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## Fiscal Competition and the Composition of Public Spending: Theory and Evidence

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Marco Caliendo  
Viktor Steiner**

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# Fiscal competition and the composition of public spending: Theory and evidence

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## Abstract

In this paper, we consider fiscal competition between jurisdictions. Capital taxes are used to finance a public input and two public goods, one which benefits mobile skilled workers and one which benefits immobile unskilled workers. We derive the jurisdictions' reaction functions for different spending categories. We then estimate these reaction functions using data from German communities. Thereby we explicitly allow for a spatially lagged dependent variable and a possible spatial error dependence by applying a generalized spatial two-stage least squares (GS2SLS) procedure. The results show, that there is significant interaction between spending of neighbouring counties in Germany.

*JEL classification:* H77, J24, J61.

*Keywords:* Tax competition, capital skill complementarity, public spending, spatial econometrics.

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# 1 Introduction

The early literature on fiscal competition claimed that competition for mobile factors would drive down taxes to inefficiently low levels (Zodrow and Mieszkowski, 1986). While the basic model has been extended in various ways (see Wilson, 1999, for a survey), the one we focus on here is the effect of fiscal competition on the composition of spending. Keen and Marchand (1997) found that jurisdictions will spend too much on public infrastructure, which attracts mobile capital, and too little on consumption goods, which benefit immobile workers. We will use a similar model and also look at jurisdictions' choices of different spending categories under fiscal competition.

The early literature also assumed that jurisdictions are so small that they treat the net return to mobile capital as given. The basic models have been extended to allow for strategic interaction among communities (Wildasin, 1988). Strategic interaction among jurisdiction has also provided the basis for most of the empirical work on fiscal competition (see Brueckner, 2003, for a survey). The empirical papers estimate reaction functions, where, for instance, one jurisdiction's property tax rate is related to the tax rates of neighboring jurisdictions.

This paper extends the literature on fiscal competition in two ways. First, we incorporate two types of labor: skilled and unskilled. In addition we assume that skilled labor is mobile while unskilled labor is not, and that capital and skilled labor are complements. This is referred to as capital skill complementarity (Griliches, 1969).<sup>1</sup> Second, we allow for three public goods: a public input, and two public consumption goods, one benefiting skilled labor and the other benefiting unskilled labor. Borck (2005) uses this type of model to study the composition of public spending in a model with small jurisdictions. By contrast, in this paper we focus on strategic interaction. We also focus on the positive implications of the theory rather than the welfare implications of fiscal competition. The paper models jurisdictions' decisions on the different types of spending and derives their reaction functions. We then estimate reaction functions for German communities using spatial regression techniques.

We believe that these extensions are significant for two reasons. First, on the empirical side, neglecting the interaction between different spending categories may blur the mecha-

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<sup>1</sup>Strictly speaking, CSC holds if the elasticity of substitution between capital and skilled workers is smaller than that between capital and unskilled workers.

nisms by which communities try to attract mobile factors and by which they interact with neighboring communities. Second, as far as the modelling side and its policy implications are concerned, we would stress that capital skill complementarity and the greater mobility of skilled than unskilled workers seem to be well documented.<sup>2</sup> Hence, jurisdictions may find that to attract capital, they also need to attract skilled workers, and to do so they may also use public goods which differentially benefit this group of workers.

Within this framework, we proceed as follows. In section 2, we present our model and derive the jurisdictions' reaction functions, where the different spending categories are related to spending of the other jurisdictions. In section 3, we describe our empirical framework for estimating the reaction functions. Section 4 describes our dataset and the results of our spatial regressions are presented in section 5. The last section concludes.

## 2 The model

Our model is based on Keen and Marchand (1997) who used Zodrow and Mieszkowski's (1986) basic model to study the composition of spending under fiscal competition.

There are 2 jurisdictions, called regions, each with independent taxing and spending power.<sup>3</sup> Similar to Huber (1999), we assume that there are four factors of production: capital  $K$ , skilled labor (or human capital),  $H$ , unskilled labor,  $L$ , and a public input,  $P$ . In each region, output is produced with the same production function,  $F(K, P, H, L)$ , which is factor-augmenting, i.e., homogeneous of degree one in private inputs. Assume that capital and skilled labor are mobile while unskilled labor is immobile. Furthermore, the mass of unskilled workers in each jurisdiction is normalized to one, as is the mass of initial skilled workers (before migration) and the capital endowment in each jurisdiction. Denoting partial derivatives by subscripts, the production function can be written in intensive form as  $f(k, p, h) \equiv F(K, P, H, 1)$ , with  $f_k, f_h, f_p > 0, f_{kk}, f_{hh}, f_{pp} < 0$ . The unskilled wage rate is  $R \equiv f(k, p, h) - kf_k(k, p, h) - hf_h(k, p, h)$ . We assume that there is capital skill complementarity (CSC) in the sense that  $f_{kh} > 0$ . In addition, we assume that public

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<sup>2</sup>See e.g. Griliches (1969), Bergström and Panas (1992), and Krusell *et al.* (2000) for evidence on CSC. For evidence on the mobility of skilled versus unskilled workers, see Mauro and Spilimbergo (1999), Hunt (2000) and Giannetti (2001).

<sup>3</sup>In the empirical part there will be more than 2 jurisdictions, but we stick with two here for simplicity. Generalizing to  $N \geq 2$  is straightforward but tedious.

infrastructure is complementary to private capital and skilled labor so that  $f_{kp}, f_{hp} > 0$ , and that  $f_{kk} + f_{kh}, f_{hh} + f_{kh} \leq 0$ .<sup>4</sup>

There is a unit tax on capital at rate  $t$ , which is used to finance the public input and two public consumption goods, one benefitting skilled labor,  $g^H$ , and one benefitting unskilled labor,  $g^L$ . For example, one might think of theaters or opera houses which primarily benefit the upper classes versus housing assistance or social assistance to the poor. The basic argument would not be changed if jurisdictions could also tax labor, provided that skilled and unskilled labor are taxed at the same rate (Borck, 2005).

An individual with skill level  $j \in \{H, L\}$  who lives in jurisdiction  $i \in \{1, 2\}$  has a quasiconcave utility function  $u(x_i^j, g_i^j)$ , where  $x$  is private consumption. Each individual is assumed to inelastically supply one unit of labor. Individuals receive income from wages and from their capital endowment,  $\bar{k}_i$ , which is the same for each individual. Therefore, the budget constraints of a skilled and unskilled individual can be written:

$$x_i^H = w_i + r\bar{k}_i \quad (1)$$

$$x_i^L = f(k_i, p_i, h_i) - (r + t_i)k_i - w_i h_i + r\bar{k}_i, \quad (2)$$

where  $w_i$  is the skilled wage in jurisdiction  $i$ .

The government budget constraint is:

$$p_i + g_i^H + g_i^L = t_i k_i. \quad (3)$$

Firms are assumed to maximize profits under perfect competition. Capital and skilled labor are mobile between regions, which implies that in equilibrium, the net return to capital, and the utility (not necessarily the net wage) of skilled workers must be equalized across jurisdictions. This implies:

$$f_k(k_1, p_1, h_1) - t_1 = f_k(k_2, p_2, h_2) - t_2 = r \quad (4)$$

$$u(x_1^H, g_1^H) = u(x_2^H, g_2^H) \quad (5)$$

$$f_h(k_1, p_1, h_1) = w_1 \quad (6)$$

$$f_h(k_2, p_2, h_2) = w_2, \quad (7)$$

$$\text{with } k_1 + k_2 = \bar{k}_1 + \bar{k}_2 \quad (8)$$

$$h_1 + h_2 = \bar{h}_1 + \bar{h}_2, \quad (9)$$

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<sup>4</sup>See also Keen and Marchand (1997). These assumption imply that the capital-skilled labor ratio is non-increasing in the rental rate of capital and non-decreasing in the skilled wage.

where  $\bar{h}_i$  is the initial population of skilled workers in jurisdiction  $i$ . Equation (4) is the location equilibrium condition for capital, and (5) the corresponding condition for skilled labor. Note that since skilled labor receives utility from public goods, this condition will not in general imply that the net return to labor is equalized across jurisdictions. (8) and (9) ensure that in equilibrium, all mobile factor suppliers are located in one of the jurisdictions.

Equations (4) – (9) determine the endogenous variables,  $k_i, h_i, w_i, r$  for  $i = 1, 2$ , as functions of tax rates,  $t_i$  and spending levels,  $g_i^H, p_i$ . Differentiation gives:<sup>5</sup>

$$\frac{dk_1}{dt_1} = -\frac{dk_2}{dt_1} < 0, \quad \frac{dh_1}{dt_1} = -\frac{dh_2}{dt_1} < 0, \quad (10)$$

$$\frac{dk_1}{dp_1} = -\frac{dk_2}{dp_1} > 0, \quad \frac{dh_1}{dp_1} = -\frac{dh_2}{dp_1} \gtrless 0, \quad (11)$$

$$\frac{dk_1}{dg_1^H} = -\frac{dk_2}{dg_1^H} > 0, \quad \frac{dh_1}{dg_1^H} = -\frac{dh_2}{dg_1^H} > 0. \quad (12)$$

CSC implies that increases in the capital tax rate in a jurisdiction drive out capital and skilled labor. Further, increasing public goods benefitting skilled labor will attract both capital and skilled labor; spending on public inputs also attracts capital and may attract skilled labor.<sup>6</sup> The effects on factor prices are generally ambiguous, but we can show that the return to capital decreases with the capital tax rate, the high skilled wage falls and the low skilled wage rises with  $g^H$  (see the Appendix).

Each government is assumed to maximize the utility of immobile unskilled workers:

$$\max_{t_i, g_i^H, g_i^L, p_i} u(g_i^L, x_i^L)$$

subject to (2)–(9).

Using (2) and (3), we can rewrite the maximization problem:

$$\max_{t_i, g_i^H, p_i} u(t_i k_i - g_i^H - p_i, f - (r + t_i)k_i - w_i h_i + r \bar{k}_i)$$

---

<sup>5</sup>See the Appendix.

<sup>6</sup>In fact this holds in a symmetric equilibrium; see Appendix.



The first order conditions for interior solutions for jurisdiction 1 can be written:<sup>7</sup>

$$\frac{\partial u_1^L}{\partial g_1^L} \left( k_1 + t_1 \frac{dk_1}{dt_1} \right) + \frac{\partial u_1^L}{\partial x_1^L} \left( -k_1 + (\bar{k}_1 - k_1) \frac{dr}{dt_1} - h_1 \frac{dw_1}{dt_1} \right) = 0 \quad (13)$$

$$\frac{\partial u_1^L}{\partial g_1^L} \left( t_1 \frac{dk_1}{dg_1^H} - 1 \right) + \frac{\partial u_1^L}{\partial x_1^L} \left( (\bar{k}_1 - k_1) \frac{dr}{dg_1^H} - h_1 \frac{dw_1}{dg_1^H} \right) = 0 \quad (14)$$

$$\frac{\partial u_1^L}{\partial g_1^L} \left( t_1 \frac{dk_1}{dp_1} - 1 \right) + \frac{\partial u_1^L}{\partial x_1^L} \left( f_p^1 + (\bar{k}_1 - k_1) \frac{dr}{dp_1} - h_1 \frac{dw_1}{dp_1} \right) = 0, \quad (15)$$

where  $u_i^j \equiv u(g_i^j, x_i^j)$  for  $j = H, L, i = 1, 2$ .

Equations (13)–(15) define jurisdiction 1's reaction functions:

$$q_1 = f(q_2), \quad (16)$$

where  $q \equiv (g^H, g^L, p)$ . Differentiating gives the slopes of the reaction functions, i.e., the response of the different spending categories in  $i$  to changes of *all* spending categories in  $j$ . It is easily seen that the theory gives no restrictions on the signs of the reaction functions. This comes as no surprise, since the simpler models of tax competition with only one tax rate and one public good also do not provide restrictions on the slope of the reaction function (e.g. Brueckner and Saavedra, 2001). Therefore, we will estimate reaction functions empirically to get a sense of the signs and significance of parameters.

This discussion is of some relevance for a number of reasons. First, the empirical literature on fiscal competition has focussed almost exclusively on the tax side, and if spending is analyzed it is usually aggregate spending, with the notable exception of Case *et al.* (1993) who analyze different spending categories. Second, politically, it is of some interest to know whether there is strategic interaction and in what direction it goes. Suppose for instance the central government wants to provide incentives to local governments by providing grants to increase spending on some public good. As is well known from the literature on oligopoly, the comparative statics depend on whether strategic variables are complements or substitutes. Therefore, if strategic interaction exists, knowing the slopes of reaction functions is an important issue.<sup>8</sup>

<sup>7</sup>The first order conditions for jurisdiction 2 are analogous.

<sup>8</sup>In a sense, for policy predictions, it would be enough to estimate a reduced form, i.e. regress spending on exogenous variables, since in the end, this is what the policymaker is interested in. However, this would blur the mechanism through which spending is affected by exogenous variables. And moreover, it might be potentially misleading, if for some reason the slopes of the reaction functions changed and the policymaker still used the “old” slopes for prediction.

### 3 Estimation

We now want to estimate reaction functions as characterized by (16) based on a cross section of German jurisdictions. Before describing our dataset in the next section, we set out the empirical model used to estimate the reaction functions.

The hypothesized shape of the reaction function for spending category  $k = 1, \dots, K$  of jurisdiction  $i$  will be:<sup>9</sup>

$$q_i^k = x_i\beta + \lambda \sum_{j \neq i} w_{ij}q_j^k + \epsilon_i, \quad (17)$$

where  $\beta$  and  $\lambda$  are parameters to be estimated,  $x$  is a vector of control variables,  $\epsilon$  is an error term, and the  $w_{ij}$ 's are weights to be used in the estimation. These weights are based on geographical contiguity (with row-standardized elements  $w_{ij} = 1/n_i$  for each of the  $n_i$  neighboring jurisdictions and  $w_{ij} = 0$  otherwise).<sup>10</sup>

Two main issues have to be addressed when estimating (17): endogeneity of the  $q_j$ s and possible spatial error dependence. To make things clear, let us rewrite the system of equations in (17) as

$$q = x\beta + \lambda Wq + \epsilon. \quad (18)$$

Clearly,  $q$  on the RHS of (18) is endogenous, since the dependent variable in each cross-sectional unit depends on a weighted average of that dependent variable in neighbouring cross-sectional units. Solving (18) for the equilibrium values of the  $q_i$  yields

$$q = (I - \lambda W)^{-1}x\beta + (I - \lambda W)^{-1}\epsilon \quad (19)$$

which shows that each element of  $x$  depends on all the  $\epsilon$  Brueckner (2003). The spatially lagged dependent variable in (17) is then correlated with the disturbance term leading to inconsistency of the ordinary least squares estimator (see e.g. Anselin (1988)).

Additional problems arise if the disturbance term is assumed to be spatially autoregressive, i.e.:

$$\epsilon = \rho M\epsilon + \xi, \quad (20)$$

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<sup>9</sup>We assume for the moment that jurisdiction  $i$  reacts to changes in category  $l$  by its neighbors only by adjusting spending on its category  $l$ , not by changing other categories  $k \neq l$ .

<sup>10</sup>See Brueckner and Saavedra (2001) for a discussion and comparison of weighting schemes in the estimation of property tax competition.

where  $M$  is a weighting matrix which we take to be the same as our weighting matrix  $W$ ,  $\rho$  is a parameter to be estimated and  $\xi$  is a well-behaved error term. Solving (20) yields

$$\epsilon = (I - \rho M)^{-1} \xi \quad (21)$$

which shows that each element of  $\epsilon$  is a linear combination of the elements of  $\xi$ , implying that  $\epsilon_i$  is correlated with  $\epsilon_j$  for  $i \neq j$ . Ignoring spatial error dependence may lead to false evidence of strategic interaction when estimating (17). Hence we seek an estimator that is able to deal with both sources of spatial correlation.

Kelejian and Prucha (1998) suggest a computationally simple three-step procedure to estimate models with spatially lagged dependent variables and spatially autoregressive disturbances based on a set of instruments  $H$ . They refer to their estimation procedure as a generalized spatial two-stage least squares (GS2SLS) procedure and we will use this approach for the following analysis.

The basic idea is to use the instruments  $H$  in a first step to estimate equation (18) by 2SLS, where  $H$  consists of the linearly independent columns of  $(X, WX, W^2X)$ . In a second step, the residuals obtained via the first step are used in a ‘generalized moments’ procedure suggested in Kelejian and Prucha (1999) to estimate the autoregressive parameter  $\rho$ . And finally, (18) is reestimated by 2SLS after transforming the model via a Cochrane-Orcutt type transformation to account for spatial correlation:

$$q_* = x_*\beta + \lambda Wq_* + \epsilon, \quad (22)$$

where  $q_* = q - \tilde{\rho}Wq$ ,  $x_* = x - \tilde{\rho}Wx$ , and  $\tilde{\rho}$  is the estimate of  $\rho$  from the second step.

Before presenting our estimation results, we describe the dataset used for the analysis in the next section.

## 4 Data

We test our model using a cross section of German communities in 2002. There are about 13,000 communities in Germany, which are further grouped into 439 counties (*Landkreise*) and 16 states (*Länder*). We use the counties as unit of analysis; excluding the four counties belonging to city states we are left with a sample of 435. The communities receive revenues from shared tax sources and intergovernmental grants, as well as levying their own taxes, mainly a business tax (*Gewerbesteuer*) and a property tax (*Grundsteuer*). Communities

are granted the right of self administration by the Constitution, but their spending rights are limited by national and state laws. Large parts of the local budgets are devoted to mandated expenditures. For some spending categories such as social assistance, the communities basically just execute federal law. For others such as fire departments or sewerage, the communities have to maintain these functions but have some autonomy over spending levels. Still other categories are discretionary spending, for instance culture and recreational spending. In sum, while local spending autonomy is limited by higher level government intervention, there remains a part of the budget over which the communities have discretion. Hence, we can test for strategic interaction in the discretionary part of local spending.

As dependent variables, we will use per capita spending in the following nine categories:

1. General administration
2. Public safety
3. Schools
4. Science, research and culture
5. Social security
6. Health, sports and recreation
7. Construction and housing, transport
8. Public facilities, business development
9. Business enterprises, general property and special assets.

As independent variables, we use a number of typical covariates used in empirical analyses of government spending: GDP per capita, population density, population aged 65 or older, population aged 15 or younger, rate of unemployment, and grants from higher levels of government. We also include dummy variables for the 16 German ‘states’ (*Länder*) and dummies for the ‘type’ of county. There are 9 types in total, ranging from low density rural counties to core cities. Variables and summary statistics are displayed in table 1.

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.
Population (in 1,000)	176.4464	136.2434
Population Density (Population per km <sup>2</sup> )	492.554	627.9325
Foreigners	6.90069	4.733153
Social Benefit Recipients	28.14	15.01925
Employed	50.68506	16.43446
Unemployed	10.78115	5.396347
Share of Young People (< 15 years)	.1494784	.0241092
Share of Old People (> 65 years)	.2475959	.0236417
GDP	23.32943	9.966437
Grants	540742.3	154131.5
Regional Type <sup>a</sup>		
Core cities in agglomerated regions	.091954	.2892937
Very dense counties in agglomerated regions	.1011494	.3018737
Dense counties in agglomerated regions	.0896552	.286016
Rural counties in agglomerated regions	.0528736	.2240387
Core cities in urbanized regions	.0643678	.2456896
Dense counties in urbanized regions	.2091954	.4072025
Rural counties in urbanized regions	.1563218	.3635783
Rural counties of high density	.1356322	.3427918
Rural counties of low density	.0988506	.2988049
Per capita spending on		
General administration	87.63505	40.01528
Public safety	43.42436	34.24638
Schools	72.89925	48.30317
Science, research, culture	39.56552	41.75963
Social security	182.34	177.0251
Health, sports, recreation	49.72569	37.44332
Construction, housing, transport	137.322	58.43769
Public facilities, Business development	120.9564	69.47166
Business enterprises, property and special assets	63.8963	56.57922
Total	1227.3	583.3251

N=435 observations. <sup>a</sup> See <http://www.bbr.bund.de> for an exact definition.

Table 2: Spatial 2SLS results

Variable	$\lambda$	Std. Error	$\rho$
Aggregate Expenditure	.222	.093*	-.319
General administration	.540	.113**	-.430
Public safety	.059	.102	-.143
Schools	.273	.116*	-.217
Science, research, culture	-.573	.118**	.117
Social security	-.146	.087 <sup>†</sup>	-.117
Health, sports, recreation	.047	.167	-.098
Constr. Hous.	.230	.113*	-.098
Business development	.641	.121**	-.516
Business enterprises	.468	.149**	-.287

N=435 in all regressions.

\* significant at 5%; \*\* significant at 1%, <sup>†</sup> significant at 10%.

Estimations are based on the GS2SLS procedure by Kelejian and Prucha (1998). Additional explanatory variables included as summarised in table 1.

## 5 Results

Results from our spatial two-stage least squares regressions are displayed in Table 2. We follow Kelejian and Prucha (1998) and estimate the model by the GS2SLS described in section 3. To economize on space, we only present the coefficients on the spatial lag  $\lambda$  and the spatial error  $\rho$ .<sup>11</sup>

First of all we want to know if there is a reaction between neighbouring counties in total spending. As can be seen from the table, the  $\lambda$  for aggregate expenditure is 0.222 and statistically significant. That means that a one Euro increase in neighbours' spending leads to a 0.22 Euro increase in own county spending. Hence, this confirms the general hypothesis of strategic interaction between counties. However, as theory suggests that the reaction functions differ for different spending categories, we have also estimated the model for the nine spending categories mentioned above.

Apart for spending on public safety and health, sports and recreation, we find significant  $\lambda$ s for all other categories. What seems to be of particular interest are the coefficients for public facilities/business development and science, culture and research. While we find a strong positive reaction for the first category (0.641), the coefficient for the second

<sup>11</sup>Full estimation results are available on request.

category is significantly negative ( $-0.573$ ). The positive reaction for public facilities and business development indicates that there is competition between counties to attract capital, i.e. if neighbouring counties expand their spending on, e.g., sewage or waste disposal, there is a strong incentive to do the same in order to stay competitive. The contrary is true for spending on science and culture. While our theory did not exclude negatively sloped reaction functions, another possibility is that any positive incentive to match other communities' spending is swamped by spill-overs from investment of neighbouring counties e.g. in theatres.<sup>12</sup> Since the regional distance between counties in Germany is in general not very large, inhabitants of one county will in general have access to the amenities of neighbouring counties.

Spending on infrastructure such as construction, housing and transport is typically also seen as a category where counties compete with each other. Thus we would expect strategic interaction here, too, and indeed we find a positive and significant coefficient ( $\lambda = 0.230$ ). We also find significantly positive coefficients for the categories general administration and schools. For schools, communities have limited discretion over spending levels, since education in Germany is a state affair. However, communities have original competencies, for instance in maintenance and extra-curricular activities. Hence, given that we control for common state trends through dummies and for spatial error dependence, the results may indicate strategic interaction even in this highly regulated category.

Finally, we find a negative relation for expenditure on social security ( $-0.146$ ), which is, however, significant at 10 % only. Here too, while the largest spending item, namely social assistance (*Sozialhilfe*), is regulated by national law, communities do have some discretion in other areas such as assistance to youths and the support of local welfare organizations.

Overall, the results show that there is significant interaction between spending of neighbouring counties in Germany. This is not only true for aggregate expenditure but also for most of the analysed sub-categories. As some of the previous literature we also find positively reaction functions for most spending items, except for social security and science/research and culture. While a variety of explanations is possible for these results, the negative coefficients are compatible with our theory; another explanation might, however, be the existence of spillovers.

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<sup>12</sup>In spillover models too, reaction functions may slope either up or down. Indeed Case *et al.* (1993) find positively sloped reaction functions for state spending in the US and interpret this in a spillover framework.

## 6 Conclusion

We have presented a general framework of strategic interaction of governments in different spending categories. Using a cross-section of German counties from 2002, we empirically estimate reaction functions at the county level. Thereby we explicitly allow for a spatially lagged dependent variable and a possible spatial error dependence by applying a generalized spatial two-stage least squares (GS2SLS) procedure. We start by estimating the reaction function for aggregate expenditures and find a statistically significant positive relation of 0.22. That means, that a one Euro increase in neighbours' spending leads to a 0.22 Euro increase in own county spending. However, as theory suggests that the reaction functions differ for different spending categories, we have also estimated the model for several spending categories, e.g. public safety, schools or social security. We find significant interaction in almost all spending sub-categories as well. This is consistent with the idea that local governments use spending to attract mobile factors of production.

It is interesting to note that we find these significant effects despite the fact that the German local government sector is highly regulated by state and national law. However, some discretion remains at the community level and communities seem to use this discretion.

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## Appendix

Differentiation of (4) – (9) gives:

$$\frac{dk_1}{dt_1} = \frac{1}{D} \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{hh} - f_{kh}) + \frac{\partial u_2^H}{\partial x_2^H} (f_{hh} + f_{kh}) \right) \quad (23)$$

$$\frac{dh_1}{dt_1} = \frac{1}{D} \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kk} - f_{kh}) - \frac{\partial u_2^H}{\partial x_2^H} (f_{kk} + f_{kh}) \right) \quad (24)$$

$$\frac{dk_1}{dg_1^H} = \frac{1}{D} \left( \frac{\partial u_1^H}{\partial g_1^H} (f_{kh} + f_{kh}) \right) \quad (25)$$

$$\frac{dh_1}{dg_1^H} = -\frac{1}{D} \left( \frac{\partial u_1^H}{\partial g_1^H} (f_{kk} + f_{kk}) \right) \quad (26)$$

$$\begin{aligned} \frac{dk_1}{dp_1} = & -\frac{1}{D} \left\{ \frac{\partial u_1^H}{\partial x_1^H} ((f_{hh} - f_{kh})f_{kp}^1 - (f_{kh} + f_{kh})f_{hp}^1 + (f_{hh} + f_{kh})f_{kp}^2) \right. \\ & \left. + \frac{\partial u_2^H}{\partial x_2^H} ((f_{hh} + f_{kh})f_{kp}^1 - (f_{kh} + f_{kh})f_{hp}^2 + (f_{hh} - f_{kh})f_{kp}^2) \right\} \end{aligned} \quad (27)$$

$$\begin{aligned} \frac{dh_1}{dp_1} = & -\frac{1}{D} \left\{ \frac{\partial u_1^H}{\partial x_1^H} ((f_{kk} + f_{kk})f_{hp}^1 + (f_{kk} - f_{kh})f_{kp}^1 - (f_{kk} + f_{kh})f_{kp}^2) \right. \\ & \left. + \frac{\partial u_2^H}{\partial x_2^H} ((f_{kk} + f_{kk})f_{hp}^2 + (f_{kk} - f_{kh})f_{kp}^2 - (f_{kk} + f_{kh})f_{kp}^1) \right\}, \end{aligned} \quad (28)$$

where

$$\begin{aligned} D = & -((f_{kh}^1)^2 + f_{kk}^1 f_{kh}^2 + f_{kh}^1 (f_{kh}^2 - f_{kk}^2) - f_{hh}^1 (f_{kk}^1 + f_{kk}^2)) \frac{\partial u_1^H}{\partial x_1^H} \\ & + (-f_{kh}^2 (f_{kh}^1 + f_{kh}^2) + f_{kk}^1 (f_{hh}^2 + f_{kh}^2) + f_{kk}^2 (f_{hh}^2 - f_{kh}^2)) \frac{\partial u_2^H}{\partial x_2^H} > 0. \end{aligned}$$

For the reaction of factor prices we get:

$$\frac{dr}{dt_1} = -\frac{1}{D} \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{hh}^1 f_{kk}^2 - f_{kh}^1 f_{kh}^2) + \frac{\partial u_2^H}{\partial x_2^H} (f_{hh}^2 f_{kk}^2 - (f_{kh}^2)^2) \right) \quad (29)$$

$$\frac{dw_1}{dt_1} = -\frac{1}{D} \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kh}^1 f_{kh}^2 - f_{hh}^1 f_{kk}^2) + \frac{\partial u_2^H}{\partial x_2^H} (f_{hh}^1 (f_{kk}^2 + f_{kh}^2) - f_{kh}^1 (f_{hh}^2 + f_{kh}^2)) \right) \quad (30)$$

$$\frac{dw_2}{dt_1} = -\frac{1}{D} \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{hh}^1 f_{kh}^2 - f_{kh}^1 f_{hh}^2 + f_{hh}^2 f_{kk}^2 - (f_{kh}^2)^2) + \frac{\partial u_2^H}{\partial x_2^H} ((f_{kh}^2)^2 - f_{kk}^2 f_{hh}^2) \right) \quad (31)$$

$$\begin{aligned} \frac{dr}{dp_1} = \frac{1}{\Delta} & \left\{ (f_{kp}^1 f_{kk}^2 - f_{kk}^1 f_{kp}^2) \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kk}^1 f_{hh}^1 - (f_{kh}^1)^2) + \frac{\partial u_2^H}{\partial x_2^H} (f_{kk}^1 f_{hh}^2 - f_{kh}^1 f_{kh}^2) \right) \right. \\ & \left. + (f_{kk}^1 f_{kh}^2 - f_{kh}^1 f_{kk}^2) \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kk}^1 f_{hp}^1 - f_{kh}^1 f_{kp}^1) + \frac{\partial u_2^H}{\partial x_2^H} (f_{kk}^1 f_{hp}^2 - f_{kp}^1 f_{kh}^2) \right) \right\} \quad (32) \end{aligned}$$

$$\begin{aligned} \frac{dw_1}{dp_1} = -\frac{1}{D} & \left\{ \frac{\partial u_1^H}{\partial x_1^H} (f_{hp}^1 (f_{kk}^1 f_{kh}^2 + f_{kh}^1 f_{kk}^2) + f_{kp}^1 (f_{hh}^1 f_{kk}^2 - f_{kh}^1 f_{kh}^2) + f_{kp}^2 ((f_{kh}^1)^2 - f_{hh}^1 f_{kk}^1)) \right. \\ & + \frac{\partial u_2^H}{\partial x_2^H} \left[ f_{hp}^2 (f_{kk}^1 f_{hh}^2 - (f_{kh}^1)^2) + f_{hh}^1 f_{kk}^2 - f_{kh}^1 f_{kh}^2 \right] \\ & + f_{hp}^1 ((f_{kh}^2)^2 - f_{hh}^2 f_{kk}^2 + f_{kh}^1 (f_{kh}^2 + f_{kk}^2) - f_{kk}^1 (f_{kh}^2 + f_{hh}^2)) \\ & \left. + f_{kp}^1 (f_{kh}^1 f_{hh}^2 + f_{kh}^1 f_{kh}^2 - f_{kh}^2 f_{hh}^1 - f_{hh}^1 f_{kk}^2) + f_{kp}^2 (f_{kh}^1 f_{hh}^2 - (f_{kh}^1)^2 + f_{hh}^1 (f_{kk}^1 - f_{kh}^2)) \right] \quad (33) \end{aligned}$$

$$\begin{aligned} \frac{dw_2}{dp_1} = -\frac{1}{D} & \left\{ \frac{\partial u_2^H}{\partial x_2^H} (f_{hp}^2 (f_{kk}^1 f_{kh}^2 + f_{kh}^1 f_{kk}^2) + f_{kp}^2 (f_{kh}^1 f_{kh}^2 - f_{hh}^1 f_{kk}^2) + f_{kp}^1 (f_{hh}^2 f_{kk}^2 - (f_{kh}^2)^2)) \right. \\ & + \frac{\partial u_1^H}{\partial x_1^H} \left[ f_{hp}^2 (f_{kk}^1 f_{hh}^2 - (f_{kh}^1)^2) + f_{hh}^1 f_{kk}^2 + f_{kh}^1 (f_{kk}^2 - f_{kh}^2) - f_{kk}^1 f_{kh}^2 \right] \\ & + f_{hp}^1 (f_{kh}^2 (f_{kh}^1 + f_{kh}^2) - f_{hh}^2 (f_{kk}^1 + f_{kk}^2)) \\ & \left. - f_{kp}^1 (f_{hh}^2 f_{kh}^2 - (f_{kh}^2)^2 + f_{kk}^2 f_{hh}^2 + f_{kh}^1 f_{hh}^2) + f_{kp}^2 (f_{kh}^2 (f_{kh}^1 - f_{hh}^2) + f_{kh}^1 (f_{hh}^2 - f_{kh}^2)) \right] \quad (34) \end{aligned}$$

$$\frac{dr}{dg_1^H} = \frac{1}{D} \left( \frac{\partial u_1^H}{\partial g_1^H} (f_{kk}^1 f_{kh}^2 - f_{kh}^1 f_{kk}^2) \right) \quad (35)$$

$$\frac{dw_1}{dg_1^H} = \frac{1}{D} \left( \frac{\partial u_1^H}{\partial g_1^H} (f_{kh}^1 (f_{kh}^1 + f_{kh}^2) - f_{hh}^1 (f_{kk}^1 + f_{kk}^2)) \right) \quad (36)$$

$$\frac{dw_2}{dg_1^H} = -\frac{1}{D} \left( \frac{\partial u_1^H}{\partial g_1^H} (f_{kh}^2 (f_{kh}^1 + f_{kh}^2) - f_{hh}^2 (f_{kk}^1 + f_{kk}^2)) \right), \quad (37)$$

where

$$\begin{aligned} \Delta = & (f_{kk}^1 + f_{kk}^2) \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kk}^1 f_{hh}^1 - (f_{kh}^1)^2) + \frac{\partial u_2^H}{\partial x_2^H} (f_{kk}^1 f_{hh}^2 - f_{kh}^1 f_{kh}^2) \right) \\ & + (f_{kh}^1 f_{kk}^2 - f_{kk}^1 f_{kh}^2) \left( \frac{\partial u_1^H}{\partial x_1^H} (f_{kk}^1 + f_{kh}^1) + \frac{\partial u_2^H}{\partial x_2^H} (f_{kh}^2 - f_{kk}^2) \right) \end{aligned} \quad (38)$$

The sign restrictions in (10) – (12) then follow from the assumptions and the fact that  $dz_2/d\theta = -dz_1/d\theta$  for  $z = h, k$  and  $\theta = t, g^H, p$ .

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