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A look behind the curtain – Measuring the complex economic effects of regional structural funds in Germany

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Abstract

This paper investigates the mutual impact channels of Germany's major regional policy instrument (GRW) on regional economic development. Different from earlier studies which have predominately focused on a partial assessment of output effects, we explicitly endogenize the factor inputs of the underlying production function. This allows us to comprehensively assess the role of the GRW in driving per capita output, employment, human and physical capital intensities as well as the region's technology level. The results from a spatial panel vector autoregressive model show that GRW funding has significant positive effects on regional output, the employment rate and human capital intensity.

Keywords: Regional policy, production function, factor inputs, SpPVAR, Impulse-response functions

JEL Classifications: C33,R11, R58, O47

1. Introduction

The German constitutional law postulates the creation of equivalent living conditions and equal opportunities across all German regions together with a uniform spatial development within the country. It is argued that a balanced development between structurally weak and strong regions fosters social balance, economic prosperity and development of the entire economy (Deutscher Bundestag 2014). The key policy instrument in Germany to support regional development is the "Joint Task for the Improvement of Regional Economic Structures" (in German: "Gemeinschaftsaufgabe 'Verbesserung der regionalen Wirtschaftsstruktur'", henceforth GRW). It is the goal of the GRW to foster investments in economic lagging regions in order to generate long-term employment effects and stimulate economic growth. The GRW operates as a coordinated action framework between the federal government and the German states who jointly decide on the main regulations for financial assistance (e.g. the set of regions which are eligible for public support). With regard to its implementation, one distinct objective of GRW funding is to strengthen the private business sector in lagging regions – mainly through financial support to physical capital investment projects of private businesses with a high share of export activity in total turnover. Another objective is to build up local public infrastructure to support regional business activities in these lagging regions (Deutscher Bundestag 2001 & 2014).

In times of persistent imbalances across European regions and scarce public funds, studying the effectiveness of regional policy at the European and national level is of major interest (studies analyzing the effects of EU structural funds are, for instance, Dall'erba and Le Gallo 2008, Pérez et al. 2009, Mohl and Hagen 2010, Pellegrini et al. 2013, Breidenbach et al. 2016 among others). Although the key focus is thereby typically set on the partial analysis of productivity or income growth effects, additional questions need to be posed and answered in order to gain a full understanding of the working of regional policy. Two key questions are: 1.) What are the complex economic effects of GRW funding when considering indirect transmission channels on regional output running through the different input factors of a region's production function such as capital intensities and knowledge inputs? 2.) Do the observed overall growth and development effects differ in their direction and quantity when decomposing overall funding into the two main focal areas of the GRW, namely private sector investment support and public infrastructure investments?

These are still open research questions despite the bulk of existing empirical studies examining the economic effects of the GRW at the regional level (e.g. Schalk and Untiedt 2000, Blien et al. 2003, Eckey and Kosfeld 2005, Alecke and Untiedt 2007, Eggert et al. 2007, Röhl and von Speicher 2009, Alecke et al. 2012 & 2013, Mitze et al. 2015, von Ehrlich and Seidel 2015, Dettmann et al. 2016, Rhoden 2016).[1] One reason is that prior studies provide ambiguous results as they are based on different conceptual frameworks and follow heterogeneous research designs (cross-sectional or panel data analysis), frequently ignoring spatial interactions across regions. For example, none of the existing studies makes of the advances in dynamic spatial panel data modelling at a small scale level (258 German labor market regions), which is by now a workhorse approach to analyze regional income convergence and evaluate structural funds effectiveness at the European level (see, for instance, Bouayad-Agha and Védrine 2010, Mohl and Hagen 2010 among others). Furthermore, the potentially heterogeneous effects of the two main objectives of GRW funding (private sector investment support and public infrastructure investments) have previously only been decomposed in Blien et al. (2003). And finally, only some empirical identification approaches used by Schalk and Untiedt (2000), Blien et al. (2003), Röhl and von Speicher (2009), von Ehrlich and Seidel (2015) and Dettmann et al. (2016) consider the impact on other social-economic variables than analyzing direct productivity effects – mostly by means of partial analyses, though. This illustrates the heterogeneity and potential shortcomings of earlier contributions in trying to gain a comprehensive understanding

[1] von Ehrlich and Seidel (2015) analyze the effects of the Zonenrandgebiet (ZRG) transfer scheme, which is based on GRW funding.

of the regional effects of German regional policy as a valuable input for political decision making.

Accordingly, the aim of this paper is to close these research gaps. To this end, we go beyond the existing empirical approaches in several aspects: Firstly, in order to robustly identify the effects of GRW funding we take advantage of a large panel data set on economic conditions at the small-scale level of 258 German labor market regions and control for dynamic adjustment processes and spatial spillovers in the regression approach to avoid estimation biases stemming from a correlation of residuals across time and cross-sections (LeSage and Pace 2010, Debarsy et al. 2012). As outlined above, this research gap is particularly relevant in the German context, which lags behind the state-of-the-art of evaluation approach as the EU level. Secondly, we enhance previous partial effects analyses of GRW funding by explicitly modelling all input and output factors of the production function, namely per capita output, gross employment rate, physical and human capital as well as technology (patents), in a simultaneous equation approach. In order to properly consider the indirect effects running through various transmission channels of the regional economy, we apply a vector autoregressive (VAR) model as well as impulse-response function (IRF) analysis. To the author's knowledge, flexible VAR models have not been used in the context of structural funds evaluation yet – both at the national as well as European level. Thirdly, besides quantifying the overall effects of GRW funding, we also distinguish between the working of its two main funding objectives focusing on the support of private sector and public infrastructure investments, respectively.

The empirical results illustrate the importance of our comprehensive research approach: In fact, we are able to identify mutual economic effects of the GRW beyond the typically identified output effects. As such, we find that GRW support to private sector and public infrastructure investments emanate significant positive effects on the regional employment rate as well as on the regional human capital intensity – with the size of the estimated effects partly differing between the two funding objectives. The identified effects are in line with theoretical growth model predictions indicating that regional policy can increase a funded region's employment and per capita output level through medium-run growth effects.

The paper proceeds as follows. In the next section, we briefly describe the main characteristics of the GRW policy instrument and review the current empirical literature dealing with an assessment of regional policy effectiveness in Germany (Section 2). The third section discusses some theoretical aspects used to derive hypotheses about the complex effects of GRW funding from a growth model perspective. Afterwards, the data (Section 4) will be presented, followed by a technical specification of the VAR approach and the associated IRF analysis (Section 5). The empirical results are discussed in Section 6. Section 7 finally concludes the work and points to future research.

2. The GRW policy: Institutional setup and empirical evaluation studies

2.1 The GRW policy

The GRW was introduced in 1969 as a coordinated action of the German federal government and the German states in order to foster employment and economic growth through funding private sector investment projects in economically lagging regions with locational disadvantages.[2] The goal of GRW funding can thus be attributed to Article 72 of German constitutional law, which grants the German federal government the legislative power to establish equivalent living conditions throughout the federal territory. In the course of German reunification in 1990, the GRW has been adapted on a one-to-one basis to the East German states. Accordingly, the GRW has become Germany's most powerful regional policy instrument to support regional development and equalize spatial differences in living conditions. Besides it status as financial power horse, the distinct political importance of the GRW also stems from

[2] The program is based on the GRW-law, see Bundesregierung (1969).

its function as central coordination framework for most policies and programs operating in Germany that intent to shape the regional development (such as the European Regional Development Fund (ERDF) and fiscal investment allowances in East Germany).[3]

Two important funding channels of the GRW are direct grants to (export-orientated) firms which are willing to invest in economically lagging regions (e.g. foundation, expansion and modernization of commercial units) as well as investments into the regional public infrastructure stock: for example rebuilding of industrial areas, development of (interregional) transport links and formation of educational establishments and research parks. Financing of the GRW is subdivided into federal and federal state means: the federal budget provides money for 14 of the German federal states and, in turn, each of the federal states provides funding based on the principle of additionality (the two exceptions with no current GRW support are Baden-Württemberg and Hamburg). Eligible regions for funding within the federal states are selected on the basis of a composite indicator evaluating the region's labor market and infrastructure situation relative to the rest of Germany (unemployment rate, gross salaries, an employment prediction as well as on an infrastructure indicator). The implementation of the GRW takes places at the level of federal states: That is, states can decide on the final allocation of funds among eligible projects, give notices of granting and control the compliance of regulations. Moreover, they are free to define the key aspects of regional development as framework for funding and its allocation (Deutscher Bundestag 2001 & 2014).

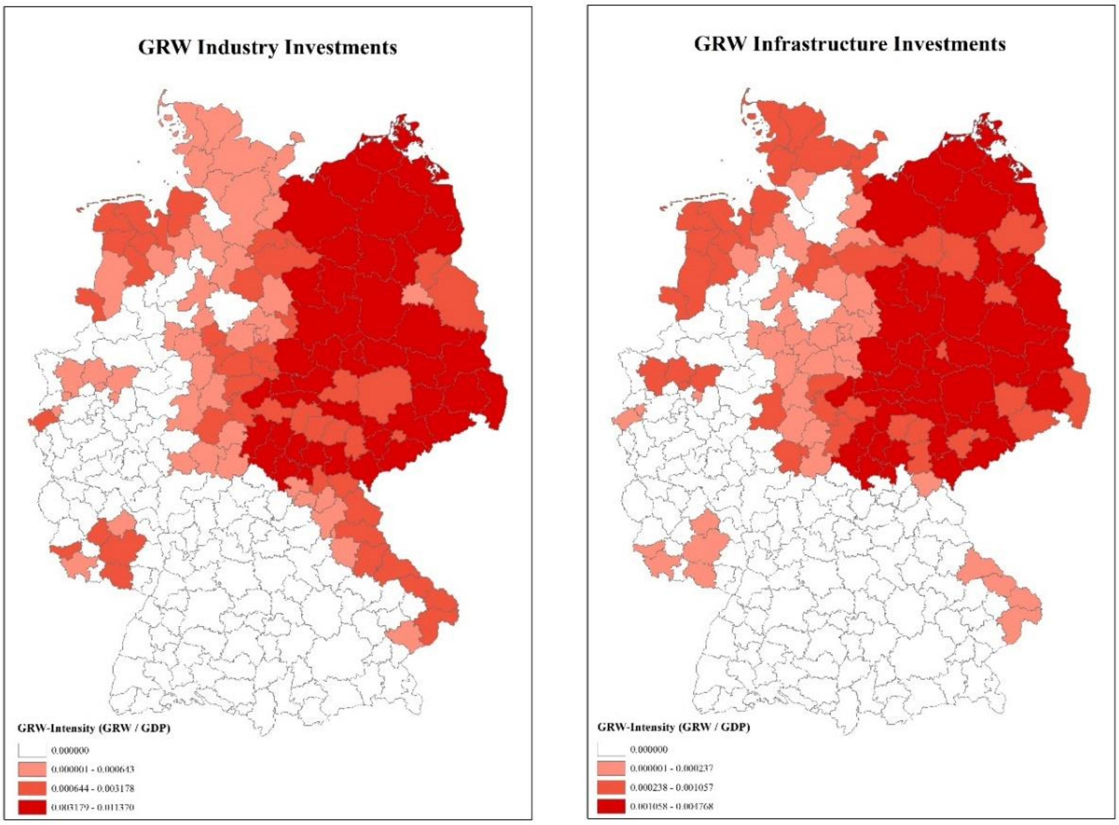
In the period 2000 to 2011, nearly 7.38 billion € were granted to foster the economically-oriented public infrastructure (68.75 % to the New Bundesländer without Berlin) and around 16.91 billion € to foster industrial investments (82.70 % to the New Bundesländer without Berlin).[4] Figure 1 illustrates the spatial distribution of the GRW funding intensity (defined as GRW

[3] For further details on the institutional setup of the GRW see, for instance, Alecke et al. (2013).

[4] Own calculation based on data from Federal Office for Economic Affairs and Export Control (BAFA), ERDF payments are included.

funding volume per GDP) in 2000 to 2011, distinguishing between private sector and public infrastructure investment support. The figure highlights the unequal spatial distribution of funding intensities in both target areas across German labor market regions. However, as illustrated in Figure A1 in the Appendix, the GRW funding intensity decreased continuously in recent years.

Figure 1: Spatial distribution of GRW funding intensities across German labor market regions (2000-2011)



Notes: Own figures based on data from the Federal Office for Economic Affairs and Export Control (BAFA).

2.2 Overview of related evaluation studies

Prior studies on the effectiveness of regional policy in Germany report ambiguous results. This ambiguity can mainly be explained with the different theoretical foundations used for model building and the heterogeneous empirical identification approaches used to isolate the causal effects of funding:[5] While one stream of studies applies a quasi-experimental approach (Mitze

[5] Röhl and von Speicher (2009) employ an empirical model without explicit theoretical foundations. Schalk and Untiedt (2000) base their analysis on a simultaneous output and factor demand system using growth theoretical foundations. The empirical specification of Eckey and Kosfeld (2005) refers to models of regional development and endogenous growth, where the regional

et al. 2015, von Ehrlich and Seidel 2015, Dettmann et al. 2016), other studies try to identify effects through parametric estimation of a single-equation production function approach (Alecke et al. 2013) or apply a shift-share method (Blien et al. 2003). The latter study is also the only one that analyzes the particular effects of GRW funding along the two focal areas of private sector and public infrastructure investment support (the main findings from the recent literature are summarized in Table A1 in the Appendix).

Moreover, while some studies rely on a cross-sectional study design, others apply panel data estimators. Panel data features more information, more variation over time and it increases the degrees of freedom (Elhorst 2003). The panel approach allows to account for (time-invariant) latent region-fixed-effects (Islam 1995). Furthermore, ignoring spatial dependence in the impact channels of GRW funding across regions may lead to inconsistent estimates (LeSage and Pace 2010). To account for the presence of latent region-fixed effects and spatial spillovers, we adapt a dynamic spatial panel model approach as, for instance, applied in Mohl and Hagen (2010) and Breidenbach et al. (2016) for the analysis of EU structural funds. The use of dynamic spatial panel estimators appears to be the most robust method to identify the policy parameters of interest.[6]

Building on this latter estimation framework, we extend the existing literature by applying a new methodological approach to count for simultaneity/endogeneity problems. Table A1 in the Appendix shows that the recent literature has mainly focused (labor) productivity or per capita

development status is determined by key factors like infrastructure, human capital, institutions, spatial and sectorial structure. Mitze et al. (2015), von Ehrlich and Seidel (2015) and Dettmann et al. (2016) use a quasi-experimental approach. While Mitze et al. (2015) and Dettmann et al. (2016) choose different factors that indicate regional conditions and affect the assignment status as control variables, von Ehrlich and Seidel (2015) include fixed effects and geographical coordinates of the municipalities. Finally, Alecke and Untiedt (2007), Eggert et al. (2007), Alecke et al. (2012 & 2013) and Rhoden (2016) base their empirical models on a neoclassical growth approach, which is also well established in the empirical literature (e.g. Ederveen et al. 2006, Dall'erba and Le Gallo 2008, Mohl and Hagen 2010, Darku 2011 among others).

[6] Mohl and Hagen (2010) conclude a positive effect of EU Objective 1 funds, while the total sum of Objective 1, 2 and 3 funds is non-significant or significantly negative, respectively. Breidenbach et al. (2016) find a negative correlation between EU structural funds and regional growth, mainly due to negative spatially-indirect effects.

income as output variable when applying a single equation estimation approach. We denote this as the direct output effect of GRW funding. However, if the GRW has an additional indirect effect on, e.g., the capital investment rate in a region, a single equation approach focusing on labor productivity as sole outcome variable would not be able to capture this indirect output effect running through an increase in the investment rate on economic output. Therefore, separate equations for all input factors involved in the production of economic output are needed to detect such indirect effects. To our knowledge, the only empirical study which applies a system approach to the analysis of GRW effects is Schalk and Untiedt (2000). The authors conduct a simultaneous analysis of output and factor demand in small multiple-equation systems focusing on the supply side of the economy with structural equations for regional production and factor demand in physical capital and labor respectively.[7]

In this study, we study the mutual dependencies among regional economic variables and deal with their associated dynamics by applying a VAR model and associated IRF analysis. Due to this approach we are able to control for the mutual endogeneity among the included variables and to analyze the effects of an isolated shock in GRW intensity on all other variables in our economic system. Variable selection is based on recent contributions in the field of growth theory, which also allows us to formulate hypotheses on the expected total (direct plus indirect) effects of GRW funding. These will be presented next.

3. Theoretical framework and research hypotheses

In growth models – either neoclassical (e.g. Solow 1956, Mankiw et al. 1992) or endogenous (e.g. Lucas 1988, Romer 1990) the dynamics of variables are modelled to follow prescribed growth mechanisms. To develop theoretically founded predictions used for variable selection

[7] At the international level, a variety of very similar studies on the effectiveness of capital investment support schemes have been published. Examples are Luger (1984) for the US, Faini and Schiantarelli (1987) for Italy, Harris (1991) for Northern Ireland and Daly et al. (1993) for Canada, among others.

in our flexible VAR approach and as priors for the interpretation of our empirical results, we mainly refer to extended versions of the Solow model (Mankiw et al. 1992, Crihfield et al. 1995) and the endogenous growth model by Romer (1990). As starting point, we formulate the production function of region *i* at time *t* as (Mankiw et al. 1992)

$$Y_i(t) = K_i(t)^{\alpha} H_i(t)^{\beta} (A_i(t) L_i(t))^{1-\alpha-\beta}, \tag{1}$$

where Y denotes regional output, K and H are physical and human capital, respectively, A is the region's technology level and L represents regional employment. The coefficients α and β measure the returns to different types of capital and, under the assumption of decreasing returns to all capital types, the restriction $\alpha + \beta < 1$ should hold. However, in the following, we deviate from the standard approach by Mankiw et al. (1992) and assume that the values determining the steady state change over consecutive time intervals and are not constant for the entire period (Islam 1995).

As public (infrastructure) investments are of major interest for our empirical model, we follow an extension introduced by Crihfield et al. (1995) (used, for instance, in a study by Brunow (2009)) and distinguish between private $K_i(t)$ and public physical capital $Z_i(t)$. Adding the latter to the production function in equation (1) leads to

$$Y_i(t) = K_i(t)^{\alpha} H_i(t)^{\beta} Z_i(t)^{\gamma} (A_i(t) L_i(t))^{1-\alpha-\beta-\gamma}, \tag{2}$$

where γ measures the return to public capital. A commonly used assumption in empirical growth models is that labor grows simultaneously with population (Islam 1995) or working-age population (Mankiw et al. 1992). However, for modelling regional growth in an ageing economy such as Germany, this appears to be an unrealistic assumption. Bräuninger and Pannenberg (2002) have accordingly developed an extension of the Solow growth model that is based on a similar idea, although it is mathematically slightly different due to their focus on the effects of unemployment. Hence, we define

(3) $$L_i(t) = P_i(0)e^{n_i t},$$

$$L_i(t) = \lambda_i(t) \cdot P_i(0)e^{n_i t},$$

where $P_i(t)$ is the economically active population aged between 15 and 65 years, n_i the exogenous growth rate of this population and $\lambda_i(t)$ represents the share of population employed ($L_i(t)/P_i(t)$), which might fluctuate over time, but is assumed to be constant in the long-run. Straightforwardly, the production function in terms of per (economically active) capita can be written as

(4) $$y_i(t) = (k_i(t)^{\alpha}\, h_i(t)^{\beta}\, z_i(t)^{\gamma})\, (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma}).$$ [8]

We take the extended production function in equation (4) as benchmark specification for the selection of variables for our empirical VAR model: That is, we use output per economically active population (y), technology (A), employment rate (λ), human capital (h), private physical capital (k) as well as public-sector physical capital (z) per economically active population. Unfortunately, the regional physical capital stocks (private and public) as well as regional technological level are difficult to measure empirically and are subject to data limitations. This may cause measurement errors. For this reason we make use of private sector (s_k) and public-sector physical capital investments (s_z) as well as technological growth (g), where the latter is proxied by the region's patent rate, defined as the share of patent applications per regional GDP, as variables for the specification and estimation of our empirical model.

[8] $y_i(t) = (Y_i(t)/P_i(t))$, $k_i(t) = (K_i(t)/P_i(t))$, $h_i(t) = (H_i(t)/P_i(t))$ and $z_i(t) = (Z_i(t)/P_i(t))$. We follow Crihfield et al. (1995) and Brunow (2009) by assuming constant returns to scale: The production function is still homogenous of degree one in the rival goods $K_i(t)$, $H_i(t)$, $Z_i(t)$ and $L_i(t)$ ($P_i(t)$, respectively, because $\lambda_i(t)$ is assumed to be constant - $l_i(t)$ is zero - in the long-run). The properties of $Z_i(t)$ are quite similar to $K_i(t)$, we assume the same marginal productivity. We additionally assume that the government utilizes public capital according to marginal productivity theory. However, $Z_i(t)$ is non-excludable (one may think about public highways or schools), but rivalry (it cannot be used simultaneously by different people at different places at the same time). Thus, the replication argument does not apply. Although public capital is an unpaid input factor for private production, it is compensated indirectly by taxes. Thus, the profit of a representative firm can be defined as: $\pi = (Y\text{-}tY) - wL - w_H H - r_K K$, where w_L and w_H are wages, while r_K is the interest rates for physical capital and t are taxes. (Y-tY) can be interpreted as net output of firms and tY as the public investment rate s_z. Moreover, technology is defined as public good. Especially due to the non-rivalry characteristic of technology, the replication argument and constant returns apply (Barro and Sala-i-Martin 2004).

Before we proceed with a more detailed data description, we first derive some hypothesis in the expected relationship between GRW funding and these variables from the perspective of regional growth theory by explicitly formulating as set of functional form equations for the input factors in regional production.

Investment rates of private, public and human capital

Based on the per capita production function in equation (4), dynamic equations for output growth and capital accumulation equation can be formulated to derive hypotheses about the dynamic direct and indirect impact channels of policy support. As such, growth rates of private, public and human capital stocks can be written as

(5) $$\frac{\dot{k}_i}{k_i} = s_{k,i}[(k_i(t)^{\alpha-1} h_i(t)^{\beta} z_i(t)^{\gamma} (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma})] - (n_i+l_i(t)+\delta),$$

$$\frac{\dot{z}_i}{z_i} = s_{z,i}[(k_i(t)^{\alpha} h_i(t)^{\beta} z_i(t)^{\gamma-1} (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma})] - (n_i+l_i(t)+\delta),$$

and

$$\frac{\dot{h}_i}{h_i} = s_{h,i}[(k_i(t)^{\alpha} h_i(t)^{\beta-1} z_i(t)^{\gamma} (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma})] - (n_i+l_i(t)+\delta),$$

where s_k, s_z and s_h measure private, public and human capital investments, respectively. The description of the GRW policy above has shown that, on the one hand, GRW support to the private sector (henceforth, *GRW industry investments*) provides non-refundable grants as an incentive for more physical investments of private firms. Thus, the GRW industry program is expected to primarily accelerate the growth rate of the private sector physical capital stock due to a higher private investment rate $s_{k,i}$ (Ederveen et al. 2003 & 2006). On the other hand, considering the GRW support to public infrastructure investments (henceforth, *GRW infrastructure investments*), funding recipients are particularly administrative body in the regions or their municipalities itself (Deutscher Bundestag 2001 & 2014). Thus, this latter type of investment grants is expected to mainly affect the public investment rate $s_{z,i}$ and, thus, the local public capital stock. However, the latter funding may also affect the private sector capital stock indirectly by establishing improved regional production conditions (higher marginal productivity of private capital). Thus, we can expect:

Hypothesis 1 (H1): GRW industry investment support primarily stimulates additional private sector investments leading to a (temporarily) higher physical investment rate in the funded region. Similarly, GRW infrastructure investment support is expected to increase the public sector investment rate directly and has an additional indirect effect on private sector investment rate via an improvement of regional production conditions.

The dynamics of human capital formation is typically expected to differ from physical capital accumulation only through heterogeneous investment rates, while all capital forms are assumed to depreciate at the same rate (Mankiw et al. 1992). Thus, according to equations (5), an increase of the per capita stock of the public and private physical capital – given a constant investment rate in human capital $s_{h,i}$ – should accelerate human capital growth indirectly.

However, although the augmented Solow model rules out a substitution effect, in the short-run, human capital is in fact a substitute to physical capital. If physical capital becomes cheaper, the input of human capital (the investment rate $s_{h,i}$, respectively) could be reduced, especially if output remains constant. Hence, one may expect that GRW support to industry investments decreases human capital input, unless both types of capital can be seen a complementary. The situation is different for GRW support to infrastructure investments. These investments also aim at supporting educational and training facilities and research parks, so that they may well attract people with higher qualification to the region. Therefore, public physical capital investments are not a direct substitutes to human capital, and we hypothesize:

H2: The effects of GRW support to industry investments on regional human capital are ex-ante unclear and depend on the relationship (substitutive or complementary of these two capital forms), while GRW support to infrastructure investments is expected to have a positive effect on the regional stock of human capital mainly operating through investments in education, training facilities and research parks.

Technological growth rate

Mankiw et al. (1992) assume that the technological growth rate is exogenously given and constant across economies. Relaxing this strong assumption, Temple (1999) describes the argumentation of theorists, economic historians or development historians that – at least – some ideas are secret and/or protected, while others are difficult to absorb. Hence, he indicates that an equal technological growth rate may hold for the long-run development, while it is rather unrealistic in the short-run (Temple 1999). Hence, we allow the regional technological growth rates g_i to vary among German regions in the short-run perspective (see Section 2.1). However, to deduce theoretical predictions here, we refer to the endogenous growth model by Romer (1990). It is assumed that technological progress is reached according to the efforts that are put into the research sector

$$\dot{A} = \delta H_A A. \tag{7}$$

Whether GRW funds have a direct effect on technological progress (proxied through the patent rate) is a question of whether the funds change the share of resources that are put into the research sector or not. As already sketched above, reductions in physical capital costs may provide an incentive to substitute human capital in favor of physical capital if both capital forms are characterized by a substitutive relationship. Differently, GRW support to public infrastructure investments has a focus, among others, on fostering research, technology or incubation units (see Section 2.1). Therefore, we hypothesize:

H3: Whether the impact of GRW support to industry investments on technological progress is positive or negative is a priori unclear and depends on its effect on human capital (see H2), while GRW support to public infrastructure investments is expected to exhibit positive effects on regional technological progress.

Output

Based on equation (4), output growth is a function of the growth rate of human, public and private physical capital as well as of the region's technological level and – in our extended model – of the employment rate. Hence, output growth can be expressed as

(6) $$\frac{\dot{y}_i}{y_i} = (1-\alpha-\beta-\gamma)\ \frac{\dot{A}_i}{A_i} + (1-\alpha-\beta-\gamma)\ \frac{\dot{\lambda}_i}{\lambda_i} + \alpha\frac{\dot{k}_i}{k_i} + \beta\frac{\dot{h}_i}{h_i} + \gamma\frac{\dot{z}_i}{z_i}.$$ [9]

This implies that a higher physical capital accumulation – via the private as well as via the public physical capital stock – affects output, ceteris paribus, positively. In addition to these known effects, there may be other (latent) impact channels of GRW funding, which go beyond those represented by the included input factors (or are only partially captured by these factors). In the literature, these additional channels of structural funds are, for instance, associated with international trade or foreign direct investments (see, e.g., Katsaitis and Doulos 2009). It is exactly this uncertainty about the mutual impact channels of GRW support on the regional economy, which motivates our choice of a flexible VAR approach. Therefore, we hypothesize:

H4: We expect that there are positive per capita output effects of both GRW investment types which mainly run through an increase in the modelled factor inputs.

Since these input factors may only imperfectly cover all output effects, we use a flexible VAR approach to capture latent per capita output effects by including GRW funding as an additional regressor in the output equation.

Employment Rate

Finally, with regard to employment, the usual assumption in the Solow growth model is that labor (labor supply is vertical) grows exogenously at the constant rate of working-age population growth (Mankiw et al. 1992) or overall population growth (Islam 1995). If the employment

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[9] $\frac{\dot{\lambda}_i}{\lambda_i}$ is expected to be zero, on average, in the long-run.

rate is allowed to vary over time, however, it can be regarded as an alternative production input as discussed above. Assuming a competitive market setting, public subsidies could thus temporarily shift the supply of money in the supported regions upwards and additional private investments are promoted. On the one hand, labor becomes more expensive relative to capital and is, ceteris paribus, replaced by capital (substitution effect). However, if the additional investments go along with an increase in output, labor input may increase as well (output effect, Bade 2012). Schalk and Untiedt (2000) indicate two reasons for such an output effect: Reduction in the user costs of capital may attract firms in the supported regions to extend their production. Moreover, firms in non-assisted regions are attracted by the lower user costs of capital and may shift their production to supported regions (Schalk and Untiedt 2000).[10] Both arguments lead to a higher demand for labor which, in turn, increases labor input, wages and may induce in-migration as well (permanent higher labor supply). Furthermore, we have to take into consideration that – according to the GRW program – firms are obligated to create or, at least, to protect existing jobs by regulation (Deutscher Bundestag 2001 & 2014). This puts some pressure on the recipients and we can expect that GRW support to industry investments foster employment in the short-run.

In contrast, GRW support to public infrastructure investments does not foster the output of particular firms, but improves the regional public capital stock. If this improvement makes firms more successful in expanding their output, the effects of GRW infrastructure are positive as well. Obviously, such an effect scenario builds on the assumption that firms do not change the composition of factor inputs along the path of output expansion. We can then expect:

H5: Given positive output effects of funding and no change in the composition of factor inputs, we expect that the effects of GRW support to industry investments as well as to infrastructure investments on the regional employment rate are positive.

[10] This argument also applies to human capital.

4. Data

For our empirical analysis we use panel data for 258 German labor market regions covering the period 2000-2011.[11] Labor market regions are based on the official classification of the *Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR)* (Status: 31.12.2014). The utilized variables and associated data sources are described in Table 1 below.[12] As the table shows, our main outcome variable in the region's per capita production is GDP per economically active working population. All factor inputs are transformed into meaningful rates, while GRW funding is measured as the intensity with regard to regional GDP. As outlined above, we decompose the total GRW intensity into industry and infrastructure support schemes, respectively. All variables are measured in logarithmic form. Summary statistics for each variable are given in Table A2 (Appendix).

Given that our sample period is affected by the macroeconomic consequences of the global economic crisis, we also construct a set of annual time dummies for inclusion in our empirical model. One should further note that the data is not free of errors: Especially data on the qualification of employees in Germany (IAB) but also regional investment rates are subject to missing values. Missing values of the industry investments have been interpolated on the basis of an autoregressive process with three lags. We assume that all data imperfections (qualification of employees data) do not lead to regional biases, so that they contribute to the random error term.

Table 1: Variable descriptions and data sources

Variable	Description	Data source
lgdp	**GDP per economically active working population** (in logs) defined as:	**GDP:** Arbeitskreis "Volkswirtschaftliche Gesamtrechnungen der Länder" (Status: August 2015)

[11] The time period used is restricted by data availability. This limits the generalization of our results. However, studying the time before 2000 would be problematic due to the reunification of Germany and the tremendous restructuring processes in East Germany between 1989 and 2000.

[12] Before taking the natural logarithm (ln), we replace zero values by a very small value (Alecke et al. 2012 & 2013).

	[GDP in € / (Population aged between 15 and 65 years * Participation rate)] **Note:** Population data is based on the extrapolation of the census 1987. The participation rate is based on the same population data till the year 2011. From 2011, the participation rate is calculated based on the population data of the census 2011.	**Population aged between 15 and 65 years:** Regionaldatenbank Deutschland (Based on the population census 1987) **Participation rate:** Statistik der Bundesagentur für Arbeit / Indikatoren und Karten zur Raum- und Stadtentwicklung (INKAR)
linvq	**Private-sector investment rate** (in logs) defined as industry investments in the manufacturing, mining and quarrying sector as share of the nominal GDP: [Industry Investments in € / GDP in €] **Note:** Missing values have been interpolated on the basis of an autoregressive process with 3 lags.	Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR), laufende Raumbeobachtungen, various issues
lhk	**Higher education rate** (in logs) defined as: [Employees with university degree / (Population aged between 15 and 65 years * Participation rate)].	Institute for Employment Research (IAB), Nuremberg
lemp	**Gross employment rate** (in logs) defined as: [Employees total / (Population aged between 15 and 65 years * Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lpat	**Patent rate** (in logs) defined as: [Patents / GDP in Mio. €]	Own calculation from the PATSTAT database (Version October 2014, European Patent Office)
lgrw (lgrw_ind, lgrw_infra)	**GRW investment intensity** (and sub components for industry and infrastructure investment support) (in logs) defined as: [GRW funding volumes in € / GDP in €].	Federal Office for Economic Affairs and Export Control (BAFA)
w_X	**Spatial lag for variable X** are constructed with the STATA command *splagvar*. All spatial lag variables have been normalized and log-transformed	

Given the moderate to long time dimension of our data (T = 12), non-stationarity of our variables may constitute a serious concern for estimation. To test this issue prior to estimation, we perform a series of panel unit root tests as suggested by Im, Pesaran and Shin (2003) (henceforth IPS). Table 2 highlights that the employment rate and human capital as well as their spatial lags show signs of non-stationarity. In order to estimate a shot-run VAR system for stationary variables, we hence detrended those variables, whereupon we can reject the null hypothesis for these variables that all panel members contain a unit root (against the alternative that they are stationary for at least some panel members).

Table 2: IPS panel unit root test for variables

Variable	Number of regions	Number of years (2000-2011)	IPS test-statistic	p-value
lgdp	258	12	-4.1221	0.000
lemp	258	12	-0.3447	0.3652
lemp_detrended	258	12	-16.0799	0.000
lhk	258	12	0.1299	0.5517
lhk_detrended	258	12	-17.6164	0.000
linvq	258	12	-17.5815	0.000
lpat	258	12	-17.4463	0.000
lgrw	258	12	-9.4251	0.000
lgrw_ind	258	12	-11.1014	0.000
lgrw_infra	258	12	-14.6072	0.000
w_lgdp	258	12	-3.3759	0.0004
w_lemp	258	12	-1.4097	0.0793
w_lemp_detrended	258	12	-17.7560	0.000
w_lhk	258	12	0.0105	0.5042
w_lhk_detrended	258	12	-18.1141	0.000
w_linvq	258	12	-15.1902	0.000
w_lpat	258	12	-13.6908	0.000
w_lgrw	258	12	-11.1076	0.000
w_lgrw_ind	258	12	-13.3155	0.000
w_lgrw_infra	258	12	-20.5042	0.000

Notes: IPS: Im et al. (2003) panel unit-root test. H0: All panels contain unit roots. HA: Some panels are stationary.
Suffix "_detrended" denotes detrended variable; see text for details.

Spatial lags of variables have thereby been calculated as the averages values in the geographical surroundings of region *i* at time *t*. The creation of spatial lags thus needs a measure for the spatial association of regions, which is typically summarized in a spatial weighting matrix. In constructing such a spatial weighting matrix to control for spatial dependence across regions, we follow Eckey and Kosfeld (2005) and use a binary first-order neighborhood matrix. The construction of the weighting matrix W proceeds as follows

(8) $w^*_{ij} = 0$ if $i = j$ and i and j $\neq$ common border

$w^*_{ij} = 1$ if $i \neq j$ and i and j = common border

$w_{ij} = w^*_{ij} / \sum_i w^*_{ij}$.

w^*_{ij} is an element of an unstandardized weighting matrix and w_{ij} is an element of a normalized weighting matrix. We normalize the weighting matrix by dividing each element of w^*_{ij} by the column sum of the matrix. In contrast to the row normalization approach, we assume that the degree of the spatial spillover depends on the sum of neighboring regions the radiating region has (see Elhorst (2014) for further information about the normalization of w_{ij}). We include spatial lags of the different variables as a way to account for spatial heterogeneity and underlying geographical spillovers among the variables. As a further pre-estimation test, we conduct a series of univariates tests based on Moran's I as a global indicator for spatial dependence across German regions (Moran 1950). The test results shown in Table 3 point to the presence of positive and persistent spatial autocorrelation for nearly all variables and sample years (with the exception of the employment rate).[13]

Table 3: Moran's I test of spatial autocorrelation across German labor market regions

Variable →		*lgdp*			*lemp*			*lhk*			*linvq*	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2000	0.474	12.401	0.000	-0.017	-0.344	0.366	0.225	5.924	0.000	0.114	3.070	0.001
2001	0.446	11.663	0.000	0.003	0.188	0.425	0.207	5.472	0.000	0.118	3.153	0.001
2002	0.422	11.059	0.000	0.012	0.420	0.337	0.198	5.239	0.000	0.161	4.297	0.000
2003	0.395	10.361	0.000	0.012	0.408	0.342	0.190	5.016	0.000	0.129	3.471	0.000
2004	0.379	9.929	0.000	0.008	0.300	0.382	0.180	4.768	0.000	0.138	3.678	0.000
2005	0.373	9.771	0.000	0.020	0.613	0.270	0.164	4.353	0.000	0.048	1.351	0.088
2006	0.342	8.965	0.000	-0.001	0.079	0.468	0.162	4.306	0.000	0.107	2.881	0.002
2007	0.330	8.670	0.000	0.001	0.136	0.446	0.153	4.077	0.000	0.100	2.698	0.003
2008	0.339	8.883	0.000	-0.000	0.090	0.464	0.149	3.969	0.000	0.189	5.022	0.000
2009	0.312	8.198	0.000	-0.023	-0.503	0.307	0.152	4.040	0.000	0.087	2.367	0.009
2010	0.300	7.891	0.000	-0.027	-0.609	0.271	0.150	3.991	0.000	0.154	4.098	0.000
2011	0.321	8.426	0.000	-0.012	-0.215	0.415	0.142	3.795	0.000	0.187	4.960	0.000
Variable →		***lpat***			***lgrw***			***lgrw_ind***			***lgrw_infra***	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2000	0.311	8.920	0.000	0.700	18.199	0.000	0.705	18.331	0.000	0.628	16.364	0.000
2001	0.508	13.337	0.000	0.702	18.257	0.000	0.702	18.238	0.000	0.665	17.318	0.000
2002	0.298	8.602	0.000	0.686	17.833	0.000	0.686	17.848	0.000	0.670	17.435	0.000
2003	0.389	11.099	0.000	0.692	17.986	0.000	0.690	17.932	0.000	0.573	14.941	0.000
2004	0.362	10.290	0.000	0.708	18.413	0.000	0.715	18.592	0.000	0.554	14.451	0.000
2005	0.323	9.076	0.000	0.698	18.153	0.000	0.703	18.276	0.000	0.671	17.468	0.000
2006	0.384	10.876	0.000	0.712	18.502	0.000	0.711	18.479	0.000	0.641	16.697	0.000
2007	0.375	10.952	0.000	0.704	18.289	0.000	0.704	18.290	0.000	0.605	15.783	0.000
2008	0.525	13.730	0.000	0.692	17.990	0.000	0.694	18.051	0.000	0.639	16.639	0.000
2009	0.348	10.600	0.000	0.691	17.967	0.000	0.704	18.299	0.000	0.626	16.301	0.000
2010	0.234	7.242	0.000	0.694	18.044	0.000	0.698	18.152	0.000	0.530	13.825	0.000
2011	0.302	9.252	0.000	0.684	17.793	0.000	0.685	17.820	0.000	0.548	14.295	0.000

Notes : Details on the underlying spatial weighting matrix used to compute the Moran's I statistic are given in the main text; Z(I) = Moran's I test statistic.

[13] A likely reason is the construction of our employment variable (See Table 1).

5. Econometric Modelling

5.1 Panel VAR Approach

VAR models have been developed as a flexible modelling tool for the analysis of multiple equations systems (Sims 1980). One of the key features of the VAR approach is that it keeps theoretical restrictions imposed to the empirical model structure at a minimum. Although VAR applications have rapidly increased in fields such as macroeconomics and international economics, regional economists have not fully explored the potential of VAR models for policy analysis and forecasting yet (Rickman 2010). Recently, however, two key extensions of the time-series VAR approach have been proposed, which particularly suit data settings in regional science and economic geography (Mitze and Stephan 2015): Firstly, the VAR approach has been adapted to estimation techniques for panel data (Holtz-Eakin et al. 1988). Secondly, the handling of spatial dependence and the interpretation of spatial effects have been incorporated in recent contributions by Beenstock and Felsenstein (2007) and Di Giacinto (2010) among others. These two developments have led to the construction and application of spatial panel VAR (SpPVAR) models.[14]

We will apply a SpPVAR model for the analysis of GRW effects. We therefore estimate a dynamic system comprising six equations with the following dependent variables: 1) per (economically active) capita output, 2) physical capital investment rate, 3) higher education rate, 4) employment rate, 5) patent rate and 6) GRW intensity. In general terms, we denote $y_{m,it}$ as the value of the *m*-th endogenous variable (with $m=1,2,...,M; M=6$) recorded for cross-section *i* (in our case: labor market regions; with $i=1,...,N$) at time *t* (with $t=1,...,T$). We can then specify a dynamic system of *M* equations with a maximum lag length of "*t-1*" as

[14] Empirical application of spatial VAR specifications can be found in Beenstock and Felsenstein (2007), Di Giacinto (2010), Monteiro (2010), Ramajo et al. (2015), Mitze et al. (2017) among others.

$$y_{1,it}=\mu_{1,i}+a_{1,1}y_{1,it-1}+a_{1,2}y_{2,it-1}+\ldots+a_{1,M}y_{M,it-1}+\varepsilon_{1,it}$$

(9) ...

$$y_{M,it}=\mu_{M,i}+a_{M,1}y_{1,it-1}+a_{M,2}y_{2,it-1}+\ldots+a_{M,M}y_{M,it-1}+\varepsilon_{M,it}$$

where $\mu_{m,i}$ is a vector of region-specific time-fixed effects included in the m-th equation,[15] $a_{m,m}$ denotes the regression coefficient indexed by equation/variable and $\varepsilon_{m,it}$ is an i.i.d. error term for the m-th equation with zero mean and finite variance. Stacking over variables and regions, we can write the VAR system more compactly as (Rickman 2010)

$$\mathbf{y}_t = \mu + \mathbf{A}(\mathbf{L})\mathbf{y}_{t-1} + \boldsymbol{\varepsilon}_t, \tag{10}$$

where μ is now a $NM \times 1$ vector of region-specific time-fixed effects, L denotes the lag operator, $\mathbf{A}(\mathbf{L})$ is a matrix of reduced-form coefficients relating past variable values to current values defined as $\mathbf{A}(\mathbf{L}) = I_N \otimes \alpha$, where I_N is an identity matrix of dimension N, $\otimes$ is the Kronecker product and α is a $M \times M$ matrix of regression coefficients $[a_{m,m}]_{M\times M}$; $\boldsymbol{\varepsilon}_t$ is an $NM \times 1$ vector of reduced-form errors with $E(\boldsymbol{\varepsilon}_t) = 0$, $E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}'_t) = \boldsymbol{\Sigma}$ and $E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}'_{t-h}) = 0$ (for $h = 1,2,\ldots$), where $\boldsymbol{\Sigma}$ denotes an $NM \times NM$ positive definite variance-covariance matrix.

Although reduced-form VARs have the advantage of avoiding the imposition of exclusion restrictions, they often face the problem of over parameterization and reveal little about the underlying economic structure (Rickman 2010). To overcome these shortcomings, the structural VAR (SVAR) model has been proposed, which makes use of economic theory or other a priori assumptions on the behavior of the process to impose restrictions for the orthogonalization of

[15] See Elhorst (2012) for a discussion of whether fixed or random effects should be the preferred empirical specification in the context of dynamic panel data models.

the shocks used for the computation of impulse response functions and variance decompositions. The SVAR corresponding to the reduced-form specification in equation (10) can be written as

$$\mathbf{B}\mathbf{y}_t = \mu + \mathbf{C}(\mathbf{L})\mathbf{y}_{t-1} + \mathbf{D}\mathbf{e}_t, \tag{11}$$

where $\mathbf{B}$ is a matrix of structural parameters for the contemporaneous variables, $\mathbf{C}(\mathbf{L})$ is a matrix of polynomials relating lagged variables to contemporaneous and $\mathbf{D}$ measures the contemporaneous responses of endogenous variables to economic shocks. As Rickman (2010) points out, premultiplying with $\mathbf{B}^{-1}$ produces the reduced-form VAR as in equation (2) with $\mathbf{A}(\mathbf{L}) = \mathbf{B}^{-1}\,\mathbf{C}(\mathbf{L})$ and $\boldsymbol{\varepsilon}_{\mathrm{t}} = \mathbf{B}^{-1}\mathbf{e}_{\mathrm{t}}$. For known $\mathbf{B}$ and $\mathbf{D}$, the structural dynamic properties of the system could be revealed when calculating $\mathbf{C}(\mathbf{L})$ and $\mathbf{e}_{\mathrm{t}}$ from the estimated reduced-form VAR. However, given that $\mathbf{B}$ and $\mathbf{D}$ are unknown, certain restrictions have to be imposed on $\mathbf{B}$ in order to identify the structural parameters and shocks (Rickman 2010).[16] As Di Giacinto (2010) argues, a fairly standard method to arrive at an exactly identified specification is to assume a recursive causal ordering of the endogenous variables (Wold 1954). This assumption of contemporaneous exogeneity is technically analogous to an orthogonalization of the error terms by means of a Choleski decomposition of the covariance matrix of the reduced form residuals (Sims 1980, Hamilton 1994).

5.2 Accounting for spatial spillovers

The above presented PVAR approach can further be extended to capture spatial dependence in the data generating processes of the variable vector $\mathbf{y}_t$. We focus on the role played by local spillovers associated with the included right-hand side regressors in each equation of the *M*-equation system. We will quantify spatial spillover effects through the inclusion of spatial lags

[16] As Rickman (2010) further points out, $\mathbf{D}$ is typically normalized as a diagonal matrix that associates each structural shock with an endogenous variable.

of $\mathbf{y}_t$, where the spatial lag for the m-th variable is defined as $\sum_{j=1}^{N} w_{ij}\, y_{m,it}$, where w_{ij} is the ij-th element of an $N \times N$ spatial weighting matrix $\mathbf{W}_N$ with potentially non-zero elements for $i \neq j$ and zero entries along the diagonal (see Section 4). For a standardized matrix $\mathbf{W}_N$ the individual elements w_{ij} thus measure the strength of association between region *i* and *j* in composing the spatial neighborhood around region *i*. Under the inclusion of spatial lags of $\mathbf{y}_t$, we can write the reduced-form of the spatially extended SpPVAR(1) system as

$$\mathbf{y}_t = \mu + \mathbf{A}(\mathbf{L})\mathbf{y}_{t-1} + \mathbf{H}(\mathbf{L})\mathbf{W}\mathbf{y}_{t-1} + \boldsymbol{\varepsilon}_t, \tag{12}$$

where $\mathbf{W} = I_M \otimes \mathbf{W}_N$ is composed of an identity matrix of dimension *M* and $\mathbf{W}_N$, assuming that spatial weights do not differ across equations. $\mathbf{H}(\mathbf{L})$ is a coefficient matrix relating past values of the spatial lag terms to current values of $\mathbf{y}_t$ as $\mathbf{H}(\mathbf{L}) = I_N \otimes \gamma$, where γ is a $M \times M$ matrix of regression coefficients $\left[\gamma_{m,m}\right]_{M\times M}$. The SVAR specification of the spatially extended system is then a straightforward extension of equation (11) as

$$\mathbf{B}\mathbf{y}_t = \mu + \mathbf{C}(\mathbf{L})\mathbf{y}_{t-1} + \mathbf{G}(\mathbf{L})\mathbf{W}\mathbf{y}_{t-1} + \mathbf{D}\mathbf{e}_t, \tag{13}$$

with $\mathbf{H}(\mathbf{L}) = \mathbf{B}^{-1}\,\mathbf{G}(\mathbf{L})$**.** Since we are interested in the short-term dynamics of the SpPVAR system, we can then interpret $\mathbf{C}(\mathbf{L})$ and $\mathbf{G}(\mathbf{L})$ as the direct and spatially indirect effects of changes in $\mathbf{y}_{t-1}$ on $\mathbf{y}_t$ based on the reduced form estimates of equation (12) and conditional on the chosen causal ordering scheme.

5.3 Estimation and impulse-response function analysis

Different approaches have been proposed in the recent econometric literature to estimate SpPVAR systems, which chiefly depend upon the degree of right-hand side endogeneity involved. In the case of the reduced-form specification of equation (12) we follow the argumentation in Beenstock and Felsenstein (2007) that $\mathbf{y}_{t-1}$ and $\mathbf{W}\mathbf{y}_{t-1}$ are weakly exogenous (given that the above stated assumption on the model's residuals holds as $E(\boldsymbol{\varepsilon}_t\boldsymbol{\varepsilon}'_{t-h}) = 0$), which greatly simplifies the consistent estimation of spatially extended panel models to the use of standard methods such as the Fixed Effects (FE) estimator. However, one complicating factor is that the estimation of the SpPVAR involves time lags of the dependent variable as an additional regressor in each equation of the SpPVAR system. In this case, the FE estimator will yield biased coefficients for $\mathbf{A}(\mathbf{L})$ given a non-zero correlation of the latter lagged endogenous variable with the model's error term. To account for this so-called "Nickel" bias in the estimation of dynamic panel data models, different extensions to the (inconsistent) FE estimator have been proposed, which either rely on (analytical or bootstrap-based) correction methods (Kiviet 1995, Everaert and Pozzi 2007) or make use of weakly exogenous instruments such as the Anderson and Hsiao (1981) Instrument Variable (IV), the Arellano and Bond (1991) first-difference GMM (FD-GMM) or the Blundell and Bond (1998) system-GMM (SYS-GMM) estimator. We apply the bootstrap-based corrected FE estimator suggested in Everaert and Pozzi (2007) to estimate the coefficients of the SpPVAR system in equation (12).

We then use IRFs to describe the reaction of one variable to shocks in another variable of the system while holding all other shocks equal to zero (Lütkepohl 2005). Starting from the estimated reduced-form expression of the SpPVAR with orthogonalized error terms, the model is rearranged into its moving average (MA) presentation, that is, in terms of the vector of structural errors and the matrix of responses of the m-th variables to a one-unit increase in the r-th structural error (with $m,r=1,...,M$). Our focus in this study rests on computing IRFs on the basis of the coefficient matrix $\mathbf{C(L)}$, while the included spatial lag terms only serve the purpose of obtaining unbiased regression results here.[17] In order to assess the statistical significance of the estimated IRFs we derive confidence intervals by means of Monte Carlo (MC) simulations (Love and Zichino 2007). We provide details on the specific causal ordering imposed on the SpPVAR system as well as the implementation of the MC simulation when discussing the empirical results in the following.

[17] Future extensions could focus on the computation of space-time IRFs (see, e,g, Di Giacinto 2010).

6. Empirical Results

In the discussion of the empirical results, we primarily focus on presenting the associated IRFs for the different effects of shocks to the GRW intensity (both overall as well as decomposed into industry and infrastructure support) on per capita output and factor inputs. The underlying regression results including the overall GRW intensity in the VAR system are shown in Table 4, while the regression results for the decomposition of GRW funding into industry and infrastructure support are reported in the Appendix (see Tables A3 and A4).[18] Furthermore, the full set of IRFs for all variables in the regional economic system is reported in Figure A2 in the Appendix as well. For the identification of effects in the IRF analysis using a Choleski decomposition of the covariance matrix of the reduced form residuals we impose the following, theory-guided recursive causal ordering at time t:

$$lgrw_t \rightarrow lhk_t \rightarrow lpat_t \rightarrow linvq_t \rightarrow lemp_t \rightarrow lgdp_t.$$

Variables more to the left have contemporaneously and time lagged effects on the other variables in the system, while variables more to the right have only delayed effects on variables appearing earlier in the ordering. That is, we assume that the GRW policy is the most exogenous factor in the model given that funding modalities are determined in a mid-run planning process. For our structural VAR approach this implies that the policy variable has a contemporaneous effect on all economic variables in the model, while potential feedback effects only take place with a lag structure. We order input factors according to their short-run flexibility (e.g. one can typically assume that decision on capital investments at time t are made on an ex-ante basis,

[18] The Appendix also contains the results of residual-based Moran's I tests to check for remaining spatial autocorrelation in the estimated equations of our SpPVAR system. As the results show, our spatial econometric approach is able to account for spatial autocorrelation in the systematic part of the SpPVAR in the majority of variable/year combinations. For details see Tables A3 to A7.

while the employment level can be adjusted continuously) and assume that factor inputs determine the state of per capita GDP as key regional outcome variable along the region's production process.

Table 4: Regression results for SpPVAR using total GRW funding intensities

Dependent Variable → Regressors ↓	*lgdp*	*lemp*	*lhk*	*linvq*	*lpat*	*lgrw*
lgdp(t-1)	0.712***	0.0300***	0.0239*	0.231	0.128	-1.477
	(0.000)	(0.000)	(0.0442)	(0.154)	(0.809)	(0.153)
linvq(t-1)	0.00870***	0.00327**	0.00337*	0.446***	-0.240***	-0.125
	(0.000)	(0.00118)	(0.0401)	(0.000)	(0.000383)	(0.332)
lhk(t-1)	0.00945	-0.00552	0.663***	0.0440	-1.193**	1.096
	(0.621)	(0.318)	(0.000)	(0.735)	(0.00610)	(0.255)
lemp(t-1)	0.0831*	0.542***	-0.0674**	-0.227	2.289*	-2.687
	(0.0454)	(0.000)	(0.00120)	(0.486)	(0.0418)	(0.211)
lpat(t-1)	0.000693	0.000784**	0.00125**	-0.0116	0.0743***	0.00162
	(0.289)	(0.00907)	(0.00658)	(0.0530)	(0.000)	(0.962)
lgrw(t-1)	0.00113**	0.000463**	0.000710**	0.00344	-0.00230	0.751***
	(0.003)	(0.00130)	(0.00450)	(0.272)	(0.836)	(0.000)
w_lgdp(t-1)	0.0788*	0.00413	-0.0251	0.164	-1.113	-0.439
	(0.0339)	(0.776)	(0.238)	(0.550)	(0.254)	(0.812)
w_linvq(t-1)	0.000476	-0.000259	0.00377	0.0344	-0.0309	0.142
	(0.922)	(0.890)	(0.190)	(0.358)	(0.806)	(0.55)
w_lhk(t-1)	-0.0675*	-0.0401***	-0.0643***	-0.0408	-0.519	-1.080
	(0.022)	(0.000)	(0.000342)	(0.850)	(0.480)	(0.463)
w_lemp(t-1)	-0.0548	0.0496	0.158***	-0.0570	2.397	-0.273
	(0.430)	(0.0509)	(0.000)	(0.907)	(0.161)	(0.936)
w_lpat(t-1)	-0.00380	-0.00119	-0.000829	0.0120	0.312**	0.331
	(0.411)	(0.511)	(0.758)	(0.741)	(0.00985)	(0.175)
w_lgrw(t-1)	0.000203	-0.0000283	-0.000206	-0.00132	0.00243	0.0612*
	(0.703)	(0.902)	(0.535)	(0.753)	(0.863)	(0.031)
Total observations	2838	2838	2838	2838	2838	2838
Number of regions	258	258	258	258	258	258

Notes: P-values are given in parentheses. *** p<0.001, ** p<0.01, * p<0.05. Coefficients for time dummies and constant term are not explicitly shown but can be obtained upon request. 250 bootstrap samples with i.i.d. resampling of the error have been used to evaluate the bias of the fixed-effects estimator; the variance-covariance matrix is estimated by using the bootstrap approach and corresponding confidence intervals have been calculated from the t-distribution.

6.1 GRW – Total

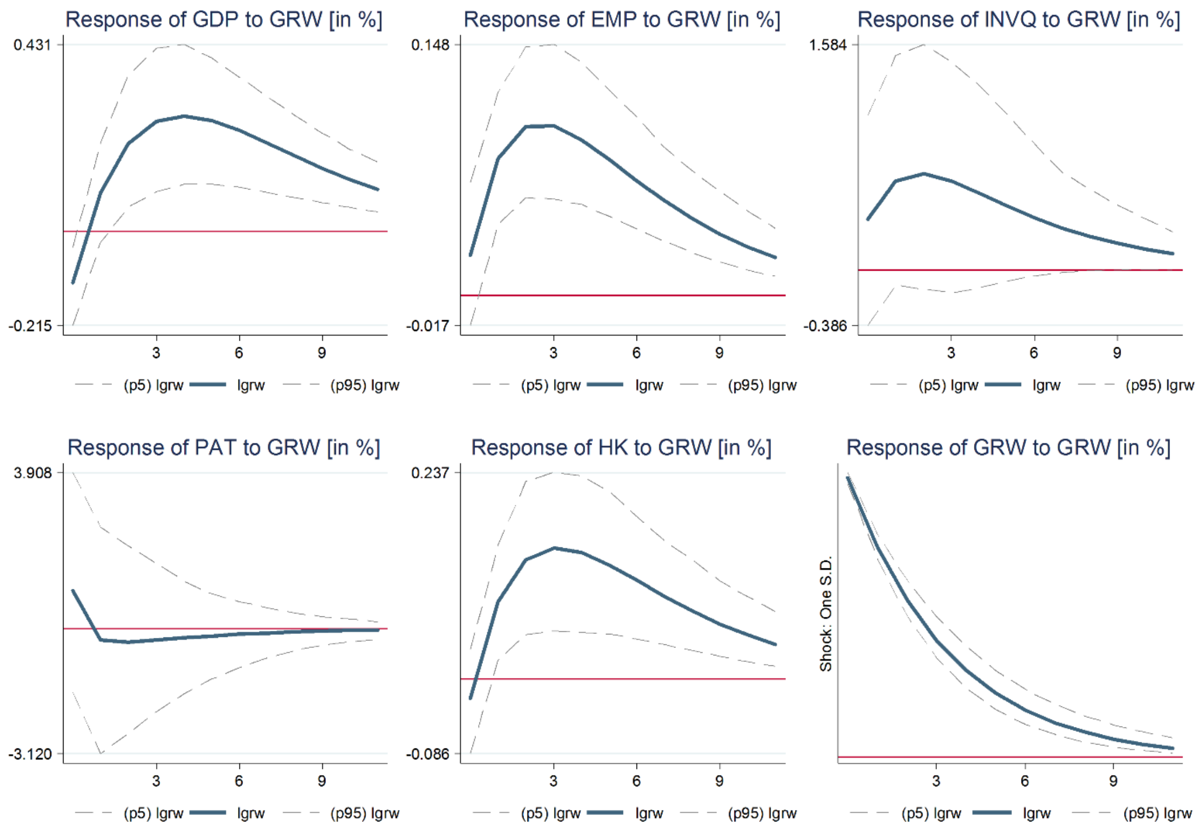
The selected IRF results of the SpPVAR model in Figure 2 using the estimation results from Table 4 illustrate the temporary growth effects of a one standard deviation shock in the total GRW funding intensity (comprising both industry and infrastructure investment support) at time *t* on regional per capita output (thereafter denoted GRW shock). The associated IRF in the upper left panel of Figure 2 shows that after a phasing-in process of roughly one to two years (time measured on the x-axis), we observe statistically significant and positive overall effects of GRW funding on regional per capita output (growth) with a peak effect being reached after roughly four years. In terms of the magnitude of the output effect, for this peak effect, we observe a 0.27% increase in regional per capita output. This result is in line with most early empirical studies on GRW effectiveness (for instance, Alecke et al. 2013 report output effects of 0.3% to 0.8% for a 1% increase in GRW funding volume, see Table A1 for further details) and thus supports our hypothesis **H4**.

As shown in the upper middle panel of Figure 2, the effect of a positive GRW shock on regional employment follows a similar pattern – though with a lower magnitude in terms of the associated marginal effect. As for the overall output effect, the temporary employment growth effects turn out to be positive and statistically significant after roughly one year of phasing in. The persistently positive (though decaying) employment growth rates over the displayed time horizon of 12 years accordingly translate into a permanently higher employment rate in funded regions. This result is in support of our hypothesis **H5**. On the one hand, GRW (industry) investments are associated with some constraints regarding the funding recipients (see Section 3.1); on the other hand, the evolution of per capita output and employment is very similar (see Figure A2). As argued above, the reported employment effect may hence be a reflex of the above identified output.

As the IRFs in the lower middle panel of Figure 2 illustrate, a positive GRW shock also affects the stock of human capital significantly after one year. The (non-significant) negative effect in the first response year may be explained by a substitution effect between physical and human capital. Especially in the case of GRW support to industry investments, physical capital becomes cheaper relative to human capital. However, a shock in the GRW intensity leads to a significant higher human capital stock in the medium-run, which is in support of the sketched transmission channel through investments in education, training facilities and research parks as outlined in **H2**.

We find that a positive shock to the GRW intensity also leads to an immediate positive effect on the physical investment rate, albeit the large standard error belt prevents that the results turns out to be statistical significant throughout the first years. However, after roughly nine years the effect becomes (marginally) significant positive and stays so afterwards. The empirical support for **H1** is thus mixed, which can be probably related to the heterogeneity of funded physical investments and physical investment rates across regions. Finally, a shock in the GRW does not affect the region's patent activity as shown in Figure 2. Thus, we do not find evidence for our hypothesis **H3** that GRW support exhibits some positive effects on regional technological progress.

Figure 2: IRFs for response of variables to shock in total GRW funding intensity



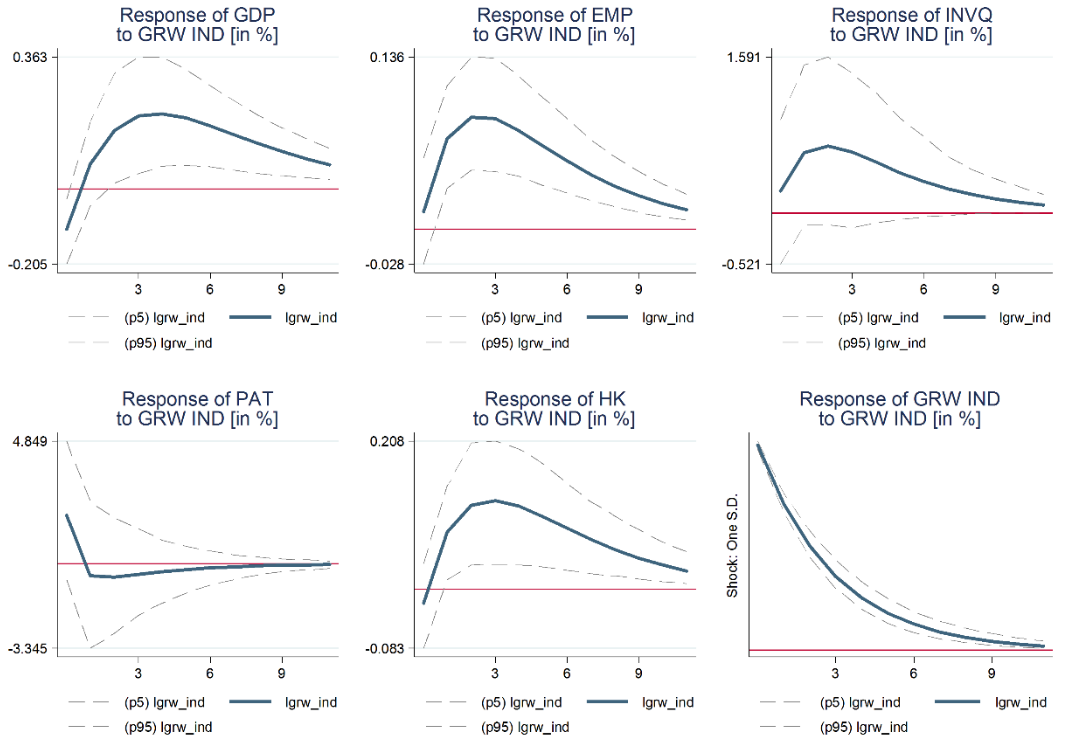
Notes: Impulse response functions are calculated on the basis of the estimated coefficients of the SpPVAR model in Table 4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.

6.2 GRW – Industry and Infrastructure Investments

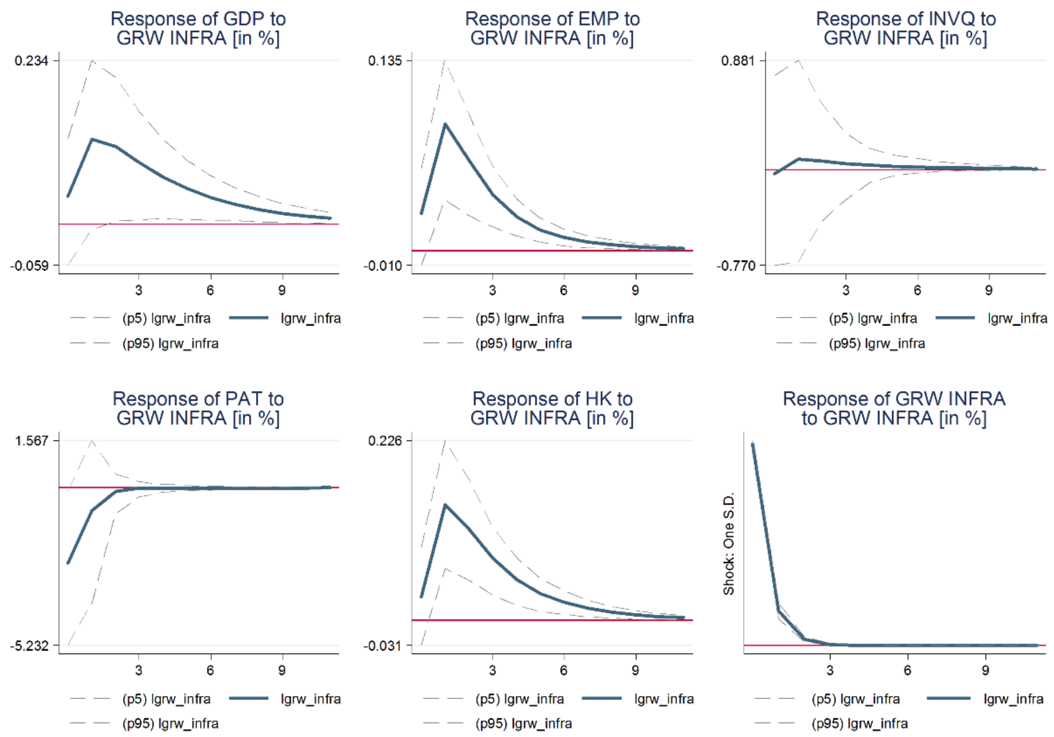
As stated earlier, we are specifically interested in studying the differences in the economic effects when decomposing overall funding intensities into GRW industry and public infrastructure investment support. As the IRFs in the upper part of Figure 3 illustrate, a positive shock in the GRW industry funding intensity goes along with a negative effect on regional per capital output in the very short-run, while the overall output effect of the GRW infrastructure intensity as shown in the lower part of Figure 3 is found to be persistently positive (albeit statistically insignificant in the first year). Different from this initial heterogeneity, however, both per capita output responses turn into statistically significant positive effects after approximately two years. Moreover, we get evidence that that GRW support to industry investments is characterized by a longer phasing-in period (reaching a peak after roughly four years compared to one year in the case of infrastructure investments) and that the magnitude of the economic effects of GRW industry investments is higher compared to GRW infrastructure investments as measured by the percentage increase in per capita output to a one-standard deviation increase in GRW funding categories. These results match our prior expectations as the industry-focused part of the GRW program supports private investments (private capital stock, respectively) directly, while GRW infrastructure investments rather supports the public capital stock (and private capital stock only indirectly). Taken together, both results confirm hypothesis **H4** indicating that a shock in both forms of GRW investment support has a (delayed) significant positive effect on per capita output.

Figure 3: IRFs for response of variables to shocks in decomposed GRW funding intensity

(a) GRW Support to Industry Investments



(b) GRW Support to Infrastructure Investments



Notes: Impulse response functions are calculated on the basis of the estimated coefficients of the SpPVAR models in Tables A3 and A4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.

A related pattern is also shown for the induced economic effects on the employment rate. The employment effects to both GRW investment types become significant positive after roughly one year, which is in line with **H5**. Despite the formal constraints for the recipients of GRW support to industry investments, a one standard deviation increase in GRW infrastructure intensity goes along with similar positive effects on the regional employment rate. The obtained results for the employment rate effect may be seen as a further indication for the significant output effects that are induced by the GRW program and accordingly translate into employment effect. This relationship is also highlighted in Figure A2 in the Appendix showing that a positive per capita output shock is associated with a positive employment rate response.

Furthermore, Figure 3 illustrates significant positive effects of GRW industry and infrastructure shocks on the stock of human capital, which turn out to be statistically significant after roughly one year. As outlined above, this slight delay in the working of the effects may be explained by the fact that GRW industry investments are more likely to substitute human capital, while GRW infrastructure investments primarily affect the public capital stock, which impacts on the production processes of firms more indirectly (for example due to the formation of educational establishments and research parks). This may explain the initial negative human capital effects of GRW industry investment support. However, the response to a positive shock in GRW industry investments becomes positive in the medium-run. Thus, regarding the GRW support to infrastructure investments, our results confirm hypothesis **H2**.

With regard to the physical investment rate, the IRFs displayed in Figure 3 point to quite different transmission channels of funding. While we basically do not observe any effect for the case of infrastructure investment support (which is in line with our theoretical expectations), we observe a positive response of the physical investment rate when shocking GRW support to industry investments. However, as for the case of overall GRW funding in Figure 2, the estimated standard errors are quite large implying that we only find a marginally significant physical investment effect in the mid-run according to our hypothesis **H1**. Finally, the reported effects for the regional patent rate in Figure 3 indicate that the decomposition of GRW funding does not alter the insignificant effect on regional patent activity as already found for the overall GRW funding intensity in Figure.[19]

7. Conclusions

The central aim of this paper was to contribute to the empirical evidence on the effectiveness of regional policy in Germany by identifying the complex effects of the German GRW policy on all factors involved in regional economic growth and development: Per capita output, physical capital investments, human capital, the employment rate and the regional patent rate (proxying technological growth). To deal with the inherent simultaneity across all variables of the regional production function, we have applied a flexible SpPVAR model and have illustrated the reaction of our endogenous variables in the economic system to shocks in the GRW intensity with the help of IRF analysis. Such a system approach to regional structural funds evaluation is still missing in the empirical evaluation literature and we thus hope that our approach can be seen as a valuable contribution to the latter.

Our empirical results emphasize the complex nature of GRW effects on the regional economy over the period 2000-2011. In line with earlier empirical contributions we find positive effects of the GRW program on per capita output of German labor market regions. However, beyond the prevailing focus on output effects in the earlier literature, we also detect significant positive responses of the employment rate as well as the human capital intensity for an increase in GRW support. Another insight from our dynamics VAR modelling approach is that these effects often build up only in the medium-run, while in the short-run some negative effects can be found,

[19] For the most part, the presented results also hold if only regions are considered for estimation that were supported at least 6 years during the period 2000 to 2011. Results are available upon request.

possibly related to the gradual phasing in of realized investment projects. Taken together, these findings emphasize that considering indirect effects and the temporal dynamics of funding effects is highly important when studying the regional economic impact of policy programs.

An interesting question related to GRW funding is whether the funding program only increases economic activity or whether funding is also able to trigger a structural change in the regions. Our results show that, besides the economic activity in form of per capita output and employment, also the human capital intensity is positively influenced by the GRW. This can be interpreted as an upgrading of the jobs in supported labor market regions. Still, we do not find statistically significant effects of GRW funding on the innovation rate (patents) of funded regions. Hence, the question to what extent GRW investments trigger structural changes remains to be answered in future research. Finally, our analysis also raises new research questions regarding the conditional effects of the GRW program. From a policy perspective it is of major interest to analyze whether the results of this study differ between different types of labor market regions and whether there are regional conditions that make GRW investment support more or less effective. Furthermore, from a methodical perspective, the method of impulse response function analysis could be extended to the computation of full space-time IRFs in the future. This extension would provide a comprehensive analysis of the spatial effects of structural funds in a system of connected regions. As for the other challenges addressed above, this issue will be left for future work.

8. Literature

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9. Acknowledgements

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Appendix

Figure A1: Temporal evolution of GRW-intensity in West and East Germany

Notes: Own figures based on data from the Federal Office for Economic Affairs and Export Control (BAFA).

Table A1: Overview of recent empirical studies on the effectiveness of GRW funding

Authors	Data and econometric approach	Regional Units	Dependent Variable(s)	Effects of the GRW policy
Schalk and Untiedt (2000)	Panel data with error-correction (1978-1989), mean values of the wages and interest rates of all other regions are included in the output function, Non-Linear Least Squares (NLS) Estimator	327 Western German administrative districts (*Kreise*)	Output (real value added), investments and employment	Positive effects regarding the investment as well as the employment target. In contrast, the effects on productivity (output per persons employed) growth and convergence are limited.
Blien et al. (2003)	Panel data incorporating a shift-share-approach (1993-1999), no spatial model	113 Administrative districts East Germany (*Kreise*)	Employment	Positive effects of the GRW industry investments on employment (infrastructure coefficient is positive, but non-significant). Positive effects of total GRW investments.
Eckey and Kosfeld (2005)	Cross-sectional data (2000-2002), spatial autoregressively distributed lag model (SADL), Maximum Likelihood (ML) Estimator	180 German labor market regions	Productivity (Gross value added per capita)	The net effect is limited (just 4 %). Neither the direct nor the indirect effects are statistically significant.
Alecke and Untiedt (2007)	1. Cross-sectional data (1994-2003), no spatial model 2. Panel data (1996-2003), no spatial model, Arellano-Bond-Estimator (First-Differenced GMM)	225 German labor market regions	Productivity (GDP per employable person)	Positive effects on the GDP per capita growth rate and on the convergence process.
Eggert et al. (2007)	Panel data (only two time periods: 1994-1999, 2000-2004), no spatial model, Pooled Ordinary Least Square (OLS) Estimator	16 German States (*Bundesländer*)	Productivity (GDP per capita)	No statistically significant effects on the growth of the GDP per capita.
Röhl and von Speicher (2009)	Panel data (1996-2006), no spatial model, Least Square Dummy Variable (LSDV) Estimator (four types of agglomeration are included as fixed-effects instead of individual fixed-effects)	113 Administrative districts East Germany (*Kreise*)	Industrial gross value added and employment	Positive effects on the industrial gross value added (highest in agglomerations). Positive effects on employment in different sectors as well.
Alecke et al. (2012)	Cross-sectional data (1994-2006) 1. No spatial model, OLS Estimator 2. Spatial Lag Model, Spatial Error Model, Spatial Durbin Model, Spatial Durbin Error Model, ML Estimator	225 German labor market regions	Productivity (GDP per total employment)	Positive effects on the convergence rate of supported regions (largest in those regions further away from their steady state level). In turn, negative spatial spillover effects are observed (total effects are positive as long as regions are far away from its steady state).

Table A1 (cont'd.): Overview of recent empirical studies on the effectiveness of GRW funding

Authors	Data and econometric approach	Regional Units	Dependent Variable(s)	Effects of the GRW policy
Alecke et al. (2013)	Cross-sectional data (1994-2006), spatially augmented multiplicative interaction model (Spatial Durbin Model)	225 German labor market regions	Productivity (GDP per total employment)	Positive effects on the speed of convergence. The impact is higher if supported regions are further away from their steady state level and if more GRW investments are supplied to neighboring regions (positive spatial spillovers).
Mitze et al. (2015)	1. Cross-sectional data (1999-2004, 2003-2007, 2005-2008) and pooled cross-sectional data (1996-2008, three-year averages), propensity score (PS) matching, no spatial model 2. Panel data (1993-2008, annual data and three-year averages), generalized propensity score (GPS) matching and use of a dose-response function, no spatial model	413 Administrative districts Germany (Kreise)	Productivity (GDP per worker)	Positive effects on regional productivity growth. However, the policy is only effective to a particular funding level (about 105 000 € per labor-unit)
von Ehrlich and Seidel (2015)	Cross-sectional data (1984, 1985, 1986, 1988 and 2010), Spatial Regression Discontinuity Design (Spatial RDD), Fuzzy RDD, Two-Stages Least Squares (2SLS) Estimator	4940 (1986) and 4967 (2010) Municipalities West Germany (Boundary Sample: 3870 (1986) and 3881 (2010))	Income, Business tax base, population and employment per km^2 Private, Industrial Private and Public Capital Stock, Human Capital	Positive effects on income, business tax base, population as well as on employment per km^2 and private, industrial private as well as public capital. In turn, no effects on human capital are observed. However, due to the relocation of economic activities the net effects are rather small (direct effects minus agglomeration and relocation externalities).
Dettmann et al. (2016)	Cross-sectional data (2000-2006 and 2007-2013), RDD, Spatial control dummy variables (treated and non-treated neighbors are included), 2SLS Estimator	325 Administrative districts West Germany (Kreise)	Gross-value added, productivity (gross-value added per employee), employment and wages sum	Positive effects on the gross value-added as well as on the productivity and no effects on wages and employment (period 2000-2006). No statistically significant effects in the period 2007-2013. Inter-regional spillovers neither arise if the neighboring region is treated or non-treated.
Rhoden (2016)	Cross-sectional data (2000-2012) 1. No spatial models, OLS Estimator 2. Spatial Durbin and Spatial Durbin Error Model, ML Estimator	402 Administrative districts Germany (Kreise)	Productivity (GDP per employee)	Positive effects on regional productivity growth, while the funds have negative effects on neighboring regions (total effects are positive).

Table A2: Summary statistics for variables 2000 to 2011

	Observations	Mean	Std. Dev.	Min	Max
lgdp	3096	10.77384	.2548694	10.04048	11.66673
lemp	3096	-.4980849	.1449697	-.9412167	-.054104
lemp_detrended	3096	-.4883598	.1443927	-.860197	-.0472641
lhk	3096	-2.983249	.4620051	-4.16754	-1.576675
lhk_detrended	3096	-3.221792	.4775752	-4.312091	-1.909949
linvq	3096	-3.827942	.5522995	-5.910307	-1.496212
lpat	3096	-5.397667	1.332901	-18.42068	-3.335155
lgrw	3096	-13.17713	6.012474	-18.42068	-2.575852
lgrw_ind	3096	-13.35975	5.845891	-18.42068	-2.853926
lgrw_infra	3096	-15.0901	5.070834	-18.42068	-3.390138
w_lgdp	3096	10.87333	.2253164	10.24876	11.45012
w_lemp	3096	-.4412998	.0860433	-.7334062	-.1873686
w_lemp_detrended	3096	-.4320978	.0892868	-.7239823	-.1842588
w_lhk	3096	-2.721685	.3560248	-3.796473	-1.802598
w_lhk_detrended	3096	-2.951084	.3576126	-3.955346	-2.156658
w_linvq	3096	-3.822068	.3798358	-5.172833	-2.373494
w_lpat	3096	-5.138939	.607518	-7.92644	-3.865051
w_lgrw	3096	-11.15047	5.458338	-18.42068	-3.835927
w_lgrw_ind	3096	-11.43041	5.298607	-18.42068	-4.020495
w_lgrw_infra	3096	-13.07163	5.201032	-18.42068	-4.500458

Notes : Zeros are replaced by a very small number (pat, grw, grw_ind, grw_infra, w_grw, w_grw_ind and w_grw_infra). Suffix "_detrended" denotes detrended variable; see Table 2 for details on variable description.

Table A3: Regression results for SpPVAR using GRW support to industry investments

Dependent Variable → Regressors ↓	*lgdp*	*lemp*	*lhk*	*linvq*	*lpat*	*lgrw_ind*
lgdp(t-1)	0.712***	0.0300***	0.0238*	0.231	0.121	-1.119
	(0.000)	(0.000)	(0.0468)	(0.154)	(0.818)	(0.260)
linvq(t-1)	0.00868***	0.00326**	0.00337*	0.446***	-0.240***	-0.112
	(0.000)	(0.001)	(0.0400)	(0.000)	(0.000)	(0.373)
lhk(t-1)	0.0101	-0.00548	0.663***	0.0412	-1.191**	1.190
	(0.595)	(0.323)	(0.000)	(0.754)	(0.00624)	(0.202)
lemp(t-1)	0.0824*	0.543***	-0.0676**	-0.220	2.290*	-2.826
	(0.0466)	(0.000)	(0.001)	(0.504)	(0.0419)	(0.191)
lpat(t-1)	0.000674	0.000775*	0.00124**	-0.0117	0.0743***	-0.0223
	(0.302)	(0.0100)	(0.00746)	(0.053)	(0.000)	(0.543)
lgrw_ind(t-1)	0.000941*	0.000434**	0.000618*	0.00374	-0.00397	0.713***
	(0.0138)	(0.00381)	(0.0117)	(0.241)	(0.724)	(0.000)
w_lgdp(t-1)	0.0813*	0.00474	-0.0247	0.169	-1.105	-0.233
	(0.0282)	(0.745)	(0.249)	(0.538)	(0.258)	(0.898)
w_linvq(t-1)	0.000364	-0.000280	0.00371	0.0350	-0.0311	0.238
	(0.940)	(0.881)	(0.197)	(0.352)	(0.805)	(0.262)
w_lhk(t-1)	-0.0672*	-0.0401***	-0.0640***	-0.0497	-0.519	-1.007
	(0.022)	(0.000)	(0.000)	(0.818)	(0.480)	(0.480)
w_lemp(t-1)	-0.0575	0.0485	0.157***	-0.0656	2.394	-1.930
	(0.407)	(0.0554)	(0.000)	(0.893)	(0.161)	(0.552)
w_lpat(t-1)	-0.00378	-0.00119	-0.000755	0.0106	0.312**	0.333
	(0.415)	(0.514)	(0.778)	(0.770)	(0.00998)	(0.132)
w_lgrw_ind(t-1)	0.000244	-0.0000359	-0.000220	0.000172	0.00389	0.0776**
	(0.646)	(0.866)	(0.501)	(0.968)	(0.777)	(0.004)
Total observations	2838	2838	2838	2838	2838	2838
Number of regions	258	258	258	258	258	258

Notes: P-values are given in parentheses. *** p<0.001, ** p<0.01, * p<0.05. Coefficients for time dummies and constant term are not explicitly shown but can be obtained upon request. 250 bootstrap samples with i.i.d. resampling of the error have been used to evaluate the bias of the fixed-effects estimator; the variance-covariance matrix is estimated by using the bootstrap approach and corresponding confidence intervals have been calculated from the t-distribution.

Table A4: Regression results for SpPVAR using GRW support to infrastructure investments

Dependent Variable → Regressors ↓	*lgdp*	*lemp*	*lhk*	*linvq*	*lpat*	*lgrw_infra*
lgdp(t-1)	0.710***	0.0288***	0.0225	0.218	0.135	-0.579
	(0.000)	(0.0000405)	(0.061)	(0.178)	(0.797)	(0.689)
linvq(t-1)	0.00883***	0.00337***	0.00355*	0.447***	-0.241***	-0.404*
	(0.000)	(0.000835)	(0.0314)	(0.000)	(0.000)	(0.0445)
lhk(t-1)	0.0129	-0.00482	0.661***	0.0530	-1.194**	0.574
	(0.496)	(0.387)	(0.000)	(0.680)	(0.006)	(0.668)
lemp(t-1)	0.0761	0.538***	-0.0681**	-0.234	2.292*	-1.968
	(0.065)	(0.000)	(0.001)	(0.469)	(0.041)	(0.566)
lpat(t-1)	0.000717	0.000816**	0.00129**	-0.0115	0.0736***	-0.0617
	(0.267)	(0.00654)	(0.00597)	(0.0559)	(0.000)	(0.318)
lgrw_infra(t-1)	0.000383	0.000318**	0.000537**	0.000276	-0.00257	0.172***
	(0.144)	(0.003)	(0.003)	(0.898)	(0.696)	(0.000)
w_lgdp(t-1)	0.0819*	0.00489	-0.0241	0.172	-1.118	-1.350
	(0.027)	(0.737)	(0.265)	(0.529)	(0.252)	(0.611)
w_linvq(t-1)	-0.000255	-0.000613	0.00336	0.0320	-0.0303	-1.078**
	(0.958)	(0.742)	(0.241)	(0.390)	(0.810)	(0.00867)
w_lhk(t-1)	-0.0628*	-0.0385***	-0.0619***	-0.0383	-0.516	-2.115
	(0.0343)	(0.00057)	(0.00053)	(0.859)	(0.476)	(0.316)
w_lemp(t-1)	-0.0520	0.0516*	0.160***	-0.0519	2.385	2.959
	(0.454)	(0.0395)	(0.000)	(0.915)	(0.163)	(0.560)
w_lpat(t-1)	-0.00274	-0.000758	-0.000326	0.0149	0.311**	0.807*
	(0.549)	(0.671)	(0.902)	(0.680)	(0.00965)	(0.024)
w_lgrw_infra(t-1)	-0.000292	0.000173	-0.0000555	0.00288	-0.000678	0.0446
	(0.381)	(0.232)	(0.809)	(0.275)	(0.946)	(0.090)
Total observations	2838	2838	2838	2838	2838	2838
Number of regions	258	258	258	258	258	258

Notes : P-values are given in parentheses. *** p<0.001, ** p<0.01, * p<0.05. Coefficients for time dummies and constant term are not explicitly shown but can be obtained upon request. 250 bootstrap samples with i.i.d. resampling of the error have been used to evaluate the bias of the fixed-effects estimator; the variance-covariance matrix is estimated by using the bootstrap approach and corresponding confidence intervals have been calculated from the t-distribution.

Table A5: Residual-based Moran's I test (overall GRW funding intensities)

Variable →		*lgdp*			*lemp*			*lhk*	
Year ↓	Moran's *I*	Z(I)	P-val.	Moran's *I*	Z(I)	P-val.	Moran's *I*	Z(I)	P-val.
2001	0.086	2.343	0.010	0.078	2.216	0.013	0.071	1.947	0.026
2002	0.124	3.327	0.000	0.141	3.895	0.000	0.037	1.053	0.146
2003	0.064	1.769	0.038	0.198	5.261	0.000	0.133	3.560	0.000
2004	0.046	1.398	0.081	0.111	2.989	0.001	-0.016	-0.325	0.372
2005	-0.005	-0.028	0.489	0.363	9.558	0.000	0.076	2.109	0.017
2006	0.117	3.157	0.001	0.254	6.706	0.000	0.161	4.278	0.000
2007	0.073	2.005	0.022	0.192	5.114	0.000	0.111	2.977	0.001
2008	0.102	2.792	0.003	0.211	5.584	0.000	0.181	4.815	0.000
2009	0.182	4.851	0.000	0.351	9.258	0.000	0.159	4.259	0.000
2010	0.055	1.547	0.061	0.111	3.005	0.001	-0.023	-0.501	0.308
2011	0.065	1.807	0.035	0.186	4.941	0.000	0.152	4.052	0.000
Variable →		*linvq*			*lpat*			*lgrw*	
Year ↓	Moran's *I*	Z(I)	P-val.	Moran's *I*	Z(I)	P-val.	Moran's *I*	Z(I)	P-val.
2001	0.005	0.224	0.411	0.077	2.151	0.016	0.094	2.559	0.005
2002	0.065	1.797	0.036	-0.095	-2.894	0.002	0.140	3.945	0.000
2003	-0.071	-1.784	0.037	-0.124	-3.580	0.000	0.094	2.687	0.004
2004	0.105	2.848	0.002	-0.109	-3.515	0.000	0.020	0.649	0.258
2005	-0.027	-0.599	0.274	0.086	2.634	0.004	0.155	4.303	0.000
2006	0.044	1.247	0.106	0.105	3.331	0.000	0.025	0.792	0.214
2007	-0.035	-0.813	0.208	0.094	3.431	0.000	0.094	2.585	0.005
2008	0.014	0.456	0.324	0.201	5.597	0.000	0.013	0.473	0.318
2009	0.029	0.851	0.197	-0.036	-1.033	0.151	0.072	2.023	0.022
2010	0.055	1.541	0.062	0.078	2.638	0.004	-0.018	-0.382	0.351
2011	-0.079	-1.952	0.025	-0.096	-2.981	0.001	0.034	1.047	0.148

Notes : Details on the underlying spatial weighting matrix used to compute the Moran's I statistic are given in the main text; Z(I) = Moran's I test statistic.

Table A6: Residual-based Moran’s I test (GRW support to industry investments)

Variable →		*lgdp*			*lemp*			*lhk*	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.087	2.372	0.009	0.079	2.235	0.013	0.070	1.930	0.027
2002	0.121	3.246	0.001	0.143	3.935	0.000	0.037	1.068	0.143
2003	0.066	1.813	0.035	0.199	5.287	0.000	0.134	3.591	0.000
2004	0.047	1.419	0.078	0.111	2.986	0.001	-0.016	-0.319	0.375
2005	-0.003	0.029	0.488	0.364	9.583	0.000	0.075	2.086	0.018
2006	0.116	3.143	0.001	0.256	6.750	0.000	0.161	4.283	0.000
2007	0.072	1.975	0.024	0.192	5.118	0.000	0.111	2.989	0.001
2008	0.101	2.750	0.003	0.211	5.588	0.000	0.182	4.860	0.000
2009	0.183	4.860	0.000	0.351	9.261	0.000	0.159	4.248	0.000
2010	0.053	1.487	0.069	0.110	2.964	0.002	-0.024	-0.536	0.296
2011	0.067	1.866	0.031	0.187	4.971	0.000	0.153	4.086	0.000
Variable →		*linvq*			*lpat*			*lgrw*	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.005	0.239	0.406	0.077	2.148	0.016	0.056	1.612	0.053
2002	0.065	1.793	0.036	-0.095	-2.895	0.002	0.159	4.435	0.000
2003	-0.070	-1.775	0.038	-0.124	-3.578	0.000	0.123	3.442	0.000
2004	0.105	2.865	0.002	-0.109	-3.513	0.000	0.011	0.402	0.344
2005	-0.027	-0.603	0.273	0.086	2.638	0.004	0.123	3.407	0.000
2006	0.044	1.255	0.105	0.105	3.332	0.000	0.055	1.602	0.055
2007	-0.035	-0.819	0.206	0.094	3.428	0.000	0.115	3.140	0.001
2008	0.012	0.421	0.337	0.201	5.599	0.000	0.007	0.300	0.382
2009	0.030	0.878	0.190	-0.036	-1.030	0.152	0.065	1.832	0.033
2010	0.055	1.532	0.063	0.078	2.640	0.004	-0.026	-0.601	0.274
2011	-0.080	-1.969	0.024	-0.096	-2.987	0.001	0.097	2.731	0.003

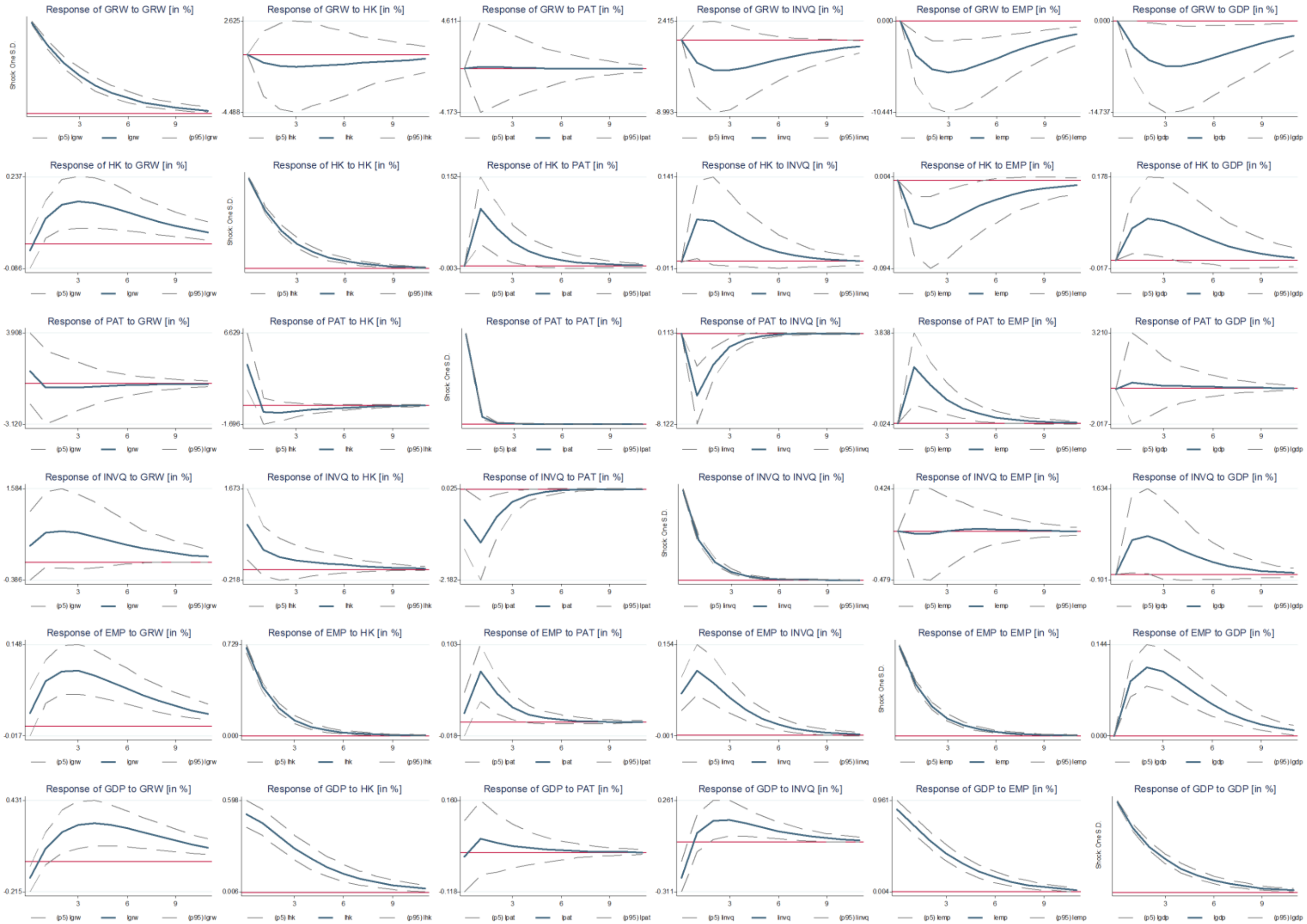
Notes : Details on the underlying spatial weighting matrix used to compute the Moran’s I statistic are given in the main text; Z(I) = Moran’s I test statistic.

Table A7: Residual-based Moran's I test (GRW support to infrastructure investments)

Variable →		*lgdp*			*lemp*			*lhk*	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.085	2.316	0.010	0.075	2.150	0.016	0.074	2.018	0.022
2002	0.121	3.263	0.001	0.157	4.320	0.000	0.047	1.314	0.094
2003	0.071	1.953	0.025	0.202	5.368	0.000	0.127	3.399	0.000
2004	0.050	1.516	0.065	0.127	3.392	0.000	-0.009	-0.138	0.445
2005	-0.001	0.066	0.474	0.362	9.518	0.000	0.076	2.100	0.018
2006	0.114	3.078	0.001	0.240	6.317	0.000	0.154	4.112	0.000
2007	0.077	2.101	0.018	0.181	4.846	0.000	0.110	2.951	0.002
2008	0.105	2.865	0.002	0.209	5.528	0.000	0.183	4.887	0.000
2009	0.184	4.893	0.000	0.352	9.272	0.000	0.149	3.991	0.000
2010	0.049	1.371	0.085	0.108	2.931	0.002	-0.027	-0.591	0.277
2011	0.074	2.037	0.021	0.190	5.051	0.000	0.158	4.220	0.000
Variable →		*linvq*			*lpat*			*lgrw*	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.010	0.355	0.361	0.077	2.152	0.016	0.111	3.013	0.001
2002	0.068	1.877	0.030	-0.095	-2.903	0.002	0.053	1.486	0.069
2003	-0.073	-1.834	0.033	-0.125	-3.590	0.000	0.057	1.588	0.056
2004	0.104	2.837	0.002	-0.109	-3.531	0.000	0.058	1.623	0.052
2005	-0.028	-0.628	0.265	0.086	2.641	0.004	0.125	3.385	0.000
2006	0.042	1.195	0.116	0.105	3.317	0.000	0.053	1.481	0.069
2007	-0.034	-0.791	0.215	0.094	3.435	0.000	0.031	0.918	0.179
2008	0.012	0.413	0.340	0.200	5.550	0.000	0.026	0.781	0.217
2009	0.028	0.827	0.204	-0.036	-1.029	0.152	0.016	0.532	0.297
2010	0.055	1.545	0.061	0.078	2.649	0.004	0.027	0.802	0.211
2011	-0.074	-1.821	0.034	-0.096	-2.990	0.001	-0.058	-1.426	0.077

Notes : Details on the underlying spatial weighting matrix used to compute the Moran's I statistic are given in the main text; Z(I) = Moran's I test statistic.

Figure A2: Full set of IRFs for response of variables to isolated shocks in the other variables of the SpPVAR



Notes: Impulse response functions are calculated on the basis of the estimated coefficients of the SpPVAR model in Table 4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.