case, using the Moore-Penrose pseudo-inverse, the Rybczynski effect can easily be separated into one movement that is orthogonal to an economy's production possibility frontier and a second along this frontier. The first movement can be uniquely characterized and leads to a higher revenue in the economy. The second movement is arbitrary and not relevant to revenue. Hence, it can be argued that the second shift is solely determined by the demand side of the economy, whereas the first shift can be interpreted as the pure Rybczynski effect as mandated from factor supply. Applying Fisher and Marshall's (2011) technique and assuming mobile factors of production we can estimate Rybczynski effects for 51 sectors and six production factors in the German economy and can calculate shadow prices for all factors.

When there are more goods than factors the interpretation of Stolper-Samuelson effects is inherently difficult. The reason for this is that the structure of exogenous price changes may render it impossible to maintain full employment for factor prices. This problem has already been pointed out by Choi (2003), who proposed endogenous price adjustments to reconcile the theoretical problem with the observation that usually many sectors do produce competitively in an economy. We adopt Fisher and Marshall's (2011) approach which uses the Moore-Penrose pseudo-inverse to calculate Stolper-Samuelson effects. These Stolper-Samuelson effects are the best linear fit for the factor price vector, given the input coefficients, similar to an ordinary least square regression analysis. The matrix of Stolper-Samuelson effects is the transpose of the Rybczynski matrix. Consequently, in models with more factors than goods Rybczynski effects can be calculated as the best linear fit of output changes as reaction to changes in endowments while Stolper-Samuelson effects can be exactly determined. We conduct such an analysis in section 3.2, assuming a Ricardo-Viner structure with sector-specific capital.

There have already been prominent attempts to determine a relationship between endowments and output, although less so in very recent years. Estimates of national revenue functions were presented by Kohli (1991) and Harrigan (1997) who sought to explain the patterns of comparative advantage. Fitzgerald and Hallak (2004) directly estimate a Rybczynski

effect in a reduced-form equation. According to their analysis it is crucial to account for productivity differences when interpreting the results.

The most important data sources for this type of analysis are the official input-output tables. The method of input-output accounting was introduced by Leontief and analyzed in several publications, e.g. Leontief (1951). Our input-output data are from the German statistical office *Destatis* for the year 2007. We aggregate the input-output matrix to 51 industries, a two-digit level of the European Community's *Classification of Products by Activity (in Germany: WZ 2003)*² for which we also have capital stocks and numbers of employees available. Employees are differentiated into five skill groups, ranging from high-skilled university graduates to low-skilled employees and are measured in person years. Capital is measured in million euros.

The remainder of the paper is organized as follows. Section 2 outlines the theoretical model. Section 3.1 and section 3.2 explain the results for the case with perfectly mobile factors and for the case with sector-specific capital, respectively. Section 4 presents the model where we account for the patent stock and section 5 concludes.

2 Theoretical derivation of the Rybczynski matrix

A marginal increase in the endowment of one production factor may lead to a very diverse sectoral output response. In a setting with high- and low-skilled workers, the Rybczynski theorem states that, given a constant relative price, an increase in the number of high-skilled workers yields a more than proportionate expansion of the sector in which high-skilled labor is used intensively and a reduced output in the other sector. This is due to the fact that the expanding sector does not only require skilled labor to increase its output, but also a higher number of low-skilled workers that will be taken from the other sector. Scarce resources move to sectors where they can be most productive, facilitating aggregate growth.

When deriving the theoretical properties of the Rybczynski effect, it is crucial to prevent changes in factor input coefficients. Hence, we start from a Leontief production function with

²At the two-digit level it is identical to ISIC Rev. 3.1.

input coefficients that are fixed by definition and constant returns to scale:

$$y_i = \min \left\{ \frac{v_{i1}}{a_{i1}}, \dots, \frac{v_{if}}{a_{if}} \right\} \quad \forall i = 1, \dots, N, \quad (1)$$

where y_i is output in sector i , v_{if} is usage of factor f in sector i , a_{if} is the average input coefficient that is optimal for producing each y_i , given output prices and factor prices. The number of sectors is N while the number of factors is F . Full employment together with the assumption that all production factors are scarce and have a strictly positive remuneration implies³:

$$v_f = \sum_{i=1}^N a_{if} y_i \quad \forall f = 1, \dots, F, \quad (2)$$

where y_i is final demand, v_f is the endowment in the economy with factor f . In matrix notation for all F production factors, this relationship can be written as:

$$v = \mathbf{A}'y, \quad (3)$$

where v is the endowment vector, y is the production vector, and \mathbf{A} is the matrix of direct and indirect factor inputs. Intuitively, this matrix describes the infinite sum of all rounds of intermediate inputs into production.

We are now faced with two problems. First, the matrix \mathbf{A} is generally not invertible. In the empirical analysis, based on the assumption that some factors are sector-specific, there are usually more sectors than production factors, and vice versa. It is extremely rare for there to be an identical number of sectors and factors. We revisit this problem below.

The second problem refers to the difficulty in determining the coefficients of matrix \mathbf{A} . To achieve this, we first have to define a matrix of direct factor inputs \mathbf{B} . Its coefficients are given by the relationship:

$$v_f = \sum_{i=1}^N b_{if} x_i \quad \forall f = 1, \dots, F, \quad (4)$$

where x_i is the overall production level including the production of intermediate inputs that

³Fisher and Marshall (2011) show that the analysis neither requires scarcity of all production factors nor positive output in all sectors.

will not be used to satisfy final demand. Of course, since each overall production level x_i is at least as large as the corresponding final demand y_i in sector i , the coefficients b_{if} are smaller than the coefficients a_{if} in the matrix of direct and indirect inputs. The above relationship in matrix notation gives:

$$v = \mathbf{B}'x, \quad (5)$$

where v is the endowment vector, x is the vector of overall production including intermediate products, and \mathbf{B} is the $N \times F$ matrix of direct factor inputs. From equation (3) and equation (5) we obtain:

$$\mathbf{A}'y = \mathbf{B}'x. \quad (6)$$

Matrix \mathbf{B}' can be easily constructed from publicly available data sources. However, as mentioned above, it is matrix \mathbf{A}' that interests us. Their relationship can be conveniently derived from a system of linear equations. In every sector i the following accounting identity must hold:

$$\sum_{j=1}^N x_{ij} + y_i = x_i \quad \forall i = 1, \dots, N, \quad (7)$$

where x_{ij} are intermediate goods from sector i used for production in sector j , y_i is final demand and x_i is overall production in sector i . When input coefficients are constant, intermediate inputs depend linearly on final demand. This relationship can be written as:

$$x_{ij} = z_{ij}x_j, \quad (8)$$

where the canonical element z_{ij} is the amount of commodity i that is needed as intermediate input to produce one unit of commodity j . Inserting yields:

$$\sum_{j=1}^N z_{ij}x_j + y_i = x_i \quad \forall i, j = 1, \dots, N, \quad (9)$$

which in matrix notation is:

$$\mathbf{Z}x + y = x. \quad (10)$$

The matrix of average intermediate input coefficients \mathbf{Z} , of course, is the input-output matrix

from official statistics. The coefficients of that matrix are those that are optimal for currently prevailing given factor and goods prices and can be interpreted as short-term fixed Leontief input coefficients. The solution to this system of equations is:

$$x = (\mathbf{I} - \mathbf{Z})^{-1}y = \mathbf{C}y, \quad (11)$$

where \mathbf{I} is the identity matrix of size N . The matrix $\mathbf{C} = (\mathbf{I} - \mathbf{Z})^{-1}$ is then called the matrix of inverse Leontief coefficients. It indicates the overall production level that is necessary to satisfy a unit vector of final demand, given the infinite rounds of intermediate production. By inserting equation (11) into equation (6) we obtain:

$$\mathbf{A}' = \mathbf{B}'\mathbf{C} = \mathbf{B}'(\mathbf{I} - \mathbf{Z})^{-1}. \quad (12)$$

As mentioned above, in the case with mobile production factors we have data on more goods than factors, $N > F$. This means that full employment can be determined as defined above. However, it implies that the empirical production possibility frontier is flat. Many possible output combinations lead to the same requirement of production factors. Or, stated differently, F full employment conditions do not determine N zero-profit conditions. It is not possible to solve equation (6) for the vector y .

Following Fisher and Marshall (2011) this problem is avoided by using the Moore-Penrose pseudo-inverse, which exists although the matrix \mathbf{A}' is not invertible.⁴ Using this pseudo-inverse of \mathbf{A}' denoted by $(\mathbf{A}')^+$ it is possible to write:

$$y = (\mathbf{A}')^+v + (\mathbf{I} - (\mathbf{A}')^+(\mathbf{A}'))z, \quad (13)$$

where z is an arbitrary vector of size N . However, the arbitrary part of y is not relevant for the *value* value of output as given by the revenue function $Y = p'y$. This can be shown by noting that if all N zero-profit conditions hold with equality, the price vector p must lie in the column space of \mathbf{A} , because the price of each of the goods is a weighted sum of F

⁴This matrix was described by Moore (1920), Bjerhammar (1951), and Penrose (1955). See also Albert (1972) for a nice exposition of its properties.

factor prices. This implies that $p'(\mathbf{I} - (\mathbf{A}')^+(\mathbf{A}'))z = 0$ for any z . Hence, as argued in the introduction, $y = (\mathbf{A}')^+v$ suffices as a solution for the output as determined by the supply side of the economy whereas all other changes in sectoral output are demand-driven. This allows for defining a $F \times N$ matrix of Rybczynski effects that indicate marginal output responses to marginal changes in factor supply, as:

$$\frac{dy}{dv} = (\mathbf{A}')^+, \quad (14)$$

where the element in row f and column i indicates the output effect in sector i caused by a marginal increase in the supply of factor f .

The Moore-Penrose pseudo-inverse also accommodates the opposite case where $N < F$ in which the number of goods is smaller than the number of factors. Such a model is, for example, implied by the assumption that one or more production factors are not mobile between sectors, but specific to a certain sector. Under these circumstances the Moore-Penrose pseudo-inverse works as a linear regression tool, fitting coefficients (output changes) such that the data (factor intensities) give the best possible fit of mandated factor endowment on real factor endowment, minimizing the sum of squared endowment residuals.

3 Classical model: labor and capital

3.1 Mobile factors

We start this analysis with a model that exclusively features production factors that are mobile between sectors. As mentioned above, with the German statistical data at hand, this implies the existence of a higher number of goods (sectors) than production factors. We can then interpret the elements of $(\mathbf{A}')^+$ as Rybczynski derivatives based on the assumptions that (1) technology remains unchanged, (2) all production factors are scarce and rival, and (3) prices remain constant.

Table 1 illustrates the five strongest Rybczynski effects for employees in the highest skill group, together with their factor intensity, calculated as the number of workers in that group

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
73	Research and development	122,071	3.2804
80	Education	78,701	5.7312
85	Health and social work	43,536	1.8333
24	Chemicals and chemical products	41,153	0.8711
50	Wholesale and retail trade of motor vehicles; repair	38,941	0.9789

Table 1. Strongest positive Rybczynski effects: high-skilled labor.

per million euros of output. Employees in the highest skill group are at managerial level in a company and are usually university graduates. It emerges that the sectors that benefit most from an increase in the endowment with high-skilled workers are indeed those sectors that use high-skilled labor intensively. The greatest impact can be seen in the research and development sector, which expands revenue by around 120,000 euros. Other growing sectors are education, health and social work, chemicals and chemical products, and the wholesale and retail trade of motor vehicles and repair.

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
19	Leather and leather products	155,123	2.7619
74	Other business activities	146,900	2.0250
37	Recycling	76,304	1.4349
55	Hotels and restaurants	60,206	1.5894
16	Tobacco products	56,424	1.0096

Table 2. Strongest positive Rybczynski effects: low-skilled labor.

Table 2 contains the top five Rybczynski effects for low-skilled labor. According to the definition, low-skilled workers perform simple, repetitive tasks. The necessary skills and knowledge can be acquired within no more than three months. In this list we find two traditional manufacturing activities, namely leather and tobacco products. In addition, there are two service sectors: other business services that include industrial cleaning, security, and call center employees and hotels and restaurants which traditionally have a high number of low-skilled personnel. The recycling sector is also in this list.

The largest Rybczynski effects for capital are listed in Table 3. The highest output increases are in the real estate sector, the same result as found by Fisher and Marshall (2011)

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
70	Real estate activities	14,971	32.7906
71	Renting of machinery and equipment	8,176	15.7653
90	Sewage and refuse disposal; sanitation	8,045	20.7103
41	Water supply	5,635	14.7962
92	Recreational, cultural, and sports activities	3,502	7.7085

Table 3. Strongest positive Rybczynski effects: capital.

for the United States. Other sectors with large positive output effects are machinery and equipment rental; sewage and refuse disposal and sanitation; water supply, and recreational, cultural, and sports activities. The factor intensity in this table is the stock of capital in million euros per million euros of output.

Recognizing the importance of the manufacturing sector in Germany, we report Rybczynski effects for all manufacturing sectors in Table 4. The picture is quite diffuse. High-skilled labor (Labor 1) and low-skilled labor (Labor 5) lead to positive and negative effects in approximately half of all manufacturing sectors. Moreover, in around half of all sectors the two effects of high-skilled and low-skilled labor have an identical sign. However, capital has a positive Rybczynski effect on manufacturing output only in five out of 23 sectors.

In Table 5 we report estimates of total factor rewards. These estimates correspond to ordinary least squares (OLS) coefficients on data points (factor intensities) which are the best linear fit for production costs on the assumed price vector $p = 1$. This restricted dependent variable requires the use of robust standard errors. Labor is measured in person years, therefore, the estimated coefficients can be interpreted as annual salaries. We only find the estimated salary for high-skilled labor to be significantly different from zero. The factor reward for one million euros of capital is estimated to be about 32,000 euros. This corresponds to an economy-wide rate of return for capital of roughly 3.2 percent, somewhat lower than the estimates for the US by Fisher and Marshall (2011).

Index (WZ 2003)	Manufacturing sector	Rybczynski effect		
		Labor 1	Labor 5	Capital
15	Food products and beverages	20,457	47,127	90
16	Tobacco products	-44,371	56,424	548
17	Textiles	-8,615	1,686	-390
18	Wearing apparel; dressing and dyeing of fur	-21,273	-48,854	-1,100
19	Leather and leather products	-54,659	155,123	327
20	Wood and wood products	9,518	-32,849	-865
21	Pulp, paper, and paper products	-43,055	-44,611	-347
22	Publishing, printing, and reproduction of recorded media	-17,391	-18,808	-446
23	Coke, refined petroleum products, and nuclear fuel	2,951	5	200
24	Chemicals and chemical products	41,153	2,175	-108
25	Rubber and plastic products	-7,244	36,205	-1,077
26	Other non-metallic mineral products	2,999	-27,971	-654
27	Basic metals	3,984	-12,291	-465
28	Fabricated metal products, except machinery and equipment	16,440	16,002	-1,670
29	Machinery and equipment n.e.c.	26,004	29,262	-1,471
30	Office machinery and computers	22,212	-2,493	145
31	Electrical machinery n.e.c.	29,128	49,642	-779
32	Radio, television, and communication equipment	15,938	-15,675	-502
33	Medical, precision, and optical instruments, watches and clocks	22,169	3,105	-1,606
34	Motor vehicles, trailers, and semi-trailers	-3,658	-41,311	-944
35	Other transport equipment	22,276	-30,880	-1,620
36	Furniture, manufacturing n.e.c.	-114	-14,737	-1,295
37	Recycling	22,678	76,304	-323

Table 4. Capital's Rybczynski effects on the manufacturing sectors.

Factor	Reward	Robust s.e.
Labor skill 1	184,723**	75,356
Labor skill 2	-13,990	56,538
Labor skill 3	23,108	38,399
Labor skill 4	47,192	57,186
Labor skill 5	161,965***	62,393
Capital	31,875***	6,640

*** p<0.01, ** p<0.05, * p<0.1

Table 5. OLS estimates of factor rewards.

3.2 Sector-specific capital

A model with sector-specific capital and a mobile workforce is the Ricardo-Viner model. It predicts that an increase in the price of one commodity increases the returns of the specific capital used in that sector.⁵ We can now interpret $(\mathbf{A})^+$ as the Stolper-Samuelson matrix, which indeed confirms this prediction from the simple two-sector model. However, note that the Ricardo-Viner model features a movement of mobile labor into the sector which experienced the increase in its relative price. Therefore, the price change in the textbook model is not a pure Stolper-Samuelson effect, but rather a response of factor prices with respect to (1) an exogenous price change, and (2) an endogenous reallocation of the mobile production factor. We do not account for such a reallocation in the calculation of the Stolper-Samuelson matrix but instead hold factor input coefficients constant. Fisher and Marshall (2011) argue that a true Stolper-Samuelson effect, as the dual of a Rybczynski effect, requires these constant factor input coefficients.

Index (WZ 2003)	Sector (GDP Share)	Effect in own sector	Minimal effect on capital specific to sector	Reward
70	Real estate (7.8%)	30,098	Retail trade	-46,798
74	Other business activities (7.3%)	621,060	Recycling	-251,258
34	Motor vehicles, trailers and semi-trailers (6.8%)	653,651	Textile products	-52,849
85	Health and social work (4.9%)	201,634	Construction	-9,471
45	Construction (4.7%)	816,627	Automobile trade, services, and repairs	-260,123

Table 6. Selected Stolper-Samuelson effects.

We find that the greatest impact of an increase in the price of goods is always on the remuneration of capital specific to goods from this sector, as predicted by the simple two-sector Ricardo-Viner model. Table 6 contains the Stolper-Samuelson effects for the German economy's five largest sectors. The effects should be interpreted as the absolute increase in the returns to one million euros of specific capital if the price of that sector (normalized to

⁵See for example Feenstra (2004) for an exposition. A recent empirical estimation of the Ricardo-Viner model has been performed by Rassekh and Thompson (1997).

one million euro) increases by a further million euros. In addition to the positive effect on capital in its own sector, this table shows the type of specific capital that is most negatively affected. This demonstrates that positive, as well as negative effects vary significantly in their exact level, differing by a factor of almost 100.

Index (WZ 2003)	Sector	Multiple biggest loser	With respect to
45	Construction	8 times	Mining of coal and lignite, extraction of peat; Wood and wood products; Other non-metallic mineral products; Fabricated metal products except machinery and equipment; Machinery and equipment n.e.c; Automobile trade, services, and repairs; Retail trade; Health and social work
72	Computer and related activities	5 times	Tobacco; Printing and publishing; Finance; Insurance; Lobbying and churches
74	Other business activities	5 times	Leather; Electrical machinery n.e.c.; Recycling; Hotels and restaurants; Other services

Table 7. Multiple biggest Stolper-Samuelson losers.

In this multi-dimensional environment it is also interesting to look at those capital-owners who lose the most in terms of returns to capital reported in Table 7. It is striking that the same types of specific capital repeatedly experience the biggest loss of income. In particular, capital specific to the construction sector seems to be vulnerable to price increases in other sectors. The sectors that negatively affect the construction industry, can be identified as inputs into this industry. There is also a trend for capital that is specific to computer services and other business activities to suffer most from price increases in other sectors.

4 Analysis of innovative activity

In this section we include sectoral patent stocks as a further production factor in our analysis. At first glance, this approach may seem at odds with the fact that firms may be able to raise output even without further research and development by simply using existing patents. However, empirical evidence suggests that this is not the case. Instead, firms rely heavily on

patenting to raise revenue, either by raising product quality and charging higher prices or by introducing new product lines. Eurostat regularly collects data about innovative activity in Europe. In the latest available survey, for 2006-2008, the the top 4 objectives for innovations in 25 European Union countries for were to "improve quality of goods and services" (56.6 percent); "increase range of goods or services" (52.2 percent); "increase market share" (42.4 percent); and "enter new markets" (39.6 percent) across all innovating enterprises. Further down, "replacing outdated products or process" (34.5 percent) was at fifth place with further objectives in declining importance being "improved flexibility", "increased capacity", "cost reductions" and "health and safety" (European Commission 2012). Accordingly, standard textbooks on innovative activity such as Ferguson and Ferguson (1994) or Greenhalgh and Rogers (2009) model the effect of a product innovation as an outward shift of the consumer demand curve. The leading motivations for innovation are also compatible with a different strain of economic literature that interprets economic growth as an increasing number of product varieties, which can be traced back to Grossman and Helpman (1991) and is reviewed in depth in the popular textbooks by Acemoglu (2009) and Aghion and Howitt (2009).⁶ In the Leontief production framework in this paper, patents can be also interpreted as available product varieties within a certain sector. Additional patents allow for a potentially higher output of the sector. Patents as a factor of production might be non-rival in use, but they are excludable. Thus, the number of patents represents the number of product varieties supplied by monopolistic producers. It is reasonable to assume that patents are not mobile across sectors.

We report the five strongest positive calculated Rybczynski effects in Table 8. It can be seen that one additional patent leads to output changes that are even larger than output effects from an additional high-skilled worker. Moreover, we can observe that, indeed, the sectors that expand most are those in which it would be expected that the importance of innovative activity is high, thus validating our calculations. The intensity of patents is the number of patents in each sector per million euros of output.

⁶Further examples of modeling innovation as an increase in the number of product varieties can be found in Coe and Helpman (1995), Keller (1998), Lentz and Mortensen (2005), Klette and Kortum (2004) and Rasmus and Mortensen (2008). Further studies emphasizing that product innovation in-creases consumer utility include Motta (1992), Cohen and Klepper (1996), Beath et al. (1997), Bonano and Haworth (1998), Fishman and Rob (2000) and Levin and Reiss (1998).

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
29	Machinery and equipment n.e.c.	203,553	1.2281
33	Medical, precision, and optical instruments, watches and clocks	174,684	1.2101
24	Chemicals and chemical products	137,564	0.7399
32	Radio, television and communication equipment	91,435	0.6952
73	Research and development	76,491	1.1720

Table 8. Strongest positive Rybczynski effects: patents.

In order to evaluate the reliability of these figures, it is appropriate to compare these values to the market prices of patents. Unfortunately, patents are not traded regularly and patent markets are not well established. Nevertheless patents are traded or auctioned from time to time, especially if a technology-intensive company restructures its portfolio, is in financial difficulty, or even goes bankrupt. Recent cases of such patent trades include the acquisition of 24,000 Motorola mobility patents by Google which show a value of 5.5 billion US dollars in the balance sheets (about 229,000 dollars per patent); the acquisition of 6,000 Nortel patents for 4.5 billion US dollars by a consortium formed by Microsoft and Apple (about 750,000 dollars per patent); the acquisition of 650 Microsoft patents by Facebook for 550 million US dollars (about 846,000 dollars per patent) and the acquisition of 1,100 Kodak patents by a consortium including Apple, Microsoft and Google for 525 million dollars (more than 477,000 dollars per patent). These values are slightly higher than the largest Rybczynski effect that we have found. However, our sectoral effects are composed of firm-specific effects and, naturally, some firms within these sectors will experience substantially larger Rybczynski effects. If patents induce such a strong boost of output the prices stated above are certainly justified.

The five strongest negative Rybczynski effects are reported in Table 9. It is clear that these sectors are indeed those that feature only a very low number of patents or even no patents at all.

Tables 10 and 11 report the five largest Rybczynski effects for high-skilled and low-skilled labor in the model with patent data. They correspond to Tables 1 and 2 which display results from the traditional model above. It is easy to see that the introduction of

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
80	Education	-138,538	0.0002
37	Recycling	-80,373	0.0073
85	Health and social work	-78,553	0.0000
63	Supporting and auxiliary transport activities; activities of travel agencies	-69,998	0.0000
55	Hotels and restaurants	-66,166	0.0002

Table 9. Strongest negative Rybczynski effects: patents.

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
80	Education	119,648	5.7312
73	Research and development	99,462	3.2804
85	Health and social work	66,753	1.8333
50	Wholesale and retail trade of motor vehicles; repair	58,260	0.9789
37	Recycling	46,433	0.4334

Table 10. Strongest positive Rybczynski effects: high-skilled labor.

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
19	Leather and leather products	154,995	2.7619
74	Other business activities	150,878	2.0250
37	Recycling	83,907	1.4349
55	Hotels and restaurants	66,465	1.5894
93	Other services	58,670	0.9923

Table 11. Strongest positive Rybczynski effects: low-skilled labor.

patents plays a minor role in the Rybczynski effects of labor. In both tables, four of the five largest Rybczynski effects from above appear again. For high-skilled labor, the four largest Rybczynski effects are even repeated in the same order as above.

Against the backdrop of these figures and a total budget for research and education of more than 18 billion euros, it seems surprising that in 2013 the programs by the German Ministry of Economics designed to stimulate commercial research amount to a total of “only” 1.38 billion euros plus another 1.24 billion euros for the DLR (German Research Center for Aeronautics and Space) (Federal Government of Germany 2012).

Less than 90 million euros are planned to be spend on programs which aim to increase the amount of high-skilled employees in Germany (Federal Government of Germany 2012. This

is particularly surprising knowing that the German government has claimed that Germany’s high-tech strategy is underpinned by: “... a requirement for a successful innovation policy with excellent and high-skilled employees. The German federal government aims to increase the number of high-skilled employees through advanced and continuous training and on-the-job training and thus assure sustainable growth in Germany” (BMBF 2010). While this statement rather focuses on activating internal labor resources, the actual strategy of the German government also aims to attract high-skilled personnel from abroad. The most promising initiative here seems to be the recent introduction of so-called “blue cards” which allow easy access for high-skilled workers to the German job market and defines reasonable conditions for a permanent extension of the labor permit after two years.

Index (WZ 2003)	Sector	Rybczynski effect	Intensity
70	Real estate activities	15,289	32.7906
71	Renting of machinery and equipment	8,280	15.7653
90	Sewage and refuse disposal; sanitation	8,028	20.7103
41	Water supply	5,754	14.7962
92	Recreational, cultural, and sports activities	3,421	7.7085

Table 12. Strongest positive Rybczynski effects: capital.

The similarity between the specification *without* patents and the specification *with* patents is even more striking when the largest Rybczynski effects of capital in Table 12 are taken into consideration. The order is identical to that identified above in Table 3 and even the values only change slightly. This indicates that the sectors that expand as a reaction to a higher capital endowment do not rely intensively on patents as an input factor. Indeed, they are service sectors where innovations do not play an important role.

5 Conclusion

In this paper we perform an empirical study, analyzing data from the production side of the German economy to estimate Rybczynski effects and Stolper-Samuelson effects in line with the method proposed by Fisher and Marshall (2011). We specify two models: a model with the two classical production factors, labor and capital, and a model where we add patents

as additional production factor. Furthermore, in the former we distinguish between a case where capital is mobile between sectors and a case where each sector employs a specific type of capital.

Our results confirm the theoretical predictions: output in some sectors increases while it decreases in others. It is clear from the first view that growing sectors do indeed use the factors intensively of which endowment is raised. When we take a more detailed look at the manufacturing branch of the German economy, we find a diffuse picture. High-skilled and low-skilled labor leads to an increased output in around half of the manufacturing sectors and that is also approximately the proportion of sectors for which the two effects go in the same direction. More interestingly, we find positive Rybczynski effects of capital in only five of 23 manufacturing sectors.

In the model with sector-specific capital we compute Stolper-Samuelson effects. We find that the factor that gains most from a price increase in one sector is always capital specific to that sector. Moreover, we can identify some sectors that are very prone to incurring the greatest losses in terms of returns to capital specific to them. For example, capital specific to the construction sector happens to lose more than any other production factors for eight out of 51 price shocks.

When we add patents as a further factor of production we see a similar pattern of positive Rybczynski effects through high-skilled labor, low-skilled labor, and capital. The Rybczynski effects of patents confirm our view that the intensity of using a factor is important, but not the only explanation for the Rybczynski effect. Moreover, we observe that a higher patent stock contributes to higher output mostly in sectors where Germany is a strong exporter.

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