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Abstract

Inspired by the theory of variety-expanding product innovation we derive a testable relationship of outsourcing on the growth rate of knowledge. We estimate this relationship with a firm-level dataset, which is a unique match of PATSTAT patent data and the Amadeus dataset. We find evidence that forward spillovers are stronger than backward spillovers, where forward spillovers are defined as spillovers going down the value chain from producers to users of intermediate inputs. Moreover, we conclude that inter-industry spillovers are stronger than intra-industry spillovers. This holds when considering only the more important forward spillovers as well as when considering both directions of knowledge flows

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1 Introduction

Productive knowledge and innovation are major determinants of economic prosperity. This hypothesis was theoretically formulated in the "new" growth theory, see e.g. Barro and Sala-i-Martin (2004). In these models growth is often fostered by knowledge spillovers, which lead to a widespread acceptance of subsidies to support research activity. For these subsidies to operate efficiently they should be directed towards an appropriate spillover channel. However, until now it is not completely understood which carriers of spillovers are important. We contribute to this literature by analyzing a largely neglected channel, spillovers through outsourcing relationships.

The concept of linkages between firms and industries as determinants of productivity spillovers goes back to the seminal work by Balassa (1961). Brown and Conrad (1967) used the input-output table to measure the "closeness" of industries, while knowledge spillovers due to the exchange of goods have been identified by Griliches (1979). In recent years the static optimization of a firm's sourcing decision has been analyzed for the closed economy by Grossman and Helpman (2002) and for the open economy and heterogeneous firms by Antràs and Helpman (2004).

In the tradition of the literature estimating the "knowledge production function" (KPF) we formulate a model in which the outsourcing of intermediate goods production to other firms is a source of knowledge spillovers. These spillovers depend on the knowledge stock already acquired in an industry and occur between and within industries. Our estimation procedure is in line with the literature on the KPF that originated from Griliches (1979) and Griliches and Pakes (1984) which focuses on regional spillovers rather than on domestic spillovers through the intermediate products channel. To simplify the analysis we assume the outsourcing pattern to be exogenously given in a way that matches the actually observed input-output data. Given this idea we perform an empirical test of our hypothesis that firms are more innovative if they engage more in the exchange of intermediate inputs with other innovative firms.[1]

The modeling of spillovers due to usage of intermediate goods is also used by Badinger and Egger (2008) who estimate intra- and inter-industry spillovers with industry-level data of 15 manufacturing sectors and 13 OECD countries. They find evidence that intra-industry spillovers are usually larger than inter-industry effects. Javorcik (2004) uses a different approach without using spatial econometrics. She finds evidence of backward spillovers from international firms located in Lithuania to their upstream contractors.

We find forward spillovers to be strong: A one unit increase in the patent stock of all firms that deliver intermediate inputs to a specific firm, raises annual patent output of this firm by 0.43 percent. Of these forward spillovers, those between industries are substantially more important than intra-industry spillovers. For backward spillovers we only estimate a semi-elasticity of 0.15, which does not differ significantly between inter-industry and intra-industry spillovers.

The remainder of the paper is organized as follows. In section 2, we motivate our hypothesis of the beneficial effect of outsourcing-driven knowledge spillovers. Section 3 describes the data that we use, while section 4 explains the estimation technique. Section 5 presents and discusses our obtained results and section 6 concludes.

2 Knowledge capital and sector linkages

The theoretical foundation for our empirical analysis fcomes from the well-established literature of endogenous technological change and from the knowledge production function (KPF) literature. In these models R&D efforts typically expand the variety of inputs, which allows for an increase in the division of labor, thus raising productivity.

[1]The traditional hypothesis in the KPF literature would state that firms are more innovative if they are in or close to a region with many other innovative firms or institutions.

This type of process innovation is based on the idea of Young (1928) and was first established by Romer (1987, 1990), or in an alternative interpretation as product innovation by Grossman and Helpman (1991a,b).[2] Coe and Helpman (1995) integrated the concept of the KPF in a product variety endogenous growth model framework.

In this model, the number of newly developed blueprints $\dot{n}_i$ is a function of labor input L_i^R, input coefficient a, and some stock of knowledge capital K_i:

$$\dot{n}_i = \frac{L_i^R K_i}{a}. \tag{1}$$

A similar equation is estimated, amongst others, by Eaton and Kortum (1996). In this model, a high level of imports from an innovative economy has a positive effect on domestic patenting activity. A collection of further popular papers estimating the KPF is listed in table 1. This compilation is far from complete, but should give a representative picture of how diverse the approaches are in the specification of the economic model, the resulting estimation equations, the choice of the estimation method and the considered types of spillovers.

[2]Good representations of these so called product variety endogenous growth models can be found in Aghion and Howitt (2009, Ch. 3) or in Acemoglu (2009, Ch. 15).

Article, data type, and base model	Estimation method, spillover type, and base equation for estimation of knowledge production function
Jaffe, A.B. (1989), panel data, modified Cobb-Douglas model	3-equation simultaneous system and some IV-specifications, regional spillovers from universities to enterprises $ln(P) = b_1 ln(RD) + b_2 ln(U) + b_3[ln(U)ln(C)] + e$
Acs, Z.J., D.B. Audretsch and M. Feldman (1992), panel data, modified Cobb-Douglas model	OLS, regional spillovers from universities to enterprises $ln(I) = b_1 ln(RD) + b_2 ln(U) + b_3[ln(U)ln(C)] + b_4 ln(L) + e$
Eaton, J. and S. Kortum (1996), cross-section, equations are motivated from a Grossman and Helpman (1991a) type endogenous growth model	Simultaneous estimation of the patent equation, the growth equation and the relative productivity level equation by two-step feasible generalized non-linear least squares, spillovers from one country to another influenced by geographical distance, level of human capital in adopting country and imports relative to GNP $ln\left(\frac{P}{L}\right) = b_0 + ln(d) + b_1 ln\left(\frac{R}{L}\right) - ln\left(\frac{c}{Y}\right) + ln\left(\frac{y_i}{y_n}\right) + e$
Acs, Z.J., L. Anselin and A. Varga (2002), cross-section, modified Cobb-Douglas model	OLS, regional spillovers from local R&D staff and from local university research expenditures to innovative activity $ln(I) = b_1 ln(RD) + b_2 ln(U) + b_3 ln(Z) + e$
Bottazzi, L. and G. Peri (2003), panel data, Romer (1990) type endogenous growth model	OLS and IV, regional distance weighted R&D spillovers $ln(I) = b_0 + b_1 ln(w_1 RD) + b_2 ln(w_2 RD) + \ldots + b_N ln(w_N RD) + b_{N+1} ln(RD) + e$
Moreno, R., R. Paci and S. Usai (2005), panel data, modified Cobb-Douglas model	Spatial econometrics, regional spillovers from innovation in other regions to innovation in the observed region as well as regional spillovers from R&D investments $ln(I) = b_1 ln(RD) + b_2 ln(Y) + b_3 ln(MA) + b_4 W ln(I_i) + \sum_i (b_i NA_i) + e$

Article, data type, and base model	Estimation method, spillover type, and base equation for estimation of knowledge production function
Zucker, L.G. et al. (2007), panel data, model not motivated	Random effects Poisson, regional spillovers from universities, firms, government and other patent stocks to new patents $ln(P) = b_0 + b_1 KS + b_2 PS + b_3 RD + e$
Gumbau-Albert, M. and J. Maudos (2009), panel data, modified Cobb-Douglas model	Negative Binomial, regional R&D and human capital spillovers weighted by distance and trade flows $ln(P) = b_1 ln(RD) + b_2 ln(H) + b_3 ln(wRD) + b_4 ln(wH) + e$
de Rassenfosse, G. and B. van Pottelsbergh de la Potterie (2009), cross-section, "inspired by" Romer (1990) type endogenous growth models	Robust OLS, no spillovers $ln(P) = ln(w) + \sum_n (w_n ln(X_n)) + s ln(R) + \sum_m (s_m ln(X_m)) + e$

Table 1. Summary of previous research and estimation strategies
Abbreviations: e: error term, P: patents, RD: R&D expenditures, U: university research, C: geographic distance to university, L: population or workforce, I: innovations, R: researchers, c: patenting costs, Y: output or GDP, y_i/y_n: relative productivity level of i, d: determinants of technology diffusion, Z: local level of concentration of e.g. innovation networks or knowledge, $w_1 RD$: weighted R&D within distance category 1 (e.g. 0-300km), $w_2 RD$: weighted R&D within distance category 2 (e.g. 300-600km), $w_N RD$: weighted R&D within Nth distance category, MA: quota of manufacturing employment, NA: national dummies, W: spatial weight matrix, KS: knowledge stock, PS: patent stock, H: regional human capital, wRD: weighted regional R&D spillovers, wH: weighted regional human capital spillovers, w: propensity to patent, w_n: n specific part of propensity to patent, X: various explanatory factors, s: productivity of researchers, s_m: m-specific part of productivity of researchers

The theoretical structure of our paper is most closely related to Eaton and Kortum (1996). However, their study analyzes spillovers due to trade between countries, while our paper focuses on spillovers between firms. This focus on firm as observational unit allows us to analyze an important source of firm-level spillovers: trade with intermediate inputs between firms within a country. Even though spillovers along the lines of international trade flows have received high attention in the past, no other study has so far tried to identify intra-country trade flows as source of knowledge spillovers. This seems surprising in light of the high potential for such spillovers. Even though we observe high and increasing volumes of international trade which are potential knowledge transmitters, trade flows within an economy are quantitatively still more important than international trade flows in almost all countries. And given that the technological advantage of R&D-intensive and highly productive firms over less productive firms is potentially large, these flows of intermediate inputs constitute an important channel for knowledge transfers.

We provide this missing link in the literature by estimating a knowledge production function with a focus on spillovers through trade of intermediate inputs. Importantly, our data on firm-specific patent activity is key for this type of analysis. A relationship where the stock of patent blueprints in each firm has a positive impact on innovative activity of one firm can be formulated as:

$$K_i = \sum_{j=1}^{I} w_{ij} n_j, \tag{2}$$

where n_j is the stock of blueprints of firm j and w_{ij} is the weight that is attributed to firm j in generating knowledge for firm i, as determined by the level of intermediate goods trade between the two firms. Intuitively, all $w_{ij} \, \forall \, j \neq i$ are smaller than w_{ii}.

The hypothesis that trade in intermediate inputs between firms contributes to an increase in a firm's knowledge stock is further motivated by the fact that outsourcing of intermediate inputs usually requires a high level of interaction, such as exchanging details about the requirements on the intermediate product and the potential specifications for production. In this respect, outsourcing differs substantially from trade in final goods. We therefore formulate the corresponding hypothesis about the effects of intermediate inputs between sectors on a sector's knowledge stock as follows:

Hypothesis 1. *The more intense a firms's offshoring relationships with other firms are, and the more innovative those firms are, the higher is the firm-specific innovation activity.*

A good representation of how the use of innovations propagates through the production process in a Leontief framework can be found in chapters 3 and 15 of the prominent collection of essays by Scherer (1984). A newer textbook by Greenhalgh and Rogers (2010) motivates the innovation spillovers in such a framework as folows:

> "The basic reason is that in many cases of innovation, one firm's finished product can become part of another firm's production process. Innovation measurement at the level of the firm suggest that product innovations are in the majority, while in the context of the economy they result in a large amount of process innovation. Some examples are new fertilizers that improve the productivity of agricultural production; new weaving machinery that enables the textile industry to create superior fabrics; cash dispensers that allow the banking industry to offer people access to their money at any time of day or night; and new computer software that permits firms in many sectors to organize information more efficiently. (..) The Leontief input-output model already rises the question of which sectors are supplying innovation to which other sectors, creating a relationship between the producers and the users of these innovations. Once these innovation supply relationships are established, there can be many instances where users of innovation feed back information about the product's performance, making suggestions for improvements and this way helping to create the next

generation of products they will buy."

The issues named above result in straight suggestions for the scientific analysis by the authorities collecting the patent data. So does the OECD Patent Statistical Manual (2009) state that patent statistics are used to map certain aspects of the innovation process like diffusion of technology or technology transfers across industries (e.g. on pages 26 and 91). The importance of these channels of knowledge transfer can be cross-checked using the Community Innovation Statistics (Eurostat 2010, pages 142-152). From Table 2 it is obvious that four out of the five most valuable sources of information for the innovation process can be directly linked to the trade of intermediate products.

Country	Within the enterprise or enterprise group	Clients or customers	Suppliers of equipment, materials, components or software	Competitors or other enterprises of the same sector	Conferences, trade fairs, exhibitions
Belgium	53.3	25.1	28.2	9.6	11.9
Bulgaria	32.2	27.5	28.3	16.6	16.5
Czech Republic	37.4	33.7	24.8	15.9	12.0
Estonia	31.0	17.5	24.6	8.9	9.4
Greece	7.3	16.1	12.7	25.9	12.5
Spain	43.4	16.5	25.1	8.8	7.8
Cyprus	92.6	49.5	80.5	35.7	45.2
Lithuania	29.9	24.4	22.1	8.5	19.1
Luxembourg	65.5	36.5	33.1	21.8	23.6
Hungary	40.5	33.9	21.5	19.8	13.1
Malta	39.5	25.6	23.1	14.4	9.2
Netherlands	42.9	26.7	18.8	8.3	5.2
Austria	60.1	47.7	28.0	20.0	18.3
Poland	53.0	29.3	20.0	17.9	16.3
Portugal	46.1	32.8	26.9	13.5	18.3
Romania	41.8	33.0	34.0	19.3	20.8
Slovenia	57.1	44.8	29.8	20.1	17.4
Slovakia	44.0	28.7	23.0	12.7	12.5
Croatia	43.6	35.2	27.8	15.3	22.4
Turkey	46.3	36.6	29.8	18.2	23.5

Table 2. The five most used sources of information 2004-2006 (as a percentage of innovative enterprises). Eurostat *Science, Technology and Innovation in Europe* 2010 edition.

The same applies for the question of the most valuable cooperation partners in the innovation process. The cooperation partners from the private sector seem to be more valuable than those from public institutions. Out of the six most important opportunities for joint innovation activities three are directly related to the trade in intermediate products: cooperation with other enterprises within your enterprise group, cooperation with clients or customers and cooperation with suppliers of equipment, materials, components or software (Eurostat 2010).

3 The data

We use a unique firm-level patent dataset created by a string match of the PATSTAT database edition April 2009 with the Amadeus dataset. PATSTAT contains, among other things, information on title and abstract of a patent application, filing and publication dates of the application, names and origin of the inventors and applicants, and the technological domain of the application according to the international patent classification (IPC). However, it does not contain information about the firms that correspond to the patent applicants. Hence, we match the PATSTAT database with firm-level information from the Amadeus data base. We merge potential patents using semi-automatic string matching based on firm/applicant names. Matching is based on PERL and the output is carefully screened to ensure correct name attribution. This procedure allows us to identify for each firm a stock of registered patents.[3]

To have our results not driven by the high number of small firms which may be innovative but cannot afford the fixed cost of applying for a patent or by a small number of very large firms, we restrict our analysis to German firms with a revenue of more than 3 million Euros in 2007 and eliminate the 5 percent largest firms in terms of revenue. This results in a cross-section of 10,255 firms, of which 1,939 have at least

[3]The use of patents as a proxy for innovative knowledge comes with a number of difficulties. These difficulties are, amongst others, that the values of patents show a large variance, patenting can be due to other incentives than purely economical ones, and patents do not completely capture the innovative knowledge in a firm. For a discussion of these issues see Griliches (1990) and Basberg (1987). Nevertheless, we see patent statistics as useful indicators for our analysis.

Variable	Mean	Std. Dev.	Min	Max
Patent Applications 2007	0.0551	0.4684	0	14
Patent Stock	19.00	138.09	0	5,302
Employees	493.32	657.16	1	4,977
Depreciation	4,895.72	13,345.86	1	508,158
Observations	10255			

Table 3. Descriptive Statistics.

one registered patent. A summary of the data can be found in table 3. However, the results are very similar when choosing a different lower cutoff for the revenue, choosing a lower cutoff in terms of employees, or not eliminating outliers in terms of revenue. In the appendix we provide descriptive information on the sectoral structure of patenting activity. More precisely, we report the number of firms in each industry contained in our sample of 10,255 firms, together with the average patent stock of a firm in each industry and the average number of patents applied for in 2007.

4 The estimation technique

Spatial econometrics is designed to analyze whether endogenous variables are not only influenced by corresponding exogenous variables, but whether there is some kind of interaction across observations. This interaction might come (1) as a direct influence of the endogenous variables of one observation on the endogenous variables of other observations; (2) as a mutual interdependence of the error terms; or (3) as an influence of the exogenous variables of one observation on the endogenous variables of other observations. Equations which are specified to determine the strength of interactions as described in (1) and (2) should not be estimated with standard regression techniques, as left-hand side and right-hand side variables are simultaneously determined. Instead, a specification as in (1) should be estimated using a spatial lag model, while a spatial error model should be used to estimate a specification as in (2).

However, the interaction that we want to identify is characterized as in (3). The weighted patent stock of other firms is an exogenous variable which influences patent output in a certain firm. The reason is that the existing patent stock is determined already in the past. We do not use discounting of past patent activity, so that patents from all years have a weight of one in the construction of a firm's patent stock.[4] The exogeneity of the spatially lagged variable implies that we do not need to use spatial econometric techniques as outlined in the previous paragraph. Instead, we can use a standard estimation strategy. Specifically, due to the count nature of the patent data we use a Poisson model, described in more detail below.

The optimal weighting of observations cannot be determined endogenously from the estimation. This is due to the fact that with cross-sectional data the weighting matrix is a $N \times N$ matrix, where N is the number of observations in the sample. This fact renders it mathematically impossible to estimate this matrix (see for example Anselin 1988). Hence, its configuration must be guided by economic theory or intuition.

When using firms as the observational unit, inverse geographical distance between their headquarters is the most often used metric to determine the strength of interaction. However, we argue that innovation spillovers do not accrue from geographical proximity in and of itself. Instead, we believe that outsourcing relationships constitute important sources of firm-interdependence and are crucial in determining innovative activity in a firm. The structure of intermediate goods trade between firms will, thus, guide us in the construction of our weighting matrices.

When constructing a measure of trade in intermediate inputs we differentiate between backward relationships and forward relationships. Backward relationships are a measure for spillovers that move up on the value chain from firms that *use* intermediate inputs to firms that *produce* these intermediate goods. Consequently, each

[4]One might argue that the past patent stock and current patent activity in one period are determined jointly if sectoral research effort and input-output linkages remain sufficiently constant over the years. However, there is a high degree of variance over time in these variables.

manufacturer of intermediate inputs receives spillovers from all its corporate customers in proportion to the volume of sales. Mathematically spoken, the element w_{ijkl} of the weighting matrix which characterizes spillovers received by firm i in sector k from firm j in sector l is the product of two terms: The first term characterizes the importance of sector l in using intermediate inputs from sector k, measured by the respective value from the input-output matrix relative to all other sectors using products from sector k. The second term characterizes the importance of intermediate inputs for firm j, relative to all other firms of the same sector l. It comes from the Amadeus firm-level database, which contains usage of intermediate inputs for all firms in our sample. This weighting matrix is based on the assumption that all firms in sector l use the same *relative composition* of intermediate inputs, whereas the *absolute* level of intermediate inputs can differ between firms. The bilateral weight of firm j in sector l for firm i in sector k, w_{ijkl}, can hence be written as:

$$w_{ijkl} := \frac{Z_{kl}}{\sum_l Z_{kl}} \cdot \frac{M_j}{\sum_{j \in \mathcal{L}} M_j}, \tag{3}$$

where Z_{kl} is the element of the input-output matrix that characterizes inputs produced in sector k and used by sector l, M_j is the volume of intermediate inputs used by firm j, and $\mathcal{L}$ describes the set of firms that operate in sector l. Hence, $\frac{Z_{kl}}{\sum_l Z_{kl}}$ is the relative importance of sector l in using intermediate inputs from sector k, measured by the share over a row of the input-output matrix. Furthermore, $\frac{M_j}{\sum_{j \in \mathcal{L}} M_j}$ is the importance of firm j in using intermediate inputs relative to all other firms in sector l measured by the intermediate inputs used by firm j as a share of total usage of intermediate inputs of firms in that sector l.

The element w_{ijkl} of the weighting matrix for forward spillovers again characterizes spillovers received by firm i in sector k from firm j in sector l. Again, each element of this spillover matrix is defined as the product of two terms: As above, the first term shows the importance of sector l in sending spillovers to sector k, by the value of intermediate inputs used in sector k and produced in sector l divided by the total value of intermediate inputs used in sector k. The second term indicates the importance of firm j relative to all other firms of the same sector l. Since we do not have information on the volume of sales of intermediate inputs, we proxy this number by the revenue of a firm. The second term, thus, is given by the revenue of firm j divided by the sum of revenue of all firms in sector l. This weighting matrix is based on the assumption that the output level of intermediate goods relative to final goods is identical for all firms in one sector and that the relative importance of a firm in purchasing inputs from other firms does not vary within sectors, but only between sectors. Hence, we write the bilateral weight of firm j in sector l for firm i in sector k, w_{ijkl}, as:

$$w_{ijkl} := \frac{Z_{lk}}{\sum_l Z_{lk}} \cdot \frac{R_j}{\sum_{j \in \mathcal{L}} R_j}, \tag{4}$$

where Z_{lk} is the element of the input-output matrix that characterizes inputs produced in sector l and used by sector k, R_j is the revenue of firm j, and $\mathcal{L}$ describes the set of firms that operate in sector l. Consequently, the first term $\frac{Z_{lk}}{\sum_l Z_{lk}}$ is the relative importance of sector l in producing intermediate inputs for sector k, measured by the share over a column of the input-output matrix. The second term $\frac{R_j}{\sum_{j \in \mathcal{L}} R_j}$ is our proxy the importance of firm j in producing intermediate inputs relative to all other firms in sector l, measured by the revenue of firm j as a share of total revenue of firms in sector l.

Both of these weighting matrices are potential descriptions of the pattern of knowledge flows due to intermediate goods trade in an economy. In other words, multiplying these weighting matrices with a vector containing the patent stock of all firms yields a potential vector of the knowledge capital that firms can use in their patenting activity. Finding a high correlation of this constructed stock of knowledge capital with actual patent output means that the weighting matrix must indeed be a good representation of actual knowledge flows in the economy.

We assume that spillovers from a firm's own patent stock have a different influence on current patent activity than spillovers from other firms' patent stocks. Thus, we include each firm's own patents as additional explanatory variable in the regression. Indeed we will find a high degree of autocorrelation in patenting activity.

Apart from their past innovation experience, firms differ with respect to other observable characteristics. Following the specification by Coe and Helpman (1995) introduced in Equation (1) it is necessary to control for the number of researchers in each firm. Since we do not have data on the composition of workers available we use the stock of employees and the annual capital depreciation in 2007 to control for the capital stock. This allows us capture all differences between firms which come from their size or their capital-labor ratios, which are highly correlated with research activity. The stock of employees, as well as the capital depreciation, are used in natural logarithms. As additional control variables we use the location of the firm on NUTS 1 level, legal structure, and decade of incorporation (respectively century of incorporation for companies established before 1900). The estimated equation can be written as:

$$p_i \sim Poisson(\mu), \qquad (5)$$

with

$$\mu = exp(\alpha + \gamma P_i + \rho \sum_{j \neq i} w_{ij} P_j + \delta_1 L_i + \delta_2 K_i + \mathbf{X}\beta + u_i), \qquad (6)$$

where p_i patent applications of firm i, P_i is the patent stock of firm i, $\sum_{j \neq i} w_{ij} P_j$ is the weighted patent stock of all other firms j, L_i is the log of firm employees, K_i is the log of depreciations in the firm's balance sheet as proxy for the capital stock, $\mathbf{X}$ is a vector of controls, including dummies for a company's legal form, decade of incorporation, and NUTS 1 location ("Bundesland") as outlined above.[5]

[5]A detailed derivation of this type of estimation equation can be found in Eaton and Kortum (1996) or in the technical appendix of Bottazzi and Peri (2002).

5 Results

We estimate six different specifications of the model presented in the previous section. The results of these estimations are presented in table 4. All estimations include the control variables outlined above but we do not report all of the coefficients.

The accumulated stock of patents in a firm always positively influences the number of new patents. The estimated coefficient is always significant and in the range between 0.82 and 0.90. This indicates that past innovation is a very good predictor for future innovation. Moreover, we see that the coefficient for employees is positive and significant in all specifications. The estimated coefficient remains surprisingly constant throughout the six columns. This positive coefficient is likely to capture a scale effect from larger firm size. On the other hand, the coefficient for capital is always insignificant. This is evidence that the capital-to-labor ratio does not play a crucial role in the determination of innovative activity.

In the first column we investigate the strength of backward spillovers between firms. We find a positive and significant coefficient of 0.151 which indicates that firms that purchase intermediate inputs have an impact on innovative success in the firms that deliver those intermediate products to them. More precisely, we find that a one unit increase in our measure of backward spillovers increases the number of new patent activities by 15.1%. We then separate the weighting matrix into one that only has positive values for intra-industry intermediate goods trade and has zeros elsewhere, and one which has zeros on the intra-industry elements and the positive values of the backward trade weighting matrix. The coefficients of both weighted patent stocks are now positive and significant, reported in column (2). They have a value similar to the value of the aggregate backward trade weighting matrix.

The specification reported in the third column introduces the weighting matrix that is based on forward trade of intermediate inputs. It tests for the strength of spillovers

VARIABLES	(1) Pat 2007	(2) Pat 2007	(3) Pat 2007	(4) Pat 2007	(5) Pat 2007	(6) Pat 2007
Patent stock	0.900***	0.837***	0.840***	0.828***	0.836***	0.823***
	(0.0265)	(0.0285)	(0.0275)	(0.0290)	(0.0267)	(0.0291)
Backward	0.151**					
	(0.0719)					
Bw. inter-industry		0.159**			0.261***	0.244***
		(0.0695)			(0.0666)	(0.0685)
Bw. intra-industry		0.197***				
		(0.0401)				
Forward			0.430***			
			(0.0734)			
Fw. inter-indutry				0.500***	0.701***	0.634***
				(0.106)	(0.0991)	(0.116)
Fw. intra-industry				0.101**		
				(0.0474)		
Intra-industry						0.0550
						(0.0496)
Labor	0.232***	0.232***	0.222***	0.213***	0.223***	0.223***
	(0.0700)	(0.0714)	(0.0710)	(0.0714)	(0.0720)	(0.0722)
Capital	0.00103	0.0291	0.0433	0.0482	0.0360	0.0440
	(0.0521)	(0.0531)	(0.0531)	(0.0532)	(0.0527)	(0.0534)
Constant	-4.684***	-5.597***	-5.790***	-6.411***	-7.830***	-7.786***
	(1.004)	(1.007)	(0.996)	(1.012)	(1.079)	(1.082)
Observations	10,255	10,255	10,255	10,255	10,255	10,255
Pseudo R2	0.5486	0.5543	0.5553	0.5588	0.5614	0.5617
AIC	2401.699	2374.443	2367.05	2351.225	2337.961	2338.713
BIC	2741.769	2721.748	2707.12	2698.53	2685.266	2693.253

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Estimation results

from firms that produce intermediate inputs to the firms that purchase those inputs to use them in their production process. The estimated coefficient of 0.430 indicates that these forward spillovers are three times more important than backward spillovers. We now perform the same exercise as above, splitting up the weighting matrix into one that only accounts for intra-industry trade and one that only accounts for inter-industry trade. The results presented in column (4) show that inter-industry forward spillovers are substantially more important than intra-industry forward spillovers.

In column (5) we only compare the strength of backward inter-industry spillovers and forward inter-industry spillovers, ignoring the impact of intra-industry spillovers. The resulting pattern is as expected, given the results from column (2) and (4). Forward inter-industry spillovers are substantially stronger than backward inter-industry spillovers. Adding a weighting matrix that accounts only for intra-industry spillovers in column (6) yields an insignificant coefficient for these types of spillovers. This is evidence for the hypothesis that indeed inter-industry spillovers are more important than intra-industry spillovers.

Keller (1998) showed that much of the innovation spillover coefficient in Coe and Helpman (1995) could be explained by random weighting matrices. In order to control for a similar problem we perform robustness checks in which we randomly shuffle the elements of each weighting matrix and repeat the estimation procedure 50,000 times. This strategy yields coefficient estimates that are normally distributed with mean zero. Only a very small share of the estimated coefficients is comparable in size to the estimates we obtain with our weighting matrix as mandated by trade in intermediate inputs.[6]

6 Conclusion

In this paper we analyze how intermediate goods procurement relationships can predict the flow of knowledge between industries in Germany. We find evidence that knowledge spillovers do exist and that input-output tables are a good indicator for them.

Differentiating between intra-industry and inter-industry spillovers our estimations show that intra-industry spillovers have no explicative power as soon as we take inter-industry spillovers into account. Using a second dimension of differentiation, the one between forward and backward spillovers, it turns out that forward spillovers seem to be more important than backward spillovers. This result holds when we estimate effects for the more important inter-industry spillovers only or if we account for inter- and intra-industry spillovers jointly.

[6] Results are available from the authors upon request.

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Appendix

Sectoral patenting activity

CPA (2002)	Sector	Firms	Av. Patent Stock	Av. Patents 2007
01	Products of agriculture, hunting and related services	22	0.05	0.0000
02	Products of forestry, logging and related services	2	0.00	0.0000
10	Coal and lignite; peat	4	3.25	0.0000
11	Crude petroleum and natural gas; services incidental to oil and gas extraction, excluding surveying	6	9	0.0000
12	Uranium and thorium ores	1	5	0.0000
13	Metal ores	2	14	0.0000
14	Other mining and quarrying products	18	5.28	0.0000
15.1-8	Food products	276	2.08	0.0036
15.9	Beverages	51	1.25	0.0000
16	Tobacco products	7	4.57	0.0000
17	Textiles and textile products	58	26.34	0.0862
18	Wearing apparel; furs	43	3.42	0.0000
19	Leather and leather products	11	10.36	0.0000
20	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	60	14.17	0.1500
21.1	Pulp, paper and paperboard	57	14.00	0.0702
21.2	Articles of paper and paperboard	61	19.85	0.0491
22.1	Books, newspapers and other printed matter and recorded media	45	1.89	0.0000
22.2-3	Printing services and services related to printing; reproduction services of recorded media	5	6.00	0.0000
23	Coke, refined petroleum products and nuclear fuel	23	3.39	0.0000
24.4	Pharmaceuticals, medicinal chemicals and botanical products	84	48.17	0.0952
24 w/o 24.4	Chemicals, chemical products and man-made fibres (except pharmaceuticals)	198	54.37	0.1818
25.1	Rubber products	34	31.32	0.1765
25.2	Plastic products	176	44.33	0.2102
26.1	Glass and glass products	30	11.67	0.0000
26.2-8	Other non metallic mineral products (except glass)	87	91.67	0.1149
27.1-3	Basic iron and steel and ferro alloys, tubes and other first processed iron and steel	76	25.80	0.0921
27.4	Basic precious metals and other non-ferrous metals	54	22.31	0556
27.5	Foundry work services	59	14.88	0.0339
28	Fabricated metal products, except machinery and equipment	328	60.72	0.2012
29	Machinery and equipment n.e.c.	645	106.76	0.2202
30	Office machinery and computers	66	77.67	0.5455
31	Electrical machinery and apparatus n.e.c.	209	55.26	0.2584
32	Radio, television and communication equipment and apparatus	19	109.84	0.0526

CPA (2002)	Sector	Firms	Av. Patent Stock	Av. Patents 2007
33	Medical, precision and optical instruments; watches and clocks	135	129.38	0.3778
34	Motor vehicles, trailers and semi-trailers	127	40.18	0.2913
35	Other transport equipment	48	31.38	0.1250
36	Furniture; other manufactured goods n.e.c.	84	36.87	0.0714
37	Secondary raw materials	24	1.00	0.0000
40.1,3	Production and distribution services of electricity; Steam and hot water supply services	313	1.3327	0.0032
40.2	Manufactured gas and distribution services of gaseous fuels through mains	64	0.63	0.0000
41	Collected and purified water; distribution services of water	35	1.11	0.0000
45.1-2	Site preparation work and works for complete construction or parts thereof; civil engineering work	195	6.53	0.0051
45.3-5	Building installation and completion work; renting services of construction or demolition equipment with operator	110	18.40	0.0545
50	Trade, maintenance and repair services of motor vehicles and motorcycles; retail trade services of automotive fuel	395	0.35	0.0000
51	Wholesale trade and commission trade, except of motor vehicles and motorcycles	1586	0.95	0.0013
52	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	395	0.11	0.0000
55	Hotel and restaurant services	45	0.04	0.0000
60.1	Railway transportation services	17	0.00	0.0000
60.2-3	Other land transportation services and transportation services via pipelines	118	0.00	0.0000
61	Water transport services	28	0.04	0.0000
62	Air transport services	10	0.00	0.0000
63	Supporting and auxiliary transport services	211	0.00	0.0000
64	Post and telecommunication services	125	4.76	0.0160
65	Financial intermediation services, except insurance and pension funding services	54	0.39	0.0000
67	Services auxiliary to financial intermediation	21	0.00	0.0000
70	Real estate services	306	0.07	0.0000
71	Renting services of machinery and equipment, without operator and of personal and household goods	71	0.04	0.0000
72	Computer and related services	160	0.01	0.0000
73	Research and development services	43	173.63	0.2093
74	Other business services	1903	2.26	0.0068
75.1-2	Public administration and defence services	20	0.00	0.0000
75.3	Compulsory social security services	3	0.00	0.0000
80	Education services	18	0.00	0.0000
85	Health and social work services	516	0.00	0.0000
90	Sewage and refuse disposal services, sanitation and similar services	78	4.96	0.0000
91	Membership organization services n.e.c.	20	0.00	0.0000
92	Recreational, cultural and sporting services	73	0.15	0.0000
93	Other services	87	0.21	0.0115

Table 5. List of sectors, firms, and their patenting activity.

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