Effects of public policy measures on regional economic growth: Evidence from German labour market regions and Chinese provinces

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Preface

The doctoral thesis at hand is a miscellany that comprises 7 sections. The motivation, conceptual framework, own contribution and the research questions of the thesis are outlined in the first section. In addition, the applied main methodological approach is shortly discussed. The subsequent five sections present the different research papers that I have written jointly with colleagues as well as a single author (see Table V1 for an overview and my own contribution). Finally, Section 7 summarises the main findings and draw policy implications on the basis of the conducted empirical research. Moreover, I discuss some limitations and point to future and open research.

Table V1 Overview papers of the cumulative dissertation

	Title	Journal	Co-Authors	Own Contribution
I	A look behind the curtain: Measuring the complex economic effects of regional structural funds in Germany	Papers in Regional Science (2019), Vol. 98, 701-735	Thomas Brenner (25 %), Timo Mitze (20 %)	Main author (55 %)
II	Absorptive capacity, economic freedom and the conditional effects of German regional policy	Submitted to: Journal of Institutional Economics[1]	Thomas Brenner (30 %), Timo Mitze (30 %)	Co-author with significant share (40 %)
III	Economic effects of regional fiscal equalisation – Empirical evidence from German labour market regions	Submitted to: Journal of Economics and Statistics[1]		Single author (100 %)
IV	Public research, local knowledge transfer and regional development: Insights from a structural VAR model	International Regional Science Review (2019), forthcoming	Thomas Brenner (15 %), Timo Mitze (10 %)	Main author (75 %)
V	Effects of R&D subsidies on regional economic dynamics – Evidence from Chinese provinces	Submitted to: Research Policy[1]	Phillip Boeing (30 %)	Main author (70 %)

[1] Published as Working Papers on Innovation and Space

Abstract

Existing dissimilar economic conditions, which are observable in many countries worldwide, are economically inefficient and also imply important political and social challenges, for example, the increasing achievements of populist movements, particularly in economically underdeveloped regions. Thus, supporting economically less prosperous regions is a highly important political objective. It is of great importance to identify drivers for economic growth and to apply efficient policy measures to spur regional development.

Based on economic growth theory, the doctoral thesis at hand contributes to the identification of the complex outcomes of four German and one Chinese policy measures aimed at fostering regional development. The German policy measures are analysed on the level of labour market regions and comprise structural funding, regional fiscal equalisation and public research activities. The Chinese study investigates the economic effects of research and development (R&D) subsidies to firms on the level of provinces. Due to recent economic and structural changes, China is chosen as additional case study: the Chinese government is currently driving the transformation from a capital-based to an innovation-based economic system by applying a variety of innovation-enhancing policy measures.

By providing novel empirical findings, the doctoral thesis at hand extends recent German and Chinese studies. These studies examine the economic effects of public polices by mainly conducting partial effect analyses (singe equation models) and by mainly focussing on the effect on one particular dependent variable (usually the regional output). Indirect effects running through other economic variables in a regional production system are disregarded, as are the effects on further economic variables. Both of these shortcomings are accounted for in the thesis at hand. Furthermore, analysing several German policy measures allows the identification of unique characteristics and a

deduction of concrete implications to foster the development of different economic variables. Finally, the thesis also examines the role played by regional conditioning factors for the working of public policies. Although each research paper provides specific research questions, the overarching research question of the thesis are as follows:

1. What are the overall economic effects of the analysed policy measures in Germany and China on different regional input and output factors of a regional production function?
2. Do the analysed German policy measures add to regional development via different transmission channels and can unique characteristics be identified?
3. Do economic responses to an increase in German structural funding and regional fiscal equalisation funding depend on conditioning factors such as a region's absorptive capacity, economic freedom and political-economic conditions?

The first two research questions are related to unconditional effects, which are the estimated effects on the basis of all German regions and Chinese provinces, respectively. In this thesis, the methodological basis of the conducted analyses are vector autoregressive (VAR) models and a graphical impulse response function analysis. This approach explicitly allows emprirical researchers to determine total effects on a set of defined economic variables that are triggered by a particular public policy measure.

With regard to the unconditional effects (research questions 1 and 2), it can be stated that German structural funding increases can be linked to statistically significant positive effects on the gross domestic product (GDP) per workforce, human capital and employment rate. Conversely, German regional fiscal equalisation is solely associated with a statistically significant positive effect on the regional employment rate. The empirical results on the effects of German public research activities show that an increase in the publication rate of public research institutes is associated with significant positive effects on the regional physical capital investment and employment rate. Although no statistically significant effects can be identified for research activities of universities, an increase in the summarised public third-party funds allocated to universities and technical colleges combined can be linked to statistically significant positive effects on the regional GDP per workforce, patent activity and employment rate. Finally, technical colleges seems to be locally more embedded: allocated (public) third-party funds to technical colleges are associated with significant positive effects on the human capital, employment and physical capital investment rate.

Using data from Chinese provinces, the empirical findings reveal that an increase of public R&D subsidies granted to Chinese firms results in a statistically significant decrease in private R&D investments. Thus, a first-order policy objective is not achieved. However, the conducted analysis also reveals a significant positive effect on the stock of private R&D personnel. Finally, an increase in the policy intensity also corresponds with statistically significant positive effects on the technological development and capital deepening (investment rates in physical capital and residential buildings).

The analysis of the role played by regional conditioning factors (research question 3) emphasises the importance of regional absorptive capacity and economic freedom for the working of German structural funding. Regions with low levels of absorptive capacity and economic freedom benefit from German structural funding mainly through an increased investment rate in physical capital, while a positive effect on the development of regional technology and GDP cannot be identified. Conversely, in regions with high levels of absorptive capacity and economic freedom, the findings reveal significant positive effects of structural funding on the regional GDP and innovation activity. Finally, the research paper on effect heterogeneity of regional fiscal equalisation suggests statistically significant differences in the estimated effects only for single years. Regional fiscal equalisation is more effective in increasing physical capital investments in East German regions and the employment rate in West German regions. In addition, only an increase in the funding intensity in

Christian Democratic Party/Christian Social Party (CDU/CSU) preferring regions is associated with significant positive effects on the human capital and physical capital investment rate. Conversely, a significant positive effect on the GDP is identified only in Social Democratic Party (SPD) preferring regions.

The findings of this thesis emphasise the complex and reciprocal mechanisms of the analysed policy measures. They add to regional development in a multifaceted way and positively affect different economic variables. That said, empirical analyses restricted to the effects on the regional output limit the interpretation of policy evaluation studies and neglect additional transmission channels. Moreover, the results reveal that policy makers have different options to spur regional development in different contexts. Finally, the empirical findings stress the prominent role of technological and institutional conditions, especially for the working of structural funding in Germany. Therefore, policy makers should provide more incentives to improve these conditions and they should direct public investments especially to regions with already proper initial conditions.

Zusammenfassung

In vielen Ländern auf der Welt herrschen ungleiche ökonomische Bedingungen. Diese werden als ökonomisch ineffizient betrachtet und implizieren zudem vielfältige politische und soziale Herausforderungen. Ein Beispiel ist der zunehmende Erfolg von populistischen Parteien, vornehmlich in ökonomisch schwächeren Regionen. Daher stellt die Entwicklung von ökonomisch schwächeren Regionen gegenwärtig ein wichtiges politisches Ziel dar. Der Identifizierung von Treibern für ökonomisches Wachstum und, darauf basierend, der Entwicklung von effizienten regionalen Politikmaßnahmen kommt dabei eine entscheidende Rolle zu.

Auf Grundlage der ökonomischen Wachstumstheorie leistet die vorliegende Arbeit anhand von vier deutschen und einer chinesischen Studie einen Beitrag dazu, die komplexen Effekte von verschiedenen Politikmaßnahmen zur Förderung regionalen Wachstums zu identifizieren. Die analysierten Politikmaßnahmen in Deutschland werden auf Ebene der Arbeitsmarktregionen untersucht und umfassen die Strukturförderung, den regionalen Finanzausgleich und öffentliche Forschungsaktivitäten. Für China werden die Effekte von Forschungs- und Entwicklungssubventionen (FuE-Subventionen) an Firmen auf der Ebene von Provinzen untersucht. China wurde dabei aufgrund der derzeit dort ablaufenden wirtschaftlichen Umbrüche als ergänzendes Fallbeispiel gewählt: aufgrund von sinkenden Wachstumsraten treibt die chinesische Regierung über eine Vielzahl an Politikmaßnahmen die Transformation von einer kapital- hin zu einer innovationsorientierten Wachstumsstrategie voran.

Durch neu gewonnene empirische Erkenntnisse erweitert die vorliegende Dissertation jüngste empirische deutsche und chinesische Studien. Jene Studien untersuchen die ökonomischen Wirkungen von Politikmaßnahmen einerseits vor allem durch Teileffektanalysen (Eingleichungsmodelle) und beschränken sich, andererseits, hauptsächlich auf die Auswirkungen der Politikmaßnahmen auf eine bestimmte Output-Variable (häufig die regionale Produktionsmenge). Daher bleiben indirekte

Effekte zwischen den einzelnen ökonomischen Variablen eines regionalen Produktionssystems sowie die Auswirkungen auf weitere wichtige ökonomische Variablen unberücksichtigt. Diese beiden bislang vernachlässigten Aspekte werden in der vorliegenden Arbeit aufgegriffen. Durch die Analyse von mehreren deutschen Politikmaßnahmen werden zudem Alleinstellungsmerkmale identifiziert und konkreter Implikationen zur Förderung verschiedener ökonomischer Variablen für Deutschland abgeleitet. Schließlich wird die Bedeutung von regionalen Kontextbedingungen untersucht, welche die Wirkungen von öffentlichen Investitionen beeinflussen. Jede Fallstudie dieser Dissertation behandelt eigene Forschungsfragen. Diese fügen sich zu folgenden übergeordneten Fragestellungen zusammen:

1. Welche Gesamteffekte haben die analysierten Politikmaßnahmen in Deutschland und China auf verschiedene regionale Input und Output-Faktoren einer regionalen Produktionsfunktion?
2. Tragen die analysierten deutschen Politikmaßnahmen durch unterschiedliche Transmissionskanäle zur regionalen Entwicklung bei und lassen sich Alleinstellungsmerkmale identifizieren?
3. Hängen die wirtschaftlichen Effekte der deutschen Strukturförderung und des regionalen Finanzausgleichs von regionalen Kontextbedingungen wie der Absorptionsfähigkeit, der Economic Freedom und den politisch-wirtschaftlichen Bedingungen einer Region ab?

Die ersten beiden Forschungsfragen fokussieren auf nicht-konditionale Effekte von Politikmaßnahmen, welche als die geschätzten Effekte auf Grundlage der Grundgesamtheit der deutschen Regionen beziehungsweise der chinesischen Provinzen definiert werden. Die durchgeführten Analysen basieren auf vektorautoregressiven (VAR) Modellen in Kombination mit graphischen Impulse Response Function Analysen. Dieser Ansatz erlaubt empirischen Wissenschaftlern ausdrücklich die Berechnung von ökonomischen Gesamteffekten auf mehrere definierte ökonomische Variablen.

Die Ergebnisse der Analysen belegen (nicht konditionalen Effekte), dass ein Anstieg der Strukturförderung in Deutschland mit statistisch signifikant positiven Effekten auf das Bruttoinlandsprodukt (BIP) pro Erwerbsperson, das Humankapital und die Beschäftigungsquote in Verbindung gesetzt werden kann. Dagegen lässt sich der regionale Finanzausgleich ausschließlich mit statistisch signifikant positiven Effekten auf die regionale Beschäftigungsquote verknüpfen. Die Resultate zu öffentlichen Forschungsaktivitäten zeigen, dass eine Erhöhung der Publikationsrate von öffentlichen Forschungsinstituten mit positiven Effekten auf die regionale Investitionsquote in physisches Kapital und die Beschäftigungsquote verknüpft ist. Während für Forschungsaktivitäten an Universitäten keine statistisch signifikanten regionalen Effekte identifiziert werden, haben öffentliche Drittmittel an Universitäten und Fachhochschulen positive Effekte auf das regionale BIP pro Erwerbsperson, die Patentrate und Beschäftigtenquote. Zudem weisen die Ergebnisse auf eine stärkere lokale Einbettung von Fachhochschulen hin: Ein Anstieg der (öffentlichen) Drittmittel an Fachhochschulen geht mit positiven Effekten auf das regionale Humankapital, die Beschäftigten- und Investitionsquote in physisches Kapital einher.

Die Analyse für chinesische Provinzen belegt, dass eine Erhöhung der öffentlichen FuE-Subventionen die privaten FuE-Investitionen senkt und somit ein primäres Ziel der Politikmaßnahme nicht erreicht wird. Jedoch kann auch ein signifikant positiver Effekt auf den Bestand an privatem FuE-Personal identifiziert werden. Darüber hinaus wirkt sich eine Erhöhung der FuE-Subventionen statistisch signifikant positiv auf die technologische Entwicklung und die Kapitalinvestitionen aus (Investitionen in physisches Kapital und Wohngebäude).

In Bezug auf die dritte Forschungsfrage dieser Dissertation heben die Untersuchungen den Einfluss der regionalen Absorptionsfähigkeit und der Economic Freedom auf die Effizienz der deutschen Strukturförderung hervor. Regionen mit einer geringen Absorptionsfähigkeit und Economic Freedom profitieren von Strukturinvestitionen vor allem durch eine erhöhte Investitionsquote. Eine positive Entwicklung der regionalen Technologie und des BIPs tritt dagegen nicht ein. Weisen Regionen dagegen eine hohe Absorptionsfähigkeit und Economic Freedom auf, lösen Strukturinvestitionen signifikant positive Effekte auf das regionale BIP und die Innovationstätigkeit aus. Zudem lässt eine der durchgeführten Teilstudien zur Effekt-Heterogenität für den regionalen Finanzausgleich in Deutschland darauf schließen, dass nur in einzelnen Jahren statistisch signifikante Unterschiede resultieren. Eine Erhöhung der regionalen Finanzausgleichszahlungen ist mit einem statistisch signifikanten Anstieg der Investitionsquote in ostdeutschen und der Beschäftigungsquote in westdeutschen Regionen verbunden. Zudem belegen die Ergebnisse, dass ein Anstieg der Finanzausgleichszahlungen nur in Regionen, welche vornehmlich die Christdemokratische Partei/Christlich-Soziale Partei (CDU/CSU) unterstützen, mit positiven Effekten auf die Human- und Investitionsquote einhergeht. Im Gegenzug lassen sich positive Effekte auf das BIP nur in Regionen identifizieren, welche besonders die Sozialdemokratische Partei Deutschlands (SPD) unterstützen.

Die Ergebnisse der vorliegenden Arbeit verdeutlichen die komplexen und wechselseitigen Wirkmechanismen der analysierten Politikmaßnahmen. Diese tragen in vielfältiger Weise zur regionalen Entwicklung bei, indem sie unterschiedliche ökonomische Variablen positiv beeinflussen. Daher greifen Analysen zu kurz, die ausschließlich die Effekte auf die regionale Produktionsmenge betrachten. Es wird zudem deutlich, dass Politiker zwischen verschiedenen Maßnahmen auswählen können, um die Entwicklung einzelner ökonomischer Faktoren zu fördern. Schließlich zeigt sich, dass regionale technologische und institutionelle Bedingungen die Effizienz von Politikmaßnahmen positiv beeinflussen – vor allem der deutschen Strukturförderung. Politiker sollten daher mehr Anreize für bessere regionale Kontextbedingungen setzen und Investitionen vornehmlich in Regionen mit bereits guten Bedingung lenken.

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1. General introduction

"[…], if we can learn about government policy options that have even small effects on long-term growth rates, we can contribute much more to improvements in standards of living than has been provided by the entire history of macroeconomic analysis of countercyclical policy and fine-tuning" (Barro and Sala-i-Martin, 2004, p. 6).

These words by Barro and Sala-i-Martin (2004) emphasise the importance of well-founded policy impact assessments in order to provide efficient policy measures that increase individual incomes and living standards. Aggregate economic growth and development is widely seen as major factor to positively affect incomes, living conditions and the welfare of individuals. That said, it is key to identify drivers for different levels of aggregated economic output, development and growth (Barro and Sala-i-Martin, 2004).

Regional economic disparities, mostly expressed by differences in the per capita gross domestic product (GDP) or the (un)employment rate, are well documented within the European Union (EU) (e.g. European Commission, 2017; Iammarino et al., 2017), as well as within single countries, such as Germany (e.g. Bundesministerium für Wirtschaft und Energie, 2017) or China (e.g. Tsui, 2014; Yao, 2009).[1] However, regional economic disparities are not immutable and are subject to persisting public market interventions and provided policy measures: Predominant dissimilar regional incomes and living standards pose a challenging task for policy makers and give rise to lively debates on fruitful regional policies to trigger regional development: "*[…], persistent territorial inequality is economically inefficient and, in the words of The Economist, has become too politically [and socially] dangerous to ignore*" (Iammarino et al., 2017, p. 1). This is underlined by the

[1] A study by the Organisation for Economic Co-operation and Development (OECD) reports larger disparities between OECD regions compared to these between countries (OECD, 2009).

increasing success of populist movements, especially in declining and economically poorer regions (Rodríguez-Pose, 2018) or the *Gilet Jaunes* protesters in France (The Economist, 2019).[2] That said, implementing more equal economic conditions by accelerating regional development is seen as an important political target, in the EU as well as in Germany or China (e.g. Bundesministerium für Wirtschaft und Energie, 2017; European Commission, 2017; Yao, 2009).

This thesis is composed of five research papers and aims to contribute to the scientific and political discussion by providing new insights into the working and economic outcomes of several policy measures in Germany and China. In doing so, the thesis identifies unique features of the analysed policy measures and differences between them. Additionally, the thesis connects economic, political and geographical issues and applies an empirical research framework that explicitly regards a point of criticism by the economic geographer Ron Martin: Martin (2001) is concerned that the discipline does not sufficiently contribute to policy debates because it is often too focused on theoretical, cultural or linguistic issues with only a limited empirical (quantitative) focus and relevance for policy makers: "*Yet the fact is that the impact of geography on the public policy realm has in general been disappointingly limited*" (Martin, 2001, p. 191).

Some of the analysed policy measures have a direct mandate to promote predominantly economically underdeveloped regions (structural funding and regional fiscal equalisation in Germany), while further analysed policies (public research activities in Germany and research funds to firms in China) are not restricted to lagging regions. However, they may also be important policy

[2] In centralised France, strong regional economic inequalities are present. As argued by The Economist (2019), more decentralized Germany can be considered as counterexample to France as the economic and industry structure is more equally distributed. One reason are the so-called *Hidden Champions*, who are successful manufacturers and employers that are frequently located in small cities (The Economist, 2019).

measures to foster regional development. The first research paper of this thesis examines the outcomes of the most powerful German structural funding programme for less developed regions (Alecke et al., 2012, 2013; Deutscher Bundestag, 2014, for additional information), which is called "Joint Task for the Improvement of Regional Economic Structures" (GRW). In doing so, direct and indirect transmission channels on the GDP (regional output) as well as on the input factors of a region's production function are analysed (see Section 2).

The second research paper deepens the analysis by determining potential conditional responses to German structural funding. The analysis particularly aims to deepen the insights regarding fertile regional conditions that may improve funding impacts (e.g. Becker et al., 2013; Breidenbach et al., 2019; Fratesi and Perucca, 2014; Gagliardi and Percoco, 2017; Rodríguez-Pose and Garcilazo, 2015, in a European context). To this end, the thesis analyses whether economic responses to a GRW funding increase are uniform across regions or whether they depend on specific regional conditions that facilitate the transformation of GRW funding into higher economic outcomes (see Section 3).

An additional German policy with high annual funding intensities are regional fiscal equalisation programmes (see Section 4). Empirical studies investigating economic secondary effects of regional fiscal equalisation are rather scarce in the empirical literature (e.g. Henkel et al., 2018; Kalb, 2010; Lehmann and Wrede, 2019). Thus, the third research paper of this thesis starts with an empirical analysis of the general economic effects of regional fiscal equalisation. In addition, the research paper also sheds light on potential conditional effects of the equalisation programmes and, eventually, compares the economic outcomes to these of structural funding in Germany.

While the preceding research papers of this thesis are focused on investment and financial compensation as a means to enhance regional private and public physical capital investments, the fourth research paper can rather be linked to the concept of knowledge driven growth strategies (see Section 5). Public research conducted at universities, technical colleges or public research institutes is considered an important component for regional development and particularly for regional innovation processes (Fritsch and Schwirten, 1999; Schubert and Kroll, 2013). In this context, potential mutual linkages between German public research activities conducted by different research actors and regional development are examined.

After the analyses on three German policy measures, the effects of research and development (R&D) subsidies to Chinese firms are investigated at the provincial level (see Section 6). The case study of Chinese provinces and public R&D subsidies as a subject of investigation is particularly interesting in the context of the underlining economic growth theory framework because the current transformation from a capital-based to an intended innovation-based economy is strongly driven by the Chinese government. While surging physical capital investments paved the way for an astonishing economic development in China after the economic opening processes in 1978 (Naughton, 2007), China's government aims to lean the future economic development on an innovation-based development strategy (Cao et al., 2013; Liu et al., 2011). To this end, firms are prominent drivers in implementing this agenda (Boeing, 2016).

The described empirical research agenda chiefly extends the recent policy evaluation literature in mainly two ways: First, this thesis does not solely investigate the effect on a particular target variable of each policy (implied transmission channel) or on regional output. Instead, the effects of various policy measures on all economic variables in a regional production system are investigated. Moreover, the applied econometric approach goes beyond partial effects analyses and allows researchers to calculate the overall effects (direct and indirect) of these policies. To this end, the conducted analyses are mainly based on a vector autoregressive (VAR) approach and impulse-response function (IRF) analyses (see Mitze et al., 2018, or Ramajo et al., 2017, for empirical applications). Second, this thesis contributes to the empirical evaluation literature by investigating potential heterogeneities in the returns on German structural funding and regional fiscal equalisation payments.

Despite the strong empirical focus of the thesis at hand, the selected public policies are soundly embedded and linked to economic growth theory (Crihfield et al., 1995; Mankiw et al., 1992; Rivera-Batiz and Romer, 1991; Romer, 1990). In doing so, the conceptual framework is mainly used for the formulation of a regional production function, a theory-guided selection of economic variables and the formulation of research hypotheses.

The remainder of the thesis is organised as follows. In the subsequent parts of Section 1, a brief introduction of the conceptual framework is presented. Furthermore, the selected policy measures and their implied transmission channel(s) are linked to economic growth theory. Thereupon, the contribution and the overarching research questions of the thesis are briefly discussed. Section 1 concludes with the presentation of the methodological approach and the applied data. This is followed by five research papers in Sections 2 to 6. Section 7 summarises the key findings of the empirical analyses and discusses policy implications. Finally, some limitations of the conducted analyses and lines for future research are discussed.

1.1 Conceptual framework: Nexus between economic growth theory and empirical policy evaluation

Based on its inherent purpose, policy impact evaluation is an applied (empirical) strand of economic research. However, impact analyses are commonly embedded in a sound theoretical framework. From a conceptual perspective, economic growth theory provides insights into the transmission channels and expected effects of public policies on (regional) economic development (e.g. Alecke et al., 2012; Dall'erba and Le Gallo, 2008; Mohl and Hagen, 2010). Such a theoretical embedding is useful for at least two reasons: First, it allows empirical researchers to specify estimation functions explicitly from theory and thus to select proper theory-grounded variables.[3] Second, the explicit use of growth theories facilitates the derivation of ex-ante hypotheses regarding the assumed effects of public policies on different economic variables and, beyond that, allows an ex-post comparison with the expected parameters (Alecke et al., 2012).

1.1.1 Economic growth theory

The thesis draws on exogenous and endogenous growth models for variable selection and to compose research hypotheses in the particular research papers. This section provides a brief review of the employed growth models.

The seminal contribution by Solow (1956) is based on a neoclassical production function, characterised by constant returns to rival inputs capital and labour as well as diminishing returns to each of these two private input factors.[4] In this model, labour supply grows exogenously at a constant rate and physical capital accumulation is determined by a fixed saving rate of the produced output. Using the time paths of the physical capital stock and labour, the time path as well as the rate of current output can be derived (Solow, 1956). Solow's seminal growth approach was extended in an influential work by Mankiw et al. (1992), who adopt the neoclassical production function but add human capital as additional input factor. Like the accumulation path of physical capital, they assume a constant rate of saved output that is invested in human capital, while both forms of capital are assumed to depreciate at an equal rate. Thus, dynamics of physical and human capital follow a similar accumulation mechanism and the time path of output depends on the accumulation mechanisms of both forms of capital (Mankiw et al., 1992). In a similar fashion, Crihfield et al. (1995)

[3] Empirical studies based on a similar theoretical framework also facilitate cross-study comparisons.

[4] Please note that Swan (1956) developed (independently of Solow, 1956) an additional seminal and closely related growth model. Both can be considered pioneers of neoclassical growth models.

add public capital as an additional input factor to the production function, assuming an equivalent accumulation mechanism and depreciation rate for all three kinds of capital. Consequently, these growth models provide the rationale to derive hypotheses on the development of the different forms of capital and regional output in the provided research papers.

The growth models above can be characterised by two essential features (Barro and Sala-i-Martin, 2004): At first, they predict (conditional) convergence: if economies have similar steady state levels, economies with an initial lower level of economic development will grow faster due to diminishing returns to capital. Second, due to the implied diminishing returns on capital, the long-term growth of per capita capital and output is ultimately ceasing without external shocks (Barro and Sala-i-Martin, 2004). To overcome this deficiency, an exogenously given constant technological growth is presumed (Crihfield et al., 1995; Mankiw et al., 1992). However, this inherent property is unsuitable for deriving hypotheses about the impact of policy measures on technological growth.

The unexplained technological growth gave rise to a future stage of growth models, also known as endogenous growth models. The main feature of this strand of growth models is that they aim to model long-term economic growth within the particular model (Aghion and Howitt, 1992; Lucas, 1988; Rivera-Batiz and Romer, 1991; Romer, 1990).[5] In doing so, the growth approaches by Romer (1990) and Rivera-Batiz and Romer (1991) explicitly model technological growth in a R&D sector, for which reason these two approaches provide a sound theoretical framework to derive hypotheses regarding the effects of policy measures on regional technological growth.

Finally, the evolution of labour supply is assumed to grow exogenously (Crihfield et al., 1995; Mankiw et al., 1992; Solow, 1956) or is assumed to be fixed (Rivera-Batiz and Romer, 1991;

[5] For additional information on (endogenous) growth models, I refer to the comprehensive textbook of Barro and Sala-i-Martin (2004).

Romer, 1990). As explained in more detail in the subsequent research papers, a constant growth rate of the population and a constant employment rate (in the long-term perspective) are assumed, while short-term variations in the employment rate are explicitly allowed. In order to derive hypotheses on the effects of public policy measures on the employment rate, this thesis refers to potential output and substitution effects between the input factors (e.g. Bade, 2012; Schalk and Untiedt, 2000, for additional information).

1.1.2 Regional production function

The thesis at hand mainly apply the following neoclassical production function (e.g. Crihfield et al., 1995; Mankiw et al., 1992) for a region *i*

$$Y_i = K_i^{\alpha} H_i^{\beta} Z_i^{\gamma} (A_i L_i)^{1-\alpha-\beta-\gamma}, \tag{1.1}$$

where Y_i denotes regional output that is produced by the input factors physical capital (K_i), human capital (H_i), public physical capital (Z_i), regional technology (A_i) and labour (L_i). Furthermore, diminishing returns to each form of capital are supposed, implying the restriction $\alpha + \beta + \gamma < 1$ (Crihfield et al., 1995).[6] However, the presented growth approaches mainly disregard the role of labour (employment rate) for the dynamics of the per capita output. Thus, in this thesis, labour at time *t* (see Bräuninger and Pannenberg, 2002, for a similar extension) is defined as

$$L_i(t) = \lambda_i(t) \times P_i(0)e^{n_i t}. \tag{1.2}$$

In Equation (1.2), λ_i denotes the regional rate of employed population (L_i/P_i) at time *t* (fixed in the long term), while the population P_i is exogenously growing with the rate n_i. Applying this definition, the regional production function per capita can be written as

[6] A neoclassical production function is applied as the empirical approach of numerous (international) policy evaluation studies is also based on neoclassical growth theory (see Alecke et al., 2012, 2013; Alecke and Untiedt, 2007; Dall'erba and Le Gallo, 2008; Darku, 2011; Ederveen et al., 2006; Eggert et al., 2007; Mohl and Hagen, 2010; Rhoden, 2016) and thus facilitates a comparison to these studies.

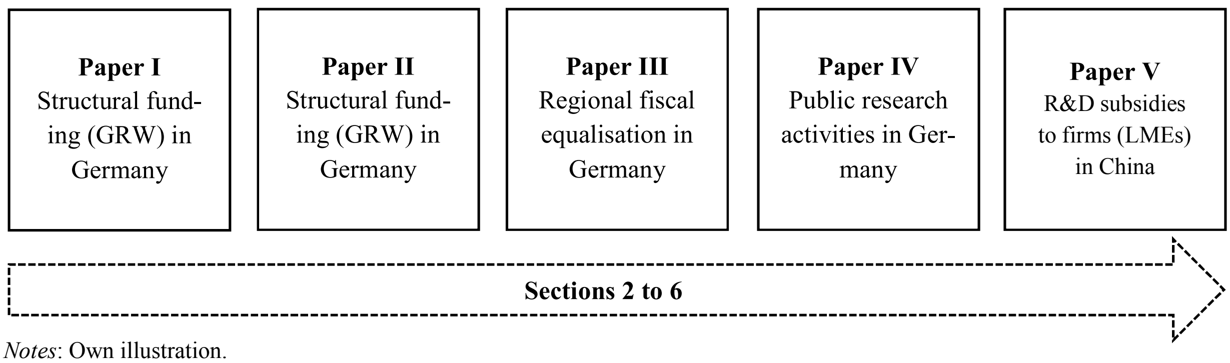
$$y_i = k_i^{\alpha} h_i^{\beta} z_i^{\gamma} (A_i \lambda_i)^{1-\alpha-\beta-\gamma}. \quad (1.3)$$

Equation (1.3) explicitly includes the effects of short-run variations in the employment rate on the regional (per capita) production process.

1.1.3 Selected policy measures and link to the conceptual framework

Each research paper examines a particular policy and its effects on regional growth and development. The implied primary target variables of the selected policy measures cover almost all economic input factors of the regional production function, as outlined in Equation (1.3).[7] The arrangement of the research papers takes the following structure: The first four research papers focus on German policy measures, while the fifth research paper changes the subject of study and applies an analysis at the provincial level in China. The research papers related to Germany are ordered according to their setting and the implied target variables that are discussed below.

Figure 1.1 Selected policy measures in the thesis



Notes: Own illustration.

As outlined in Figure 1.1, the empirical analysis of the thesis sets in by investigating the effects of GRW funding in Germany (see Sections 2 and 3). The policy aims, on the one hand, to spur addi-

[7] Due to the different concepts, aims and target variables of the selected policies, a comparison of the estimated results and magnitudes is not always meaningful (especially between German and Chinese policies), but is carried out where it is considered useful (see Section 4).

tional private sector investments and, on the other hand, to support investments in the local infrastructure (Alecke et al. 2012, 2013; Deutscher Bundestag, 2014). Therefore, the GRW policy measure primarily targets the private and public physical capital variable in Equation (1.3).

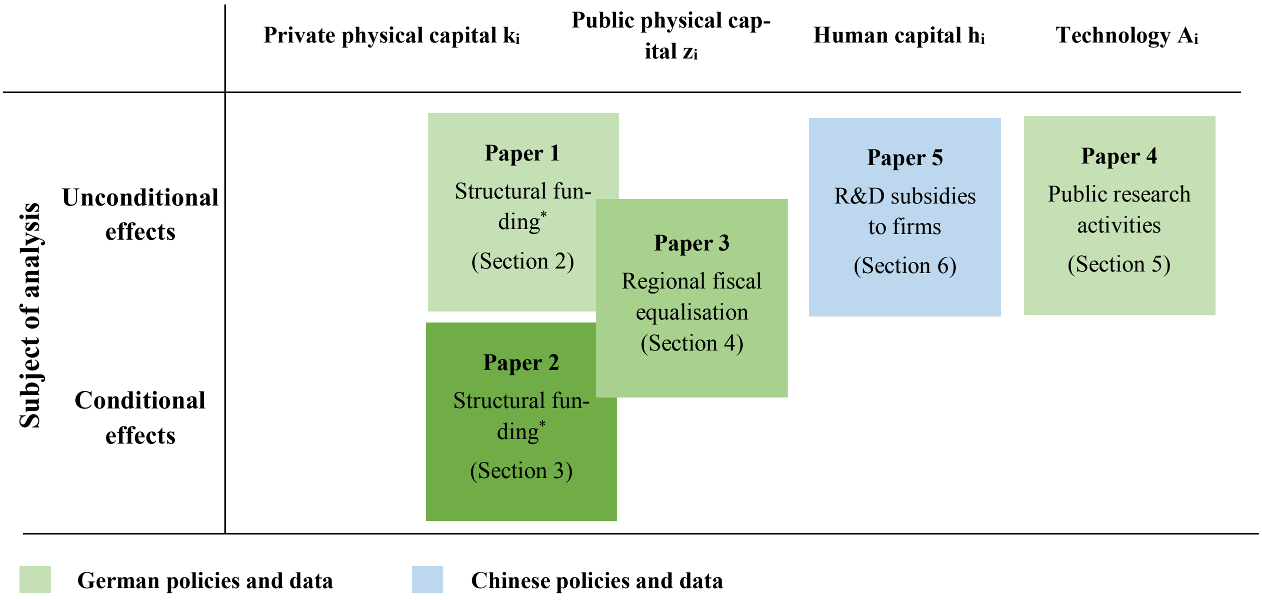
The third research paper sheds light on the unconditional and conditional effects of regional fiscal equalisation in Germany and, in addition, provides a comparison to GRW funding (see Section 4).[8] Although the settings and regulations of regional fiscal equalisation are different to the GRW, basic aims and applied instruments show some similarities and allow a comparison between the two policy measures: Regional fiscal equalisation also comprises a redistributive character by allocating public funds to financially weaker regions in order to increases their financial flexibility and to ensure the regional endowment of public goods (Lenk et al., 2013). However, in contrast to the GRW, regional fiscal equalisation does not have an immediate private sector target. Consequently, equalisation payments mainly affect the regional public physical capital as primary target variable in Equation (1.3).

The fourth research paper draws attention to public research activities conducted in universities, technical colleges and public research institutes (see Section 5). To analyse their impact on the regional economy, the effects of various research activities (scientific publications, acquired third-party funds) on economic development are investigated. In doing so, regional technology can be considered as the primary transmission channel of German public research activities (Fritsch and Schwirten, 1999; Schubert and Kroll, 2013).

[8] In this thesis, *unconditional effects* are defined as the funding effects using the basic population of regions for analysis (full set of German or Chinese regions). In this setting, the regions are not subdivided according to regional characteristics (see Sections 2, 4, 5 and 6). *Conditional effects* are defined as heterogeneous funding effects that depend on regional initial conditions: regions are subdivided according to regional characteristics and subsequently the magnitude of the estimated effects is compared across groups.

The fifth research paper examines the economic impacts of R&D subsidies allocated to firms in China (see Section 6). By applying Chinese data at the provincial level, the research paper contributes to the vibrant discussion on the outcomes of R&D subsidies to firms by examining how these subsidies affect several economic variables. Because innovation activities are human capital intensive (Romer, 1990), the implied primary target variable of Chinese R&D subsidies is the provincial human capital (investment rate), which is proxied by private R&D investments and R&D personnel of firms. Figure 1.2 summarises the implied transmission channel(s) (target variable(s)) of each analysed policy measure in the thesis.

Figure 1.2 Implied theory-grounded transmission channels of each policy



Notes: Own illustration. *Please note that German structural funding also aims to improve regional employment via the (private) investment grants (Deutscher Bundestag, 2014).

1.2 Contribution and overarching research questions

This section formulates three overarching research questions that emphasise the research focus of the thesis. Each research paper in the thesis deals with a specific policy, asks particular research questions and derives separate hypotheses that aims to deepen the insights in the overarching research focus of the thesis. In doing so, the thesis adds to recent literature in several ways.

Besides the identified transmission channel(s) above, policy measures may emanate effects on further economic input and output variables of a regional production function (see Fratesi and Wishlade, 2017, on the multifaceted character of European cohesion policy). To this end, this thesis does not solely investigate the policy effect on a specific economic variable in a single equation approach (with the particular target variable or regional output as dependent variable) but on all economic variables in Equation (1.3). Therefore, indirect policy effects, which may run through other variables in the production system, are also considered to calculate the overall effects of an increase in the policy variable on each economic input and output variable.[9]

Recent empirical policy evaluation studies do not study the effects on a wide set of economic variables of a production function and/or do not identify overall policy effects: With respect to the GRW policy, a large part of the empirical literature analyses solely the direct effects on regional output (e.g. Alecke et al., 2012, 2013; Alecke and Untiedt, 2007; Eckey and Kosfeld, 2005; Eggert et al., 2007; Mitze et al., 2015; Rhoden, 2016). Convserly, only one study by Schalk and Untiedt (2000) considers mutual dependencies between physical capital, employment and regional output.[10]

Furthermore, the number of empirical studies investigating the economic effects triggered by German regional fiscal equalisation is rather low (e.g. Henkel et al., 2018; Kalb, 2010; Lehmann and Wrede, 2019) and a comprehensive analysis on the overall economic effects is missing in the empirical literature so far.

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[9] See Section 1.3 for a detailed description on the taxonomy of policy effects in the thesis.

[10] The studies by Blien et al. (2003), Dettmann et al. (2016), Röhl and von Speicher (2009) and von Ehrlich and Seidel (2015) also analyse the direct effects of the GRW on additional economic variables.

The same applies for empirical studies identifying the economic effects of public research activities on regional economic growth in Germany. Although recent empirical studies investigate the effects on a set of economic variables, they are often restricted to partial effect analyses (e.g. Fritsch and Slavtchev, 2007; Schubert and Kroll, 2013; Spehl et al., 2007).

Finally, the empirical literature on the outcomes of Chinese R&D subsidies is mostly restricted to single equation models, investigating the impact on provincial R&D investments of firms (Chen, 2018) or on the provincial patent activity (Fan et al., 2012; Li, 2009; Sun, 2000).[11] Consequently, the thesis adds to the empirical literature by putting forward the following first overarching research question:

1. *What are the overall economic effects of the analysed policy measures in Germany and China on different regional input and output factors of a regional production function? (Unconditional effects)*

In addition to each individual research paper, the collection of four research papers on the working and economic outcomes of various German policy measures allows an overview and comparison between them. Hence, this thesis also aims to identify unique characteristics of policy measures:

2. *Do the analysed German policy measures add to regional development via different transmission channels and can unique characteristics be identified? (Unconditional effects)*

Finally, the thesis adds to an innovative string of European policy evaluation studies that take potential *conditional* effects of European policy measures into account (e.g. Becker et al., 2013; Breidenbach et al., 2019; Fratesi and Perucca, 2014; Gagliardi and Percoco, 2017; Rodríguez-Pose and Garcilazo, 2015).[12] Based on these studies, potential heterogeneous returns to GRW and fiscal

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[11] Please note that the recent literature is discussed in each research paper in more detail (Sections 2 to 6).

[12] The first two research questions deal with unconditional funding effects.

equalisation funding in Germany are investigated (see Sections 3 and 4). So far, only the studies by Röhl and von Speicher (2009) and Rhoden (2016) regard potential regional heterogeneities in the economic returns to GRW funding, while the conditional effects of German regional fiscal equalisation have not been analysed. That said, the last overarching research question is as follows:

3. *Do economic responses to an increase in German structural funding and regional fiscal equalisation funding depend on conditioning factors such as a region's absorptive capacity, economic freedom and political-economic conditions? (Conditional effects)*

1.3 Empirical strategy

In order to answer the research questions above, a (spatial) panel VAR approach and a corresponding IRF analysis is applied.[13] As pointed out by Rickman (2010), VAR models are so far hardly used by regional economists to analyse the complex outcomes of policy measures on several economic variables.

The application of a VAR approach has the following benefits for the presented research aim: First, the estimated effect in a single equation model may allow only insufficient conclusions because potential indirect effects are neglected. On the one hand, policy measures may affect an economic variable directly, which is indicated by the estimated coefficient of the policy variable in a single equation model. This is interpreted here as the *direct effect*. On the other hand, it is likely that policies affect a particular economic variable through other economic variables and mutual dependencies in a regional production system.[14] This is interpreted as *indirect effect* here. The applied

[13] Please note that the applied spatial model can be referred to as time-space recursive model that includes besides the explanatory variables (lagged in time and time-space) a time as well as a time-space lag of the respective dependent variable (see Sections 2-5 for a detailed description). Section 6 provides a panel VAR approach.

[14] A particular policy may positively affect, for example, the regional level of technology and, conversely, this increase of the technological level may subsequently affect regional GDP per capita.

VAR approach allows researchers to sum up direct and indirect effects to *overall funding effects* (see Rickman, 2010, for an overview on structural VAR models or Mitze et al., 2018, for an empirical application).

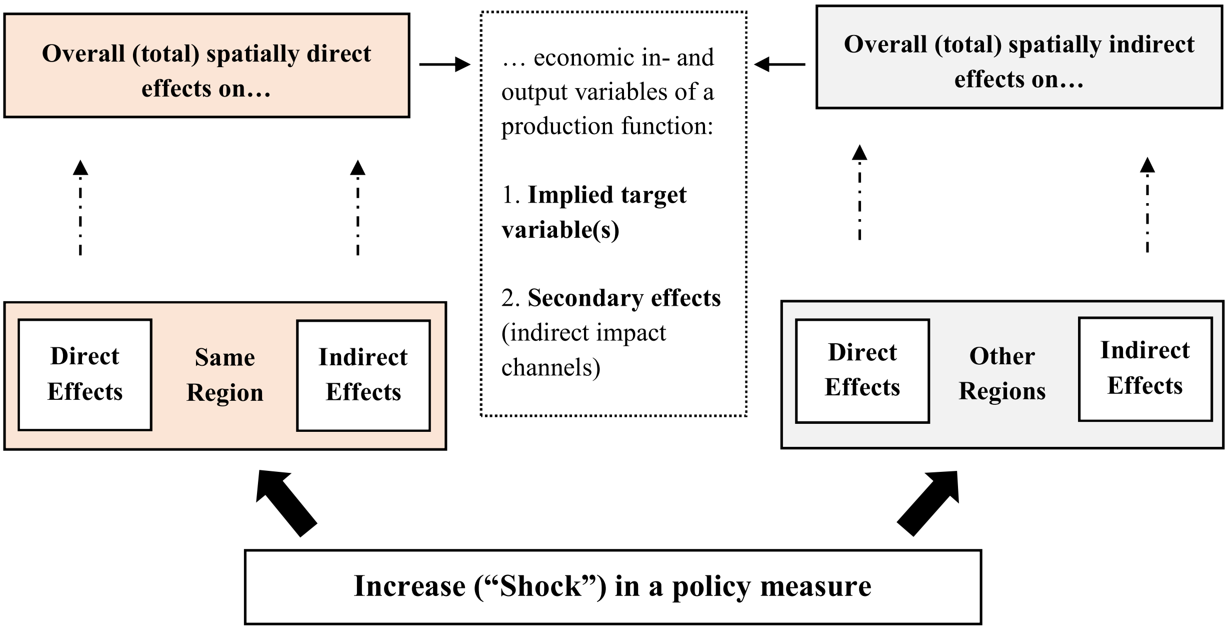
In addition, spatial lag variables are included as controls to the applied VAR models in Sections 2 through 5. For a better understanding, the effect taxonomy has to be expanded here: Within the spatial econometric taxonomy, a *spatially* direct effect is defined as the impact of an increase in an explanatory variable (e.g. policy variable) on the particular dependent variable in the same region, while a *spatially* indirect effect indicates the impact of an increase in an explanatory variable (e.g. policy variable) on other regions (Elhorst, 2012, 2014; Mitze et al., 2018). This distinction of spatially direct and spatially indirect effects can also be transferred to VAR models by calculating the respective overall spatially direct and indirect effects (Mitze et al., 2018). In doing so, the overall spatially direct and indirect effects are assumed to be mutually isolated and unlinked here (so-called short-term effects: see Elhorst, 2012, 2014). The conducted empirical analyses in the thesis are primarily focused to calculate and illustrate the *overall spatially direct effects* of policy measures.[15] Figure 1.3 summarises the taxonomy of policy effects in the applied spatial panel VAR approach (time-space recursive model).

The second benefit of a VAR approach and an associated IRF analysis is that the described *overall spatially direct effects* can be calculated for all economic input and output factors of a regional production function. Thus, it explicitly accounts for potential multifaceted dimension of policies by considering mutual dependencies and unintended effects on variables other than the implied target variable(s). These unintended effects can be named as *secondary effects* or *indirect impact*

[15] See Elhorst (2012, 2014) for additional information on short- and long-term effects in spatial panel models.

channels. Finally, an IRF analysis allows researchers to graphically illustrate the estimated overall effects to an increase in the particular policy variable (Lütkepohl, 2005).[16]

Figure 1.3 Employed taxonomy of *short-term* policy effects in a time-space recursive spatial panel VAR approach



Notes: Own illustration.

1.4 Data

The empirical analyses in Sections 2 through 5 are based on data for 258 German labour market regions from 2000 to 2011. To this end, the classification of labour market regions by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) is used (e.g. Alecke et al., 2012, 2013; Alecke and Untiedt, 2007). This classification aims to harmonise the place of residence and the workplace of the population, because at least some part of regional inhabitants commute to work in other regions. That said, this issue raises concerns regarding potential measurement errors when constructing normalised variables (intensities) in the research papers (e.g. GDP per capita or workforce). In order to reduce such measured errors, the observed

[16] Further applied methods are paper-specific and thus presented in the respective research paper (Sections 2 to 6).

commuting traffic across German small-scale regions is used to construct so-called labour market regions. This labour market region classification is seen as best functional definition of German regions for the purpose of the conducted analyses in the thesis. Moreover, they also represent the administrative level that is used to determine, for example, the eligibility of GRW structural funding receipts (Deutscher Bundestag, 2014).

The conducted analysis in Section 6 is based on data for 31 Chinese provinces covering the time period 2000 to 2010. The administrative level of Chinese provinces is chosen as no consistent data is available on a smaller administrative level. Moreover, the chosen provincial level allows a comparison to other recent Chinese policy evaluation studies on the same administrative level (e.g. Chen, 2018; Fan et al., 2012; Li, 2009; Sun, 2000).

All core variables in this thesis are used in form of intensities and are transformed by the natural logarithm. The associated data sources, the detailed construction of the applied variables and further paper specific data issues are presented in each research paper separately.

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2. A look behind the curtain: Measuring the complex economic effects of regional structural funds in Germany

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Notes: The numbering of sections, tables, figures, hypotheses, formulas and the general layout of the article has been changed in order to provide a better readability within the thesis. This leads also to a varying placement of the tables and figures in the thesis version compared to the published version in *Papers in Regional Science*. Moreover, citation and references have also been harmonized and adjusted to the layout of the thesis.

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 technological growth. 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: Factor inputs, impulse-response functions, production function, regional policy, SpPVAR

JEL Classification: C33, R11, R58, O38, O47

2.1 Introduction

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 that jointly decide on the main regulations for financial assistance (e.g., the set of regions which is 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 export activity as share of total turnover. Another objective is to build up the 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 analysing the effects of EU structural funds are, for instance, Breidenbach et al., 2016; Dall'erba and Le Gallo, 2008; Mohl and Hagen, 2010; Pellegrini et al., 2013; Pérez et al., 2009).[17] Although

[17] As we will discuss in greater detail later on when we address the policy relevance of our empirical findings, there is a very high thematic overlap between the goals and institutional setup of the German GRW and the EU Structural Funds. Thus, although our

the key focus in prior studies 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: (i) 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 the capital intensity and knowledge inputs? and (ii) do the observed overall growth 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., Alecke et al., 2012, 2013; Alecke and Untiedt, 2007; Blien et al., 2003; Dettmann et al., 2016; Eckey and Kosfeld, 2005; Eggert et al., 2007; Mitze et al., 2015; Röhl and von Speicher, 2009; Rhoden, 2016; Schalk and Untiedt, 2000; von Ehrlich and Seidel, 2015).[18] 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 evaluation studies makes use of recent advances in dynamic spatial panel data modelling at a small scale level (258 German labour market regions), which is by now the mainstream approach for analysing regional income convergence and evaluating structural funds' effectiveness at the European level (see, for example, Bouayad-Agha and Védrine, 2010; Mohl and Hagen, 2010). Furthermore, the potentially heterogeneous effects of the two main objectives of

results only provide evidence for the effectiveness of German regional policy, the main implications may be easily translated to the European case.

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

GRW funding (private sector investment support and public infrastructure investments) have previously only been decomposed in Blien et al. (2003). And finally, only the 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 further socio-economic variables other than analysing 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 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 scope of existing empirical approaches in several aspects: First, 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 labour 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 (Debarsy et al., 2012; LeSage and Pace, 2010). As outlined above, this research gap is particularly apparent in the German context, which lags behind the state-of-the-art of evaluation approaches at the EU level. Second, we enhance previous partial analyses of GRW funding effectiveness 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 funding effects running through various transmission channels of the regional economy, we apply a vector autoregressive (VAR) model in combination with an impulse-response function (IRF) analysis. To the authors' knowledge, flexible VAR models have not been used in the context of structural funds evaluation yet − neither at the national nor at the European level. Third, 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 channels. 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 2.3 discusses some theoretical aspects used to derive hypotheses about the complex effects of GRW funding from a growth model perspective. Afterwards, the data will be presented in Section 2.4, followed by a technical description of the VAR approach and the associated IRF analysis in Section 2.5. The empirical results are discussed in Section 2.6. Section 2.7 finally concludes the work and points to future research.

2.2 The GRW Policy: Institutional setup and empirical evaluation studies

2.2.1 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.[19] 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. After the German reunification in 1990, the GRW has been transferred to the new Laender in East Germany (Alecke et al., 2012, 2013). Accordingly, the GRW has become Germany's most powerful regional policy instrument to support regional development and equalize spatial differences in living conditions (Deutscher Bundestag, 2014). Besides its mission as financial power horse, the distinct political relevance also comes from its function as important coordination framework for numerous policies in Germany that aim to foster the regional development (Alecke et al., 2012, 2013).[20]

It is further worth noting that the GRW funding scheme is thematically and institutionally very closely related to the EU Structural and Investment Funds, particularly the European Regional Development Fund (ERDF).[21] One central task of the ERDF, which is very similar to the goal of GRF funding, is that it tries to balance regional disparities within the EU by supporting lagging regions.[22] To this end, among others, the ERDF aims to foster economic growth and create additional employment by providing different types of investment aids to firms. In addition, the ERDF supports investments in different infrastructure measures: basic (transport), innovation, educational, social,

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[19] The programme is based on the GRW law, see Bundesregierung (1969).

[20] For further details on the institutional setup of the GRW see, for instance, Alecke et al. (2012, 2013) or Deutscher Bundestag (2014).

[21] The EU Structural and Investment Funds mainly operate through five distinct funds: ERDF, European Social Fund (ESF), Cohesion Fund (CF), European Agricultural Fund for Rural Development (EAFRD) and European Maritime and Fisheries Fund (EMFF) (European Union, 2013b).

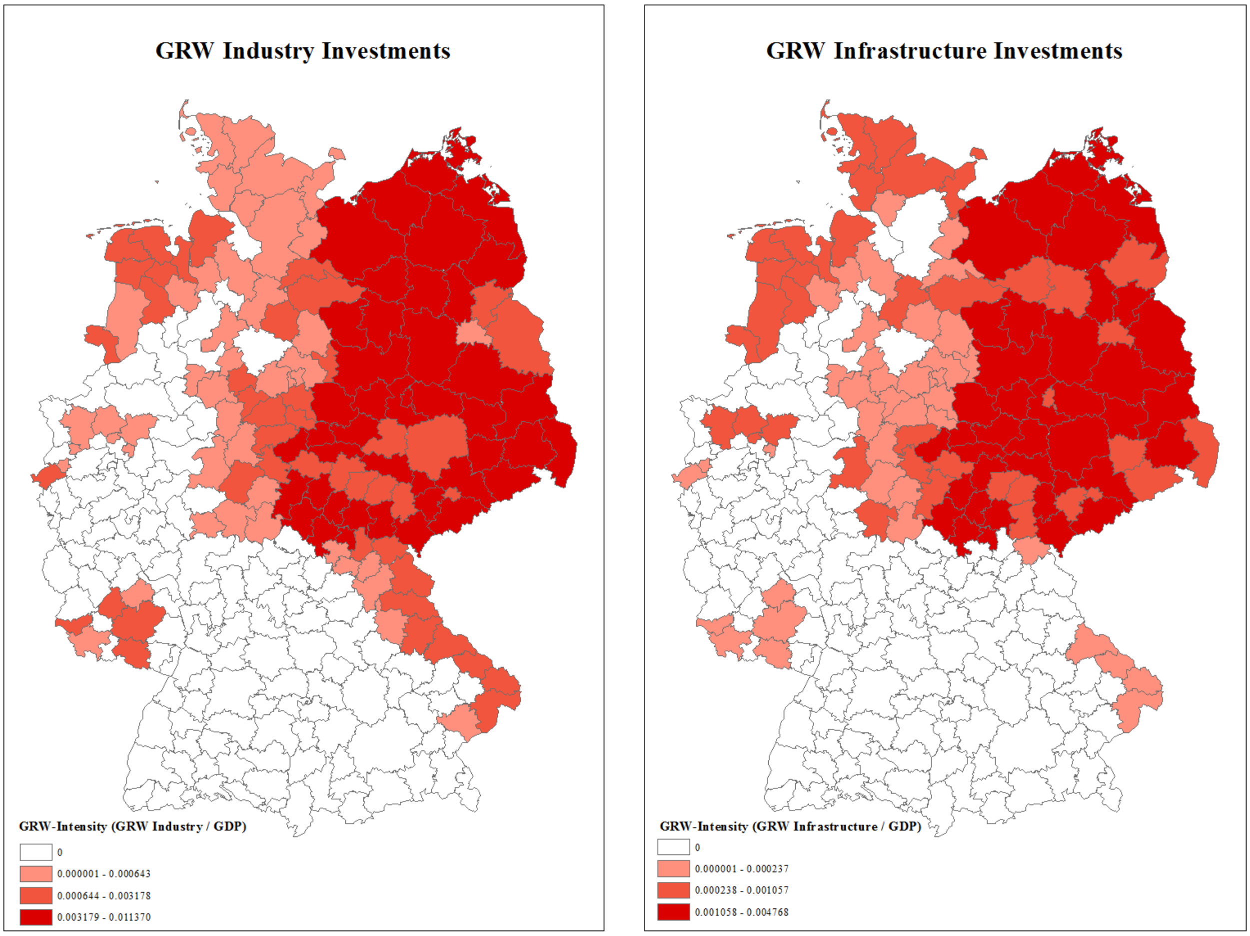
[22] Slightly different from the definition of eligible regions for funding in the GRW scheme, the ERDF classifies regions into three categories: less developed regions (GDP per capita is less than 75% of the average level in the EU), transition regions (75%–90% of the average GDP in the EU) and more developed regions (above 90% of the average GDP in the EU). Regarding the investment volume for growth and employment, 52.45% of these funds are allocated to less developed regions (European Union, 2013b).

health or business infrastructure (European Union, 2013a). Due to this strong overlap, ERFD funding is included into the coordination framework of the GRW as an integral part of the overall funding scheme for less developed German regions (see Deutscher Bundestag, 2014).

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 (e.g., rebuilding of industrial areas, development of intra- and 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 labour market and infrastructure situation relative to the rest of Germany (thereby considering the unemployment rate, gross salaries, employment predictions as well as an infrastructure indicator). The implementation of the GRW takes place at the level of federal states: That is, states can decide on the final allocation of funds among eligible projects, give notice of granting and control the compliance of regulations. Moreover, they are free to define the key target areas of regional development as framework for funding and its allocation (Deutscher Bundestag, 2001, 2014).

In the period 2000 to 2011, nearly 7.38 billion euro were granted within the GRW framework to develop the business oriented public infrastructure (68.75% to the New Bundesländer without Berlin) and around 16.91 billion euro to foster industrial investments (82.70% to the New Bundesländer without Berlin).[23] Figure 2.1 illustrates the spatial distribution of the GRW funding intensity (defined as GRW 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 (private sector investment support, local public infrastructure) across German labour market regions. However, as illustrated in Figure A2.1 in the Appendix, the GRW funding intensity decreased continuously in recent years.

Figure 2.1 Spatial distribution of GRW funding intensities across German labor market regions (2000-2011)



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

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

2.2.2 Overview of related evaluation studies

Prior studies on the effectiveness of regional policy in Germany report ambiguous results. This ambiguity can mainly be explained by the different theoretical foundations used for model building and the heterogeneous empirical identification approaches used to isolate the causal effects of funding.[24] While one stream of studies applies a quasi-experimental approach (Dettmann et al., 2016; Mitze et al., 2015; von Ehrlich and Seidel, 2015), 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 analyses the particular effects of GRW funding along the two funding channels of private sector and public infrastructure investment support (the main findings from the recent literature are summarized in Table A2.1 in the Appendix).

Moreover, while some studies rely on a cross-sectional study design, others apply panel data estimators. The panel data approach features more information, more variation over time and it increases the degrees of freedom for statistical inference (Elhorst, 2003). The panel data approach also 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

[24] 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 development status is determined by key factors such as infrastructure, human capital, institutions, spatial and sectoral structure. Mitze et al. (2015), von Ehrlich and Seidel (2015) and Dettmann et al. (2016) use a quasi-experimental evaluation 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 specifications on a neoclassical growth model approach, which is also well established in the international empirical literature (examples are Ederveen et al., 2006; Dall'erba and Le Gallo, 2008; Mohl and Hagen, 2010; Darku, 2011).

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 the effectiveness of EU structural funding. The use of dynamic spatial panel estimators appears to be the most robust method to identify the policy parameters of interest.[25]

Building on this latter estimation framework, we extend the existing literature by applying a new methodological approach that accounts for simultaneity/endogeneity problems. Table A2.1 in the Appendix shows that the recent literature has mainly focused on analysing (labour) productivity or per capita income as outcome variables of interest 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, for example, the capital investment rate in a region, a single equation approach focusing on labour 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 identify such indirect effects. To our knowledge, the only empirical study which applies a system approach to the analysis of GRW effectiveness is Schalk and Untiedt (2000). The latter authors conduct a simultaneous analysis of output and factor demand in a small multiple-equation system focusing on the supply side of the economy with structural equations for regional production and factor demand in physical capital and labour, respectively.[26]

[25] Mohl and Hagen (2010) report 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 spatial spillovers of funding.

[26] 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.

In this study, we investigate 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 mutual endogeneity among the included variables and to analyse 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.

2.3 Theoretical framework and research hypotheses

In growth models – either neoclassical (e.g., Mankiw et al., 1992; Solow, 1956) or endogenous (e.g., Lucas, 1988; Romer, 1990) – the dynamics of variables follow prescribed growth mechanisms. To develop theoretically sound predictions used for variable selection in our flexible VAR approach and for the formation of prior expectations when interpreting our empirical results, we mainly refer to extended versions of the Solow model (Crihfield et al., 1995; Mankiw et al., 1992) 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):

$$Y_i(t) = K_i(t)^{\alpha}\, H_i(t)^{\beta}\, (A_i(t)\, L_i(t))^{1-\alpha-\beta}, \tag{2.1}$$

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 income level change over consecutive time intervals and are thus not treated as constant for the entire period (Islam, 1995).

As public (infrastructure) investments are of major interest for our empirical model, we adopt a model 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 (2.1) then leads to:

$$Y_i(t) = K_i(t)^{\alpha}\, H_i(t)^{\beta}\, Z_i(t)^{\gamma}\, (A_i(t)\, L_i(t))^{1-\alpha-\beta-\gamma}, \tag{2.2}$$

where γ measures the return to public capital. A commonly used assumption in empirical growth models is that labour grows simultaneously with population (Islam, 1995) or working-age population (Mankiw et al., 1992). However, for modelling regional growth in an aging 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 logic, although it is implemented in a slightly different way given that the focus of the latter authors is set on studying the effects of unemployment. For the purpose of this analysis, we define L as:

$$L_i(t) = \lambda_i(t) \cdot P_i(0)e^{n_i t}, \tag{2.3}$$

where $P_i(t)$ is the economically active population aged between 15 and 64 years, n_i denotes 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 (denoted by $l_i(t)$), 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:

$$y_i(t) = k_i(t)^{\alpha}\, h_i(t)^{\beta}\, z_i(t)^{\gamma}\, (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma}.\text{[27]} \tag{2.4}$$

[27] Note that $y_i(t) = (Y_i(t)/P_i(t))$, $k_i(t) = (K_i(t)/P_i(t))$, $h_i(t) = (H_i(t)/P_i(t))$ 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 $L_i(t)$. The properties of $Z_i(t)$ are quite similar to $K_i(t)$, i.e. 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 rival (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

We take the extended production function in Equation (2.4) as benchmark specification for the selection of variables to be included in our empirical VAR model: that is, we use output per economically active working population (y), technology (A), gross 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 the regional technological level are difficult to measure empirically and they are subject to data limitations. This may cause measurement errors. Therefore, 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.

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

2.3.1 Investment rates of private, public and human capital

Based on the per capita production function in Equation (2.4), dynamic equations for output growth and capital accumulation can be formulated to arrive at hypotheses about the dynamic direct and indirect impact channels of GRW policy support. As such, growth rates of private, public and human capital stocks can be written as:

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for private production, it is compensated indirectly by taxes. Thus, the profit of a representative firm can be defined as: $\pi = (Y-\psi Y) - wL - rHH - rKK$, where w denotes wages, while rH and rK are the rates of return for human and physical capital, respectively; ψ are taxes. $(Y-\psi Y)$ can be interpreted as net output of firms and ψY as the public investment rate sz. Moreover, technology is defined as public good in the long run. Especially due to the non-rivalry characteristic of technology, the replication argument and constant returns apply in the long run (Barro and Sala-i-Martin, 2004).

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

$$\frac{\dot{z}_i}{z_i} = s_{z,i}[k_i(t)^{\alpha}\, h_i(t)^{\beta}\, z_i(t)^{\gamma-1}\, (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma}] - (n_i+\delta), \tag{2.5}$$

and

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

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 by private firms. Thus, the GRW industry programme 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., 2006). On the other hand, considering the GRW support to public infrastructure investments (henceforth, GRW infrastructure investments), funding recipients are particularly administrative bodies 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 2.1 (H2.1):** *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 Equation (2.5), an increase of the per capita stock of public and private sector 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 may be seen as a substitute to physical capital. That is, if physical capital becomes cheaper, the input of human capital 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 as 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 levels to the region. Therefore, public physical capital investments are not direct substitutes to human capital, and we can expect:

> **H2.2** *The effects of GRW support to industry investments on regional human capital are ex-ante unclear and depend on the nature of the relationship between human and physical capital (substitutive or complementary). GRW support to infrastructure investments is expected to have a positive effect on the regional stock of human capital mainly operating through public investments in education, training facilities and research parks.*

2.3.2 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 long-run development, while it is a rather unrealistic expectation in the short run (Temple, 1999). Hence, we allow the regional technological growth rates g_i to vary across German regions in the short run. However, to deduce theoretical predictions here, we refer to the endogenous growth model by Romer (1990). It is assumed that technological progress (new designs) is reached according to the efforts that are put into the research sector as:

$$\dot{A}_i = \delta H_{A,i} A_i \text{ and } \frac{\dot{A}_i}{A_i} = \delta H_{A,i}. \tag{2.6}$$

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 the user costs of physical capital may provide an incentive to substitute human capital in favour 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 subsection 2.2.1). Therefore, we can expect:

> **H2.3** *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 H2.2), while GRW support to public infrastructure investments is expected to exhibit positive effects on regional technological progress.*

2.3.3 Output

Based on Equation (2.4), output growth is a function of the growth rate of human, public and private physical capital as well as the region's technological level and – in our extended model – the employment rate (constant in the long run). Hence, output growth can be expressed as:

$$\frac{\dot{y}_i}{y_i} = (1\text{-}\alpha\text{-}\beta\text{-}\gamma)\ \frac{\dot{A}_i}{A_i} + (1\text{-}\alpha\text{-}\beta\text{-}\gamma)\ \frac{\dot{\lambda}_i}{\lambda_i} + \alpha\frac{\dot{k}_i}{k_i} + \beta\frac{\dot{h}_i}{h_i} + \gamma\frac{\dot{z}_i}{z_i}.^{28} \tag{2.7}$$

This implies that a higher physical capital accumulation – via the private as well as public sector 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 can expect:

> **H2.4** *The per capita output effects of both GRW investment types are positive and mainly run through an increase in the modelled factor inputs but may also stem from other latent transmission channels.*

Hence, given that the included 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 as well.

2.3.4 Employment rate

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

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

is allowed to vary over time, it can be regarded as an alternative production input as already discussed above. Assuming a competitive market setting, public subsidies could thus temporarily increase the financial resources in the supported regions and induce the provision of additional private investments. On the one hand, labour 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, labour input may increase as well through output effects (Bade, 2012).

Schalk and Untiedt (2000) indicate two reasons for such output effects to occur: first, the 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 thus shift their production to supported regions (Schalk and Untiedt, 2000).[29] Both arguments lead to a higher demand for labour which, in turn, increases labour input, wages and may induce in-migration as well (permanent higher labour supply). Furthermore, it has to be taken into consideration that – according to the GRW programme – 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 fosters 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 investments 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. Taken together, we can expect:

[29] This argument also applies to human capital.

H2.5 *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.*

2.4 Data and Variables

For our empirical analysis we use panel data for 258 German labour market regions covering the period 2000-2011.[30] The definition of labour market regions is 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 2.1.[31] As the table shows, our main outcome variable in the region's per capita production function 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 levels. 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 A2.2 (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 for industry investments have been interpolated on the basis of an autoregressive

[30] The time period used for estimation is limited 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. Particularly, East Germany faced a significant outmigration prior to 2000, which is likely to bias the estimation results with regard to certain outcome variables such as per capita GDP and the employment rate.

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

process with three lags. We assume that all data imperfections (qualification of employees' data) do not lead to systematic regional biases, so that they contribute to the random error term.

Table 2.1 Variable descriptions and data sources

Variable	Description	Data source
lgdp	Nominal GDP per economically active working population (in ln) defined as: [GDP in € / (Population aged 15 to 64 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 until the year 2011. From 2011, the participation rate is calculated based on the population data of the census 2011.	GDP: Arbeitskreis "Volkswirtschaftliche Gesamtrechnungen der Länder" (Status: August 2015) Population aged 15 to 64 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 physical capital investment rate (in ln) 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 are interpolated on the basis of an auto-regressive process with 3 lags.	Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR), laufende Raumbeobachtungen, various issues
lhk	Higher education rate (in ln) defined as: [Employees with university degree / (Population aged 15 to 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lemp	Gross employment rate (in ln) defined as: [Employees total / (Population aged 15 to 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lpat	Patent rate (in ln) 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 ln) are defined as: [GRW funding volumes in € / GDP in €]	Federal Office for Economic Affairs and Export Control (BAFA)
w_X	Spatial lags for each variable are constructed in absolute values using the STATA command splagvar. Thereupon, all spatial lag variables are normalized and ln-transformed similar to the non-spatial variables above.	

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 the time-series properties of variables prior to estimation, we perform a series of panel unit root tests as suggested by Im et al. (2003) (henceforth IPS). Table 2.2 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 that all panel members contain a unit root (against the alternative that they are stationary for at least some panel members) for these variables.

Table 2.2 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.

We also incorporate spatial lags of the different variables in the estimation approach as a way to account for spatial heterogeneity and underlying geographical spillovers among the variables. These spatial lags are calculated as the average 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 $\mathbf{W}_N$ proceeds as follows:

$$w^*_{ij} = 0 \text{ if } i = j \text{ and } i \text{ and } j \neq \text{common border}$$
$$w^*_{ij} = 1 \text{ if } i \neq j \text{ and } i \text{ and } j = \text{common border} \tag{2.8}$$
$$w_{ij} = w^*_{ij} / \textstyle\sum_i w^*_{ij},$$

where w^*_{ij} is an element of a non-standardized 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}).

As a further pre-estimation test to assess the degree of spatial dependence in our data, we conduct a series of univariate tests based on Moran's *I* as a global indicator for spatial dependence across German regions (Moran, 1950). The test results shown in Table 2.3 point to the presence of positive and persistent spatial autocorrelation for almost all variables and sample years (with the exception of the employment rate).[32]

[32] A likely reason for the non-existing spatial dependence in the employment rate is its specific construction (See Table 2.1).

Table 2.3 Moran's *I* test of spatial autocorrelation across German labor market regions

Variable →	lgdp			lemp			lemp_detrended			lhk			lhk_detrended		
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.	Moran's *I*	Z(I)	P-val.
2000	0.474	12.401	0.000	-0.017	-0.344	0.366	-0.012	-0.210	0.417	0.225	5.924	0.000	0.232	6.118	0.000
2001	0.446	11.663	0.000	0.003	0.188	0.425	0.013	0.445	0.328	0.207	5.472	0.000	0.222	5.848	0.000
2002	0.422	11.059	0.000	0.012	0.420	0.337	0.029	0.841	0.200	0.198	5.239	0.000	0.219	5.790	0.000
2003	0.395	10.361	0.000	0.012	0.408	0.342	0.032	0.926	0.177	0.190	5.016	0.000	0.218	5.742	0.000
2004	0.379	9.929	0.000	0.008	0.300	0.382	0.032	0.939	0.174	0.180	4.768	0.000	0.216	5.695	0.000
2005	0.373	9.771	0.000	0.020	0.613	0.270	0.050	1.385	0.083	0.164	4.353	0.000	0.206	5.447	0.000
2006	0.342	8.965	0.000	-0.001	0.079	0.468	0.026	0.782	0.217	0.162	4.306	0.000	0.213	5.621	0.000
2007	0.330	8.670	0.000	0.001	0.136	0.446	0.028	0.840	0.201	0.153	4.077	0.000	0.211	5.578	0.000
2008	0.339	8.883	0.000	-0.000	0.090	0.464	0.029	0.858	0.195	0.149	3.969	0.000	0.212	5.595	0.000
2009	0.312	8.198	0.000	-0.023	-0.503	0.307	0.003	0.186	0.426	0.152	4.040	0.000	0.222	5.862	0.000
2010	0.300	7.891	0.000	-0.027	-0.609	0.271	-0.002	0.061	0.476	0.150	3.991	0.000	0.228	6.012	0.000
2011	0.321	8.426	0.000	-0.012	-0.215	0.415	0.022	0.675	0.250	0.142	3.795	0.000	0.229	6.026	0.000
Variable →	**linvq**			**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.**	**Moran's *I***	**Z(I)**	**P-val.**
2000	0.114	3.070	0.001	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	0.118	3.153	0.001	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	0.161	4.297	0.000	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	0.129	3.471	0.000	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	0.138	3.678	0.000	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	0.048	1.351	0.088	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	0.107	2.881	0.002	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	0.100	2.698	0.003	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	0.189	5.022	0.000	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	0.087	2.367	0.009	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	0.154	4.098	0.000	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	0.187	4.960	0.000	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.

2.5 Econometric Modelling

2.5.1 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, Rickman (2010) emphasizes that VAR models are still scarcely used by regional economists to forecast regional economic relationships and conduct policy analyses with mutual outcome variables. However, compared to the inert use of the VAR approach for applied analyses in regional economics, the discipline has been quite active in extending the methodological foundations of the approach, for instance, by incorporating spatial dependency structures in spatial panel VAR (SpPVAR) models.[33]

We will apply a SpPVAR model for the analysis of GRW effects. Therefore, we estimate a dynamic system comprising six equations with the following dependent variables: (i) per (economically active) capita output; (ii) physical capital investment rate; (iii) higher education rate; (iv) gross employment rate; (v) patent rate; and (vi) GRW investment intensity. We apply a maximum lag length of "*t-1*" so that our dynamic system of M equations (with M = 6) can be specified as (Mitze et al., 2018)

$$
\begin{aligned}
y_{1,it} &= \mu_{1,i} + \tau_{1,t} + a_{1,1} y_{1,it-1} + a_{1,2} y_{2,it-1} + \ldots + a_{1,M} y_{M,it-1} + \varepsilon_{1,it} \\
&\ldots \\
y_{M,it} &= \mu_{M,i} + \tau_{M,t} + a_{M,1} y_{1,it-1} + a_{M,2} y_{2,it-1} + \ldots + a_{M,M} y_{M,it-1} + \varepsilon_{M,it}.
\end{aligned}
\tag{2.9}
$$

[33] See Mitze et al. (2018) for additional information on methodical advancements in the field. Moreover, empirical application of spatial VAR specifications can be found, for example, in Beenstock and Felsenstein (2007), Di Giacinto (2010), Monteiro (2010), Ramajo et al. (2017) and Mitze et al. (2018).

In Equation (2.9), $\mu_{m,i}$ and $\tau_{m,t}$ (with m = 1, …, M) denote region- and time-specific effects, respectively, that are included in each of the mth equations, $a_{m,m}$ are regression coefficients and $\varepsilon_{m, it}$ is an i.i.d. error term (Mitze et al., 2018). Stacking over variables and regions, we can write the VAR system more compactly as (Mitze et al., 2018; Rickman, 2010)

$$\mathbf{y}_t = \mu + \tau_t + \mathbf{A(L)y}_{t-1} + \boldsymbol{\varepsilon}_t, \tag{2.10}$$

where μ and τ_t are now NM × 1 vectors of region- and time-fixed effects, respectively; **L** is the lag operator and **A(L)** is a reduced-form coefficient matrix relating past values *t-1* to current values *t* (Mitze et al., 2018; Rickman, 2010). Moreover, $\boldsymbol{\varepsilon}_t$ denotes an NM × 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,…), where $\boldsymbol{\Sigma}$ is an NM × NM variance-covariance matrix (Mitze et al., 2018).

One advantage of reduced-form VARs is that they do not require imposing exclusion restrictions, however, at the same time they often face the problem of over-parameterization and they disregard the economic structure. To overcome these shortcomings, the structural VAR (SVAR) model has been proposed, which uses economic theory or other a priori assumptions on the behaviour of the process to impose restrictions to receive orthogonalized shocks used for the computation of impulse response functions as well as variance decompositions (Rickman, 2010). Building on Rickman (2010), the corresponding SVAR to the reduced-form specification in Equation (2.10) can be expressed as:

$$\mathbf{By}_t = \mu + \tau_t + \mathbf{C(L)y}_{t-1} + \mathbf{De}_t. \tag{2.11}$$

Following Rickman (2010), **B** denotes a matrix of contemporaneous structural parameters, while **C(L)** denotes a matrix of polynomials that relates time lagged to contemporaneous variables and **D** indicates the various contemporaneous responses of the endogenous variables to economic shocks. Premultiplying the equation with $\mathbf{B}^{-1}$ leads to the reduced-form VAR as in Equation (2.10) with $\mathbf{A(L)} = \mathbf{B}^{-1}\,\mathbf{C(L)}$ and $\boldsymbol{\varepsilon}_t = \mathbf{B}^{-1}\mathbf{e}_t$. For known **B** and **D**, the structural properties of the system could be revealed when calculating **C(L)** and $\mathbf{e}_t$ using the estimated reduced-form model. However, given that **B** and **D** are unknown, certain restrictions have to be imposed on **B** in order to identify the various structural parameters and shocks (Rickman, 2010). As Di Giacinto (2010) argues, a regular method to arrive at an exactly identified specification is to assume a particular recursive causal ordering regarding the included endogenous variables. This ordering is also referred to as Wold causal ordering (Wold, 1954). Moreover, Di Giacinto (2010) states that this assumption of contemporaneous exogeneity is technically analogous to an orthogonalization of the error terms by performing a Choleski decomposition of the variance-covariance matrix of the estimated residuals from the reduced-form VAR (see also Hamilton, 1994; Sims, 1980).

2.5.2 Accounting for spatial spillovers

The above presented Panel VAR 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 of $\mathbf{y}_t$, where the spatial lag for the m-th variable is defined as $\sum_{j=1}^{N} w_{ij}\, y_{m,it}$ (Mitze et al., 2018). For a standardized matrix $\mathbf{W}_N$ (see Section 2.4) 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(2.10) system as:

$$\mathbf{y}_t = \mu + \tau_t + \mathbf{A(L)}\mathbf{y}_{t-1} + \mathbf{H(L)}\mathbf{W}\mathbf{y}_{t-1} + \boldsymbol{\varepsilon}_t, \tag{2.12}$$

where $\mathbf{W} = I_M \otimes \mathbf{W}_N$ is consisting of an identity matrix I (with dimension = M) and $\mathbf{W}_N$, assuming that spatial weights do not differ across equations (Mitze et al., 2018). **H(L)** is a coefficient matrix relating past values of the spatial lag terms to current values of $\mathbf{y_t}$ as $\mathbf{H(L)} = I_N \otimes \gamma$, where γ is a M × M matrix of regression coefficients $\left[\gamma_{m,m}\right]_{M\times M}$. The structural VAR specification of the spatially extended system is then a straightforward extension of equation (2.11) as:

$$\mathbf{By}_t = \mu + \tau_t + \mathbf{C(L)y}_{t-1} + \mathbf{G(L)Wy}_{t-1} + \mathbf{De}_t, \tag{2.13}$$

with $\mathbf{H(L)} = \mathbf{B}^{-1}\,\mathbf{G(L)}$. Since we are interested in the short-term dynamics of the SpPVAR system, we can then interpret $\mathbf{C(L)}$ and $\mathbf{G(L)}$ 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 (2.12) and conditional on the chosen causal ordering scheme.

2.5.3 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 (2.12), we follow the argumentation in Beenstock and Felsenstein (2007) that $\mathbf{y_{t-1}}$ and $\mathbf{Wy_{t-1}}$ 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 **A(L)** given a non-zero correlation of the latter lagged endogenous variable with the model's error term (Nickell, 1981). To account for this so-called "Nickell" 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 (Everaert and Pozzi, 2007; Kiviet, 1995) or make use of weakly exogenous instruments such as the Anderson and Hsiao (1981) instrument variable (IV), the Arellano and Bond (1991) first-difference generalized method of moments (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 (2.12).

We then use IRFs to illustrate the reaction of one variable to (uncorrelated) shocks in the further variables of the regional system (Lütkepohl, 2005). Therefore, the model is rearranged into its moving average (MA) presentation that is expressed by the vector of structural uncorrelated errors and the estimated coefficient matrices (Mitze et al., 2018). Our focus in this study rests on computing IRFs on the basis of the coefficient matrix **C(L)**, while the included spatial lag terms only serve the purpose of obtaining unbiased regression results here.[34] We construct confidence intervals by conducting Monte Carlo (MC) simulations to evaluate the statistical significance of the particular IRFs (Love and Zicchino, 2006). We provide details on the specific causal ordering imposed on the SpPVAR system as well as the implementation of the MC simulations when discussing the empirical results in the following.

2.6 Empirical results

In the discussion of the empirical results, we primarily focus on presenting the associated IRFs for the different effects of a temporary, one standard deviation shock 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 for the VAR system including the overall GRW intensity used to run the IRF analysis are shown in Table 2.4, while regression results for the decomposition of GRW funding into industry and infrastructure support can be found in the Appendix (see Tables

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

A2.3 and A2.4).[35] Furthermore, the full set of IRFs for all variables in the regional economic system is reported in Figure A2.2 in the Appendix as well.

As outlined above, the specification of a structural VAR requires certain a priori restrictions. We make use of the Choleski decomposition of the covariance matrix of the model's reduced form residuals to identify the individual effects in the IRF analysis and accordingly and impose the following, theory-guided recursive causal ordering at time *t*:

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

The interpretation of this sequence of effects is as follows: variables more to the left affect the other variables in the system both contemporaneously and with a time lag, while variables more to the right only affect variables appearing earlier in the ordering only with a time lag. In other words, this ordering assumes that the GRW policy is the most exogenous variable in the model given that funding modalities are determined in a mid-run planning process and are not affected by short-run changes in economic conditions. 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 over time. Further, 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, 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.

[35] 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 A2.5, A2.6, A2.7.

2.6.1 GRW: total investments

The selected IRF results of the SpPVAR model in Figure 2.2 based on the estimation results reported in Table 2.4 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. The associated IRF in the upper left panel of Figure 2.2 shows that after a phasing-in interval of roughly one to two years (note that time periods following this “GRW-shock” are measured on the abscissa) we observe statistically significant and positive overall effects of GRW funding on regional per capita output (growth) with a peak in the effect being reached after roughly four years. In terms of the magnitude of the output effect, for this peak effect, we observe a 0.22% 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% for a 1% increase in GRW funding volume, see Table A2.1 for further details) and thus supports our hypothesis **H2.4**.

As shown in the upper middle panel of Figure 2.2, 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 hypothesis **H2.5**. On the one hand, GRW (industry) investments are associated with some constraints regarding the funding recipients (see subsection 2.2.1); on the other hand, the evolution of per capita output and employment is very similar (see Figure A2.2). As argued above, the reported employment effect may hence be a reflex of the above identified output effect.

Table 2.4 Regression results for SpPVAR using total GRW funding intensities

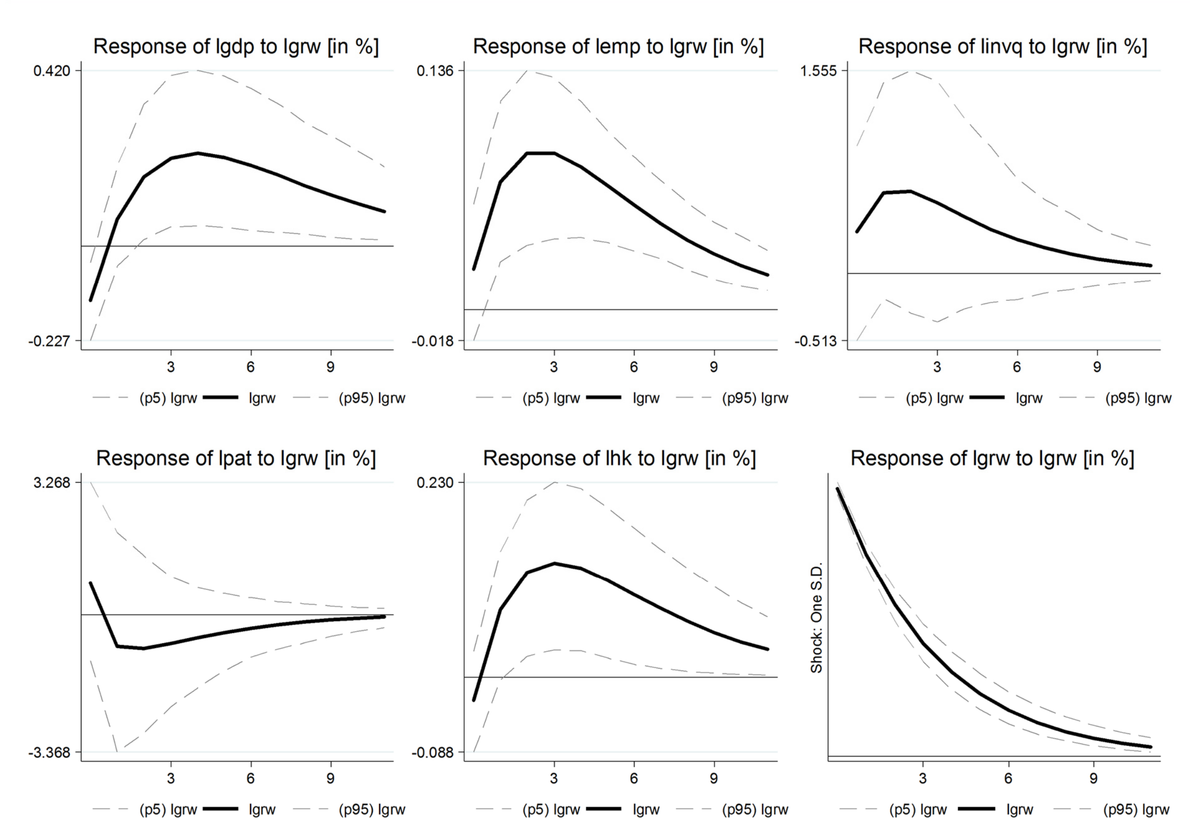
Dependent Variable → **Regressors ↓**	**lgdp**	**lemp**	**lhk**	**linvq**	**lpat**	**lgrw**
lgdp(t-1)	0.787***	0.0355***	0.0272*	0.267	0.770	-1.742
	(0.000)	(0.000)	(0.0148)	(0.0719)	(0.101)	(0.0595)
linvq(t-1)	0.00934***	0.00339***	0.00326*	0.445***	-0.220***	-0.146
	(0.000113)	(0.000689)	(0.0493)	(0.000)	(0.000958)	(0.252)
lhk(t-1)	0.0292	0.00419	0.686***	0.0910	-2.672**	0.628
	(0.412)	(0.736)	(0.000)	(0.731)	(0.00156)	(0.707)
lemp(t-1)	-0.279***	0.506***	-0.156***	-1.286**	1.416	-2.394
	(0.000)	(0.000)	(0.000)	(0.00630)	(0.394)	(0.421)
lpat(t-1)	0.000907	0.000793**	0.00129**	-0.0116	0.0768***	0.000419
	(0.220)	(0.00855)	(0.00500)	(0.0522)	(0.000)	(0.990)
lgrw(t-1)	0.00114**	0.000429**	0.000690**	0.00370	-0.00512	0.753***
	(0.00242)	(0.00327)	(0.00658)	(0.230)	(0.647)	(0.000)
w_lgdp(t-1)	0.0644*	0.0286*	0.0182	0.104	0.173	-0.953
	(0.0479)	(0.0218)	(0.341)	(0.645)	(0.830)	(0.519)
w_linvq(t-1)	-0.000146	0.000268	0.00463	0.0301	0.00808	0.111
	(0.976)	(0.885)	(0.116)	(0.405)	(0.949)	(0.637)
w_lhk(t-1)	-0.0629	-0.103***	-0.0667	-0.562	0.735	1.663
	(0.431)	(0.000806)	(0.134)	(0.340)	(0.724)	(0.661)
w_lemp(t-1)	0.0170	0.108**	0.212**	0.491	2.105	-4.030
	(0.872)	(0.00628)	(0.00135)	(0.538)	(0.458)	(0.438)
w_lpat(t-1)	-0.00131	0.000379	0.00184	0.00728	0.399***	0.326
	(0.788)	(0.830)	(0.482)	(0.829)	(0.000628)	(0.163)
w_lgrw(t-1)	-0.0000466	-0.000126	-0.000331	-0.00148	-0.000697	0.0606*
	(0.928)	(0.580)	(0.328)	(0.723)	(0.960)	(0.0301)

Notes: Observations $N = 2838$. Number of regions $i = 258$. P-values are given in parentheses. ***p < 0.001, **p < 0.01, *p < 0.05. Coefficients for time dummies are not explicitly shown but can be obtained upon request. For estimation 250 bootstrap samples with i.i.d. resampling of the error are 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 are calculated from the *t*-distribution.

As the IRFs in the lower middle panel of Figure 2.2 illustrate, a positive GRW shock also significantly affects the stock of human capital after two years. The negative albeit non-significant 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 **H2.2**.

We find that a positive shock to the GRW intensity also leads to an immediate positive effect on the physical investment rate, although the large standard error renders the effect statistically insignificant. The empirical support for **H2.1** is thus weak, which can be probably related to the heterogeneity of funded physical investments and physical investment rates across regions. Finally, an increase in GRW funding also does not significantly affect the region's patent activity as shown in Figure 2.2. Thus, we do not find evidence for hypothesis **H2.3** that GRW support exhibits some positive effects on regional technological progress.

Figure 2.2 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 2.4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.

To test for the robustness of the results, we also estimate an augmented SpPVAR specification, which controls for differences in the age structure across regions and their change over time as a potential influencing factor of the region's labour market and economic performance (Fuchs, 2016).[36] Given that prevailing differences in the age structure between East and West Germany may correlate with differences in GRW funding volumes, the augmented SpPVAR approach can hence be regarded as being less sensitive to a potential omitted variable bias.[37] However, the estimated linkages between the core variables of the SpPVAR system remain unaffected by the additional inclusion of the age structure.

2.6.2 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 2.3 illustrate, a positive shock to the GRW industry funding intensity goes along with a negative output effect in the very short run, which then turns into positive, albeit marginally statistically significant effects in the mid run. In comparison, the overall output effect of the GRW infrastructure intensity − as shown in the lower part of Figure 2.3 − is found to be positive and significant in the first year after the GRW shock and then turns out to be statistically insignificant for the remaining time periods.

Moreover, we get evidence that GRW support to industry investments is characterized by a longer phasing-in interval reaching a peak in the effect after roughly four years compared to the immediate one-year peak effect in the case of infrastructure investments. Further, the magnitude of the economic effects of GRW industry investments is generally higher compared to the one from GRW infrastructure investments as measured by the percentage increase in per capita output to a one-

[36] The variable age structure is defined as the region's percentage share of population aged 15-64 in total population relative to the corresponding population share in Germany.

[37] We highly acknowledge the comment from an anonymous reviewer pointing to this potential source of an estimation bias.

standard deviation increase in GRW funding categories. These results match our ex ante expectations as the industry-focused part of the GRW programme supports private investments (private capital stock, respectively) directly, while GRW infrastructure investments rather support the public capital stock (and the private capital stock only indirectly). Taken together, both results partly confirm hypothesis **H2.4** indicating that a shock in both forms of GRW investment support has a (delayed) positive effect on per capita output, which is statistically significant only for GRW infrastructure investments.

A related pattern is also shown for the induced economic effects on the employment rate. The employment effects to shocks in both GRW investment types turn to be significantly positive after roughly one year, which is in line with **H2.5**. 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 hence be seen as a further indication for the significant output effects that are induced by the GRW programme and accordingly translate into positive employment effects as well. This relationship is also highlighted in Figure A2.2 in the Appendix showing that a positive shock in per capita output is associated with a positive employment rate response.

Furthermore, Figure 2.3 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 (GRW infrastructure investments), respectively two years (GRW industry investments). As outlined above, this time delay in the transmission 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 turns into a positive response to human capital in the medium run. Thus, regarding the GRW support to infrastructure investments, our results confirm hypothesis **H2.2**.

With regard to the physical investment rate, the IRFs displayed in Figure 2.3 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 increasing GRW support to industry investments. However, as for the case of overall GRW funding in Figure 2.2, the estimated standard errors are quite large implying that we only find a marginally significant physical investment effect in the mid run according to hypothesis **H2.1**. Finally, the reported effects for the regional patent rate in Figure 2.3 indicate that the decomposition of GRW funding does not alter the finding of an insignificant effect on the regional patent activity as already observed for the overall GRW funding intensity in Figure 2.2 (significant negative for GRW infrastructure investments in the year of the shock).[38]

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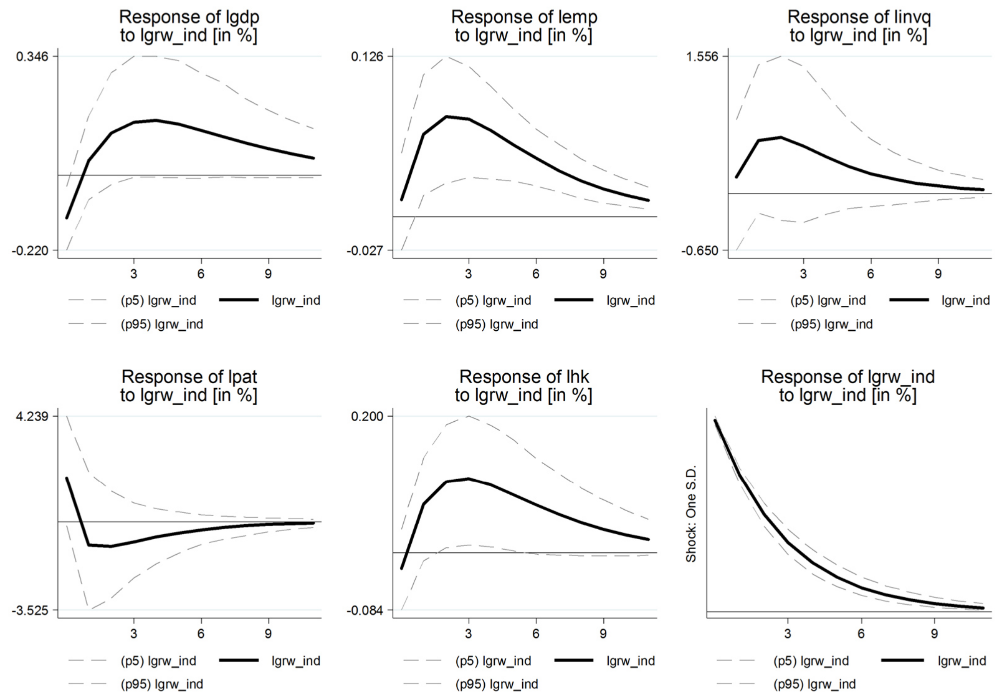
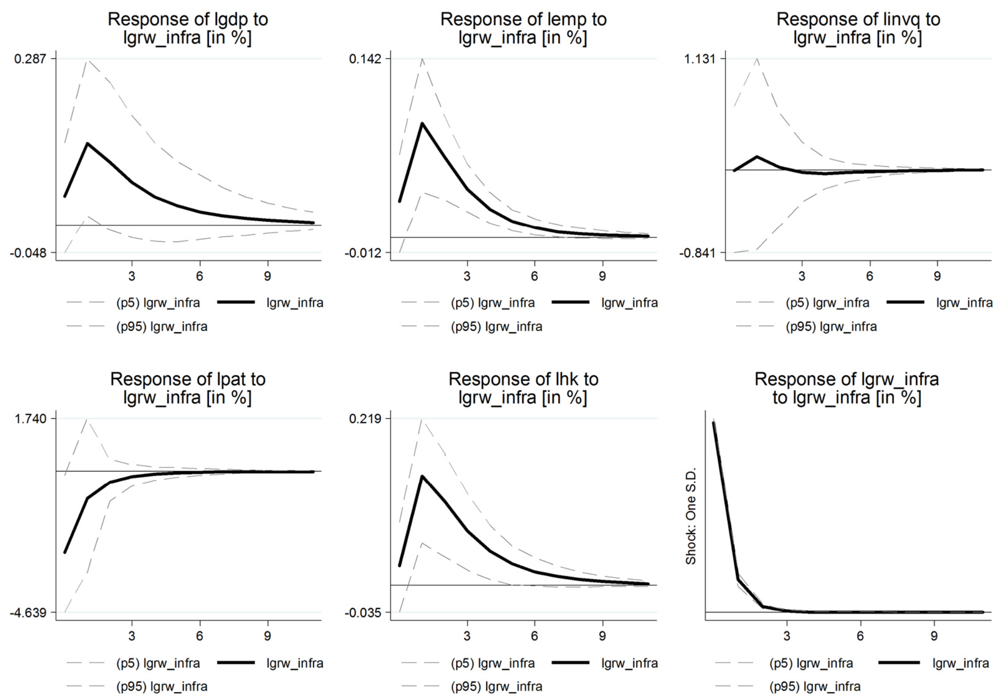
[38] For the most part, the presented results also hold if only regions are considered for estimation that were supported more than 6 years during the period 2000 to 2011. However, the effects of total GRW investments on per capita output turn out to be insignificant, while we find significantly positive effects for GRW infrastructure investments. Results are available upon request.

Figure 2.3 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 A2.3 and A2.4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.

2.7 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 the determination of 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 programme on per capita output of German labour market regions. Medium-run output effects can be triggered by receiving a mix of GRW industry and infrastructure funding. Moreover, 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 dynamic 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, possibly related to the gradual phasing 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 programmes.

Although the empirical results obtained here provide only evidence for positive economic effects of regional policy in Germany, given the close thematic and institutional similarities between the

GRW scheme and the ERDF at the European level, our results may also provide new input to the heated debate on regional policy effectiveness in the EU. In fact, as shown above, ERDF investments are included as an integral part in the overall GRW coordination framework in Germany. In this context, it can be expected that our optimistic results with regard to funding effectiveness of regional policy instruments running through private sector investment aids and support to local public infrastructure are, at least, transferable to less developed regions in countries with very similar economic structures and institutional setup such as France, Scandinavia, the UK or Eastern European countries with structural similarities to the East German situation. However, due to different economic conditions and the quality of regional institutions, a generalization of our empirical results to all European countries should only be done with great care. However, our second contribution to the literature, namely the application of the novel SpPVAR approach, could be easily transferred to all European countries or to the EU as a whole and should provide more knowledge about the generality of our results.

Furthermore, an interesting question related to GRW funding is whether the funding programme 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 jobs in supported labour 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 programme. From a policy perspective it is of major interest to analyse whether the results of this study differ between different types of labour market regions or not and if 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.

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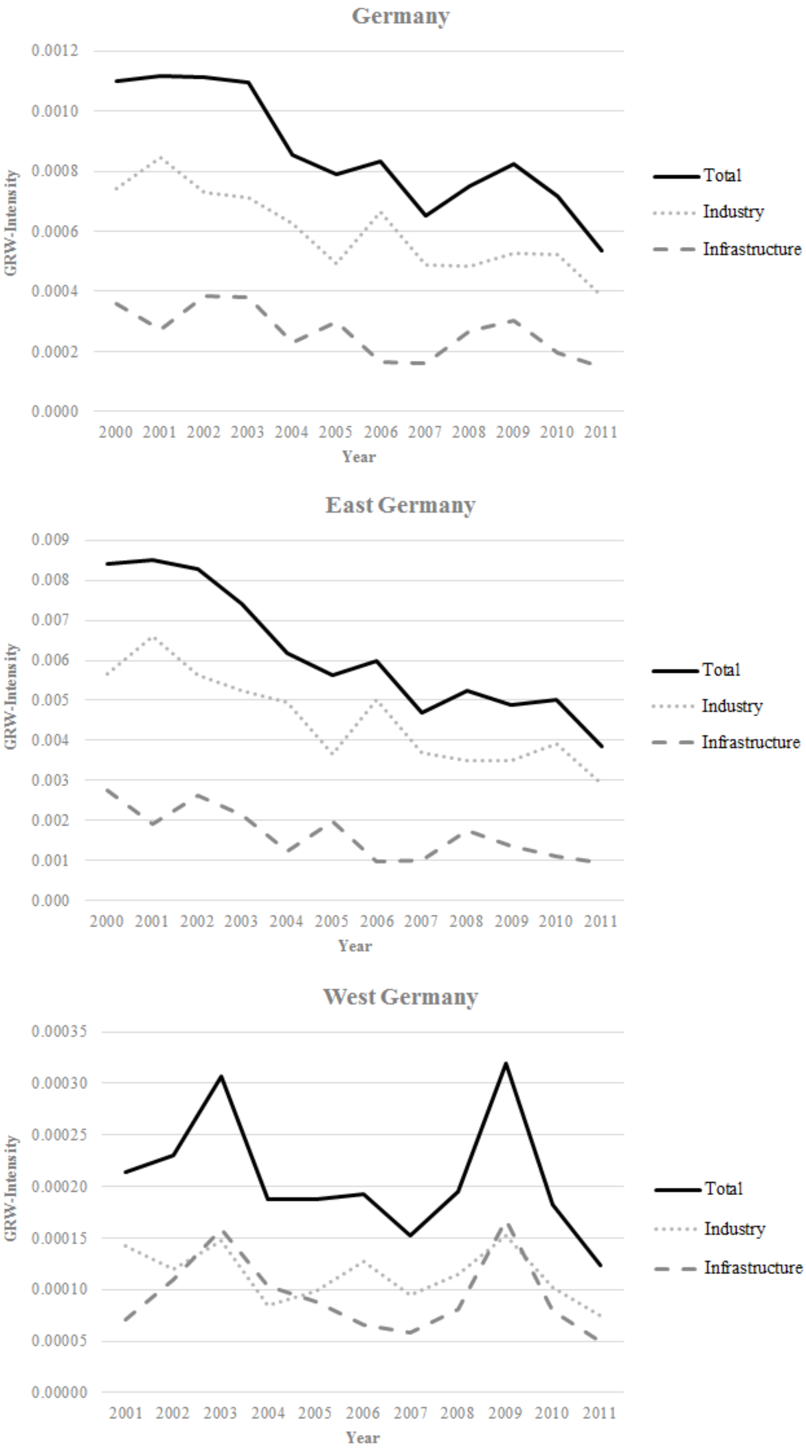
A2. Appendix

Figure A2.1 Temporal evolution of GRW funding intensities in West and East Germany



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

Table A2.1 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)	Error-correction model (ECM) for panel data (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 shiftshare-approach (1993-1999), no spatial model estimated	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 estimated 2. Panel data (1996-2003), no spatial model estimated, 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 estimated, 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 estimated, 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. OLS Estimator for non-spatial model 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 A2.1 (continued)

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 estimated 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 estimated	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 wage 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. OLS Estimator for non-spatial model 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 A2.2 Summary statistics for variables 2000 to 2011

	Observations	Mean	Std. Dev.	Min	Max
lgdp	3096	10.77384	0.2548694	10.04048	11.66673
lemp	3096	-0.4980849	0.1449697	-0.9412167	-0.054104
lemp_detrended	3096	-0.4883598	0.1443927	-0.860197	-0.0472641
Lhk	3096	-2.983249	0.4620051	-4.16754	-1.576675
lhk_detrended	3096	-3.221792	0.4775752	-4.312091	-1.909949
linvq	3096	-3.827942	0.5522995	-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	0.2253164	10.24876	11.45012
w_lemp	3096	-.4412998	0.0860433	-0.7334062	-0.1873686
w_lemp_detrended	3096	-.4320978	0.0892868	-0.7239823	-0.1842588
w_lhk	3096	-2.721685	0.3560248	-3.796473	-1.802598
w_lhk_detrended	3096	-2.951084	0.3576126	-3.955346	-2.156658
w_linvq	3096	-3.822068	0.3798358	-5.172833	-2.373494
w_lpat	3096	-5.138939	0.607518	-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 in the normalized variables are replaced by a very small number before taking the ln (lpat, lgrw, lgrw_ind, lgrw_infra, w_lgrw, w_lgrw_ind, w_lgrw_infra). Suffix "_detrended" denotes detrended variable; see Table 2.1 for details on variable description.

Table A2.3 Regression results for SpPVAR using GRW support to industry investments

Dependent Variable → **Regressors ↓**	**lgdp**	**lemp**	**lhk**	**linvq**	**lpat**	**lgrw_ind**
lgdp(t-1)	0.786***	0.0354***	0.0269*	0.267	0.763	-1.486
	(0.000)	(0.000)	(0.0157)	(0.0695)	(0.104)	(0.110)
linvq(t-1)	0.00932***	0.00339***	0.00326*	0.445***	-0.220***	-0.141
	(0.000120)	(0.000711)	(0.0498)	(0.000)	(0.000971)	(0.253)
lhk(t-1)	0.0290	0.00408	0.686***	0.0887	-2.675**	0.859
	(0.414)	(0.743)	(0.000)	(0.738)	(0.00154)	(0.639)
lemp(t-1)	-0.276***	0.506***	-0.155***	-1.278**	1.423	-2.076
	(0.000)	(0.000)	(0.000)	(0.00709)	(0.391)	(0.522)
lpat(t-1)	0.000884	0.000785**	0.00128**	-0.0117	0.0769***	-0.0226
	(0.233)	(0.00939)	(0.00558)	(0.0517)	(0.000)	(0.531)
lgrw_ind(t-1)	0.000937*	0.000400**	0.000588*	0.00394	-0.00673	0.714***
	(0.0156)	(0.00807)	(0.0189)	(0.210)	(0.552)	(0.000)
w_lgdp(t-1)	0.0651*	0.0288*	0.0181	0.112	0.173	-0.987
	(0.0447)	(0.0213)	(0.342)	(0.624)	(0.830)	(0.540)
w_linvq(t-1)	-0.000318	0.000243	0.00457	0.0306	0.00822	0.186
	(0.947)	(0.895)	(0.121)	(0.401)	(0.948)	(0.381)
w_lhk(t-1)	-0.0640	-0.103***	-0.0675	-0.571	0.751	3.293
	(0.422)	(0.000777)	(0.132)	(0.332)	(0.719)	(0.439)
w_lemp(t-1)	0.0150	0.107**	0.210**	0.488	2.092	-9.016
	(0.886)	(0.00662)	(0.00145)	(0.541)	(0.461)	(0.110)
w_lpat(t-1)	-0.00124	0.000393	0.00192	0.00658	0.400***	0.328
	(0.798)	(0.825)	(0.464)	(0.846)	(0.000621)	(0.124)
w_lgrw_ind(t-1)	-0.0000839	-0.000130	-0.000339	-0.000294	0.00135	0.0760**
	(0.869)	(0.544)	(0.306)	(0.945)	(0.921)	(0.00475)

Notes: Observations $N = 2838$. Number of regions $i = 258$. P-values are given in parentheses. ***p < 0.001, **p < 0.01, *p < 0.05. Coefficients for time dummies are not explicitly shown but can be obtained upon request. For estimation 250 bootstrap samples with i.i.d. resampling of the error are 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 are calculated from the t-distribution.

Table A2.4 Regression results for SpPVAR using GRW support to infrastructure investments

Dependent Variable → **Regressors ↓**	**lgdp**	**lemp**	**lhk**	**linvq**	**lpat**	**lgrw_infra**
lgdp(t-1)	0.783***	0.0341***	0.0255*	0.250	0.786	-0.818
	(0.000)	(0.000)	(0.0231)	(0.0910)	(0.0951)	(0.566)
linvq(t-1)	0.00949***	0.00350***	0.00345*	0.446***	-0.221***	-0.403*
	(0.000103)	(0.000463)	(0.0356)	(0.000)	(0.000921)	(0.0416)
lhk(t-1)	0.0279	0.00263	0.684***	0.0750	-2.663**	-2.670
	(0.434)	(0.832)	(0.000)	(0.777)	(0.00155)	(0.320)
lemp(t-1)	-0.276***	0.506***	-0.156***	-1.254**	1.412	2.946
	(0.000)	(0.000)	(0.000)	(0.00769)	(0.395)	(0.541)
lpat(t-1)	0.000928	0.000822**	0.00133**	-0.0115	0.0761***	-0.0721
	(0.211)	(0.00630)	(0.00438)	(0.0551)	(0.000)	(0.242)
lgrw_infra(t-1)	0.000463	0.000316**	0.000546**	0.000534	-0.00290	0.170***
	(0.103)	(0.00335)	(0.00279)	(0.803)	(0.659)	(0.000)
w_lgdp(t-1)	0.0647*	0.0291*	0.0193	0.108	0.177	-1.198
	(0.0458)	(0.0203)	(0.310)	(0.630)	(0.826)	(0.614)
w_linvq(t-1)	-0.000909	-0.00000214	0.00428	0.0277	0.0111	-1.012*
	(0.849)	(0.999)	(0.142)	(0.442)	(0.929)	(0.0119)
w_lhk(t-1)	-0.0586	-0.101***	-0.0645	-0.553	0.719	-14.43*
	(0.462)	(0.000939)	(0.142)	(0.348)	(0.730)	(0.0151)
w_lemp(t-1)	0.0143	0.104**	0.209**	0.437	2.132	20.74*
	(0.892)	(0.00833)	(0.00160)	(0.584)	(0.452)	(0.0126)
w_lpat(t-1)	-0.000629	0.000677	0.00222	0.00987	0.396***	0.741*
	(0.897)	(0.698)	(0.389)	(0.770)	(0.000678)	(0.0368)
w_lgrw_infra(t-1)	-0.000264	0.000171	-0.0000753	0.00302	-0.000706	0.0441
	(0.469)	(0.229)	(0.741)	(0.253)	(0.943)	(0.0933)

Notes: Observations $N = 2838$. Number of regions $i = 258$. P-values are given in parentheses. ***p < 0.001, **p < 0.01, *p < 0.05. Coefficients for time dummies are not explicitly shown but can be obtained upon request. For estimation 250 bootstrap samples with i.i.d. resampling of the error are 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 are calculated from the *t*-distribution.

Table A2.5 Residual-based Moran's *I* test (overall GRW funding intensities)

Dependent 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	0.094	2.556	0.005	0.096	2.707	0.003	0.077	2.120	0.017
2002	0.119	3.204	0.001	0.171	4.665	0.000	0.047	1.333	0.091
2003	0.057	1.589	0.056	0.197	5.253	0.000	0.142	3.806	0.000
2004	0.054	1.606	0.054	0.090	2.443	0.007	-0.013	-0.240	0.405
2005	0.011	0.408	0.342	0.380	9.979	0.000	0.085	2.331	0.010
2006	0.111	3.013	0.001	0.244	6.438	0.000	0.158	4.192	0.000
2007	0.060	1.666	0.048	0.184	4.922	0.000	0.114	3.060	0.001
2008	0.101	2.759	0.003	0.213	5.628	0.000	0.173	4.617	0.000
2009	0.170	4.519	0.000	0.359	9.457	0.000	0.184	4.910	0.000
2010	0.045	1.286	0.099	0.136	3.657	0.000	0.006	0.259	0.398
2011	0.042	1.200	0.115	0.183	4.867	0.000	0.161	4.275	0.000
Dependent 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	0.000	0.112	0.455	0.059	1.674	0.047	0.104	2.832	0.002
2002	0.056	1.554	0.060	-0.093	-2.847	0.002	0.135	3.799	0.000
2003	-0.068	-1.708	0.044	-0.122	-3.501	0.000	0.097	2.761	0.003
2004	0.104	2.831	0.002	-0.115	-3.716	0.000	0.019	0.617	0.269
2005	-0.027	-0.611	0.271	0.093	2.851	0.002	0.156	4.317	0.000
2006	0.037	1.073	0.142	0.109	3.441	0.000	0.025	0.791	0.214
2007	-0.033	-0.771	0.220	0.096	3.477	0.000	0.094	2.595	0.005
2008	0.019	0.601	0.274	0.202	5.620	0.000	0.018	0.586	0.279
2009	0.031	0.907	0.182	-0.035	-0.991	0.161	0.069	1.928	0.027
2010	0.055	1.542	0.062	0.080	2.691	0.004	-0.017	-0.358	0.360
2011	-0.081	-2.013	0.022	-0.090	-2.800	0.003	0.035	1.071	0.142

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 test statistic.

Table A2.6 Residual-based Moran's *I* test (GRW support to industry investments)

Dependent 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	0.094	2.544	0.005	0.096	2.703	0.003	0.077	2.098	0.018
2002	0.115	3.106	0.001	0.172	4.709	0.000	0.048	1.348	0.089
2003	0.060	1.656	0.049	0.199	5.300	0.000	0.143	3.819	0.000
2004	0.055	1.647	0.050	0.090	2.435	0.007	-0.013	-0.234	0.407
2005	0.012	0.441	0.330	0.380	9.997	0.000	0.084	2.310	0.010
2006	0.111	3.003	0.001	0.246	6.484	0.000	0.158	4.206	0.000
2007	0.060	1.666	0.048	0.184	4.914	0.000	0.114	3.056	0.001
2008	0.100	2.724	0.003	0.213	5.635	0.000	0.175	4.667	0.000
2009	0.170	4.531	0.000	0.359	9.461	0.000	0.183	4.873	0.000
2010	0.043	1.218	0.112	0.135	3.613	0.000	0.004	0.215	0.415
2011	0.045	1.278	0.101	0.184	4.897	0.000	0.162	4.311	0.000
Dependent Variable →		**linvq**			**lpat**			**lgrw_ind**	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.001	0.127	0.450	0.059	1.664	0.048	0.074	2.079	0.019
2002	0.056	1.552	0.060	-0.093	-2.849	0.002	0.149	4.171	0.000
2003	-0.068	-1.701	0.044	-0.121	-3.493	0.000	0.127	3.533	0.000
2004	0.105	2.847	0.002	-0.114	-3.710	0.000	0.010	0.363	0.358
2005	-0.027	-0.613	0.270	0.093	2.852	0.002	0.123	3.410	0.000
2006	0.038	1.086	0.139	0.109	3.444	0.000	0.053	1.565	0.059
2007	-0.034	-0.776	0.219	0.096	3.470	0.000	0.115	3.148	0.001
2008	0.018	0.573	0.283	0.203	5.623	0.000	0.013	0.467	0.320
2009	0.032	0.925	0.177	-0.035	-0.986	0.162	0.061	1.720	0.043
2010	0.055	1.535	0.062	0.081	2.697	0.004	-0.020	-0.453	0.325
2011	-0.082	-2.026	0.021	-0.090	-2.808	0.002	0.095	2.678	0.004

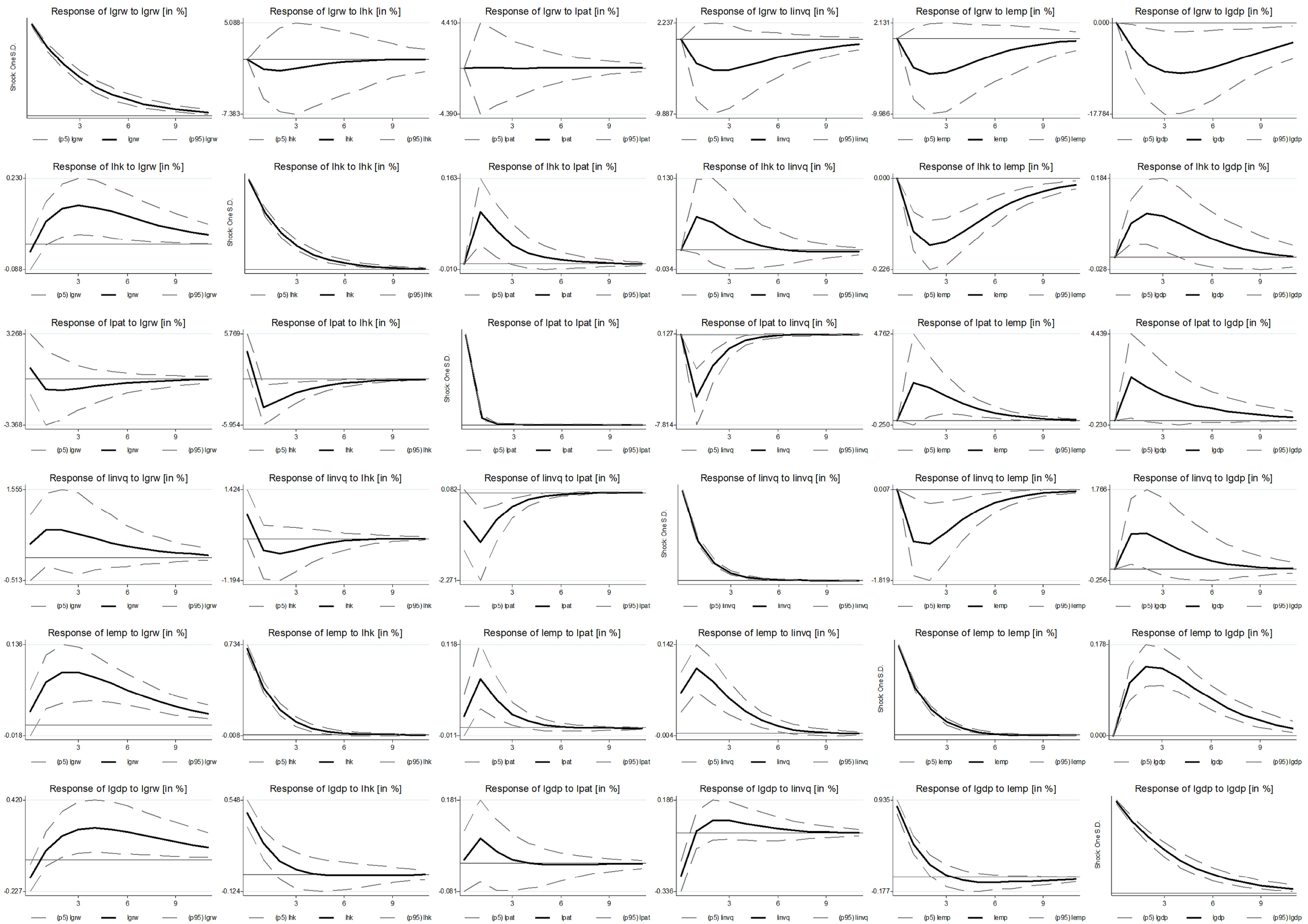
Notes: Details on the underlying spatial weighting matrix used to compute the Moran's *I* statistic are given in the main text; Z(I) = Moran's *I* test statistic.

Table A2.7 Residual-based Moran's *I* test (GRW support to infrastructure investments)

Dependent 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	0.090	2.453	0.007	0.091	2.579	0.005	0.081	2.207	0.014
2002	0.118	3.174	0.001	0.185	5.052	0.000	0.058	1.602	0.055
2003	0.064	1.764	0.039	0.200	5.323	0.000	0.135	3.622	0.000
2004	0.056	1.659	0.049	0.104	2.816	0.002	-0.007	-0.072	0.471
2005	0.013	0.468	0.320	0.377	9.922	0.000	0.084	2.313	0.010
2006	0.108	2.914	0.002	0.229	6.036	0.000	0.150	4.006	0.000
2007	0.064	1.773	0.038	0.173	4.636	0.000	0.113	3.028	0.001
2008	0.104	2.835	0.002	0.210	5.554	0.000	0.176	4.701	0.000
2009	0.170	4.535	0.000	0.359	9.460	0.000	0.174	4.645	0.000
2010	0.038	1.085	0.139	0.133	3.561	0.000	0.002	0.148	0.441
2011	0.050	1.407	0.080	0.187	4.957	0.000	0.166	4.423	0.000
Dependent Variable →		**linvq**			**lpat**			**lgrw_infra**	
Year ↓	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**	**Moran's *I***	**Z(I)**	**P-val.**
2001	0.006	0.250	0.401	0.058	1.651	0.049	0.111	3.011	0.001
2002	0.059	1.630	0.052	-0.093	-2.861	0.002	0.035	1.020	0.154
2003	-0.070	-1.770	0.038	-0.123	-3.531	0.000	0.054	1.507	0.066
2004	0.104	2.816	0.002	-0.115	-3.734	0.000	0.061	1.701	0.044
2005	-0.029	-0.655	0.256	0.093	2.855	0.002	0.120	3.244	0.001
2006	0.035	1.001	0.158	0.108	3.431	0.000	0.051	1.441	0.075
2007	-0.033	-0.759	0.224	0.096	3.483	0.000	0.026	0.777	0.218
2008	0.018	0.560	0.288	0.201	5.579	0.000	0.017	0.543	0.294
2009	0.030	0.888	0.187	-0.035	-1.004	0.158	0.020	0.634	0.263
2010	0.056	1.547	0.061	0.082	2.726	0.003	0.023	0.711	0.239
2011	-0.076	-1.869	0.031	-0.090	-2.804	0.003	-0.056	-1.364	0.086

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 A2.2 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 2.4. Solid lines are IRFs and dashed lines are 95% confidence intervals generated from Monte Carlo simulations with 200 reps.

3. Absorptive capacity, economic freedom and the conditional effects of German regional policy

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Abstract: This paper analyses the role played by regional absorptive capacity and economic freedom for the working of German regional policy. We construct synthetic composite indicators to measure differences in conditioning factors across German regions and categorise regions ac-cording to their indicator rankings. We then estimate the subsample-specific transmission channels of regional policies in a structural vector-autoregressive (VAR) framework and compare the direction and magnitude of effects across groups by impulse response function (IRF) analysis and ex-post *t*-tests. The empirical results point to two main channels of policy impact: While regions with low levels of absorptive capacity and economic freedom benefit from public funding only in terms of a traditional funding channel (i.e. higher investment rates), the link running from regional policy to technology growth and GDP development is weak for this group of regions. In comparison, our findings reveal significant positive policy effects on regional GDP and innovation activity through a knowledge-based funding channel for regions with high absorptive capacity and economic freedom. This underlines the role of technological and institutional conditions for the direction and magnitude of funding effects from regional policy. Hence, regional institutional quality should be considered by policy makers as a means to trigger policy effectiveness.

Keywords: Regional development, regional policy, absorptive capacity, economic freedom, structural VAR, impulse response functions

JEL Classification: C33, R11, R58, O47

3.1 Introduction

A central objective of the European Union (EU) and its member states is to support the socio-economic development of less prosperous regions to foster territorial cohesion (e.g. European Commission, 2017). In Germany, the “Joint Task for the Improvement of Regional Economic Structures” (Gemeinschaftsaufgabe Verbesserung der regionalen Wirtschaftsstruktur, henceforth GRW) is the central instrument of regional policy to support a well-balanced economic development across space by stimulating additional investments in lagging regions (Deutscher Bundestag, 2014). The study at hand builds on and extends a recent work by Eberle et al. (2019) that models regional policy transmission channels in a small scale economic system. The main aim of this work is to analyse the *conditional* economic effects of GRW funding, i.e. the heterogeneity of policy effects on regional outcome variables in the light of underlying technological, entrepreneurial and institutional differences across German regions.

While several prior investigations on the regional effects of GRW funding are available, a main contribution to the empirical literature is that we explicitly account for the multifaceted nature of regional policy which aims at addressing multiple socio-economic objectives (e.g. Fratesi and Wishlade, 2017, in the context of EU regional policy). We do so by means of identifying policy effects on the basis of a small-scale econometric systems approach that allows capturing the mutual transmission channels of GRW funding on regional economic outcomes. Specifically, we estimate a structural spatial panel vector-autoregressive (SpPVAR) model and use Impulse Response Function (IRF) analysis to assess the direct and indirect GRW funding effects for the regional economy. Although our analysis cannot distinguish among the whole range of policy fields addressed by the GRW, we are nonetheless able to separate the working of its two main pillars, namely, investment grants to private firms (GRW industry funding), on the one hand, and investment support to the local public infrastructure (GRW infrastructure funding), on the other hand. In the empirical analysis, we combine this VAR approach to regional policy analysis to provide a comprehensive picture of the transmission channels of funding by policy field.

The key novelty and contribution of this paper is the identification of heterogeneous responses to GRW funding, which chiefly depend on the regions' ability to transform (policy) inputs into economic outcomes. In doing so, we start from the burgeoning empirical literature on the role of 'conditioning factors' for regional growth and the success of funding programmes stressing the importance of the regions' technological and entrepreneurial basis as well as institutional quality. While one strand of the related literature directly relates conditioning factors to regional growth performances (see, for instance, Bologna et al., 2016, and Spruk and Kešeljević, 2018, for the link between economic freedom and regional economic development), another strand of the literature focusses their role for policy effectiveness, e.g., related to foreign aid (e.g. Burnside and Dollar 2000), federal spending in the United States (e.g. Suárez Serrato and Wingender, 2016) or – most closely related to the study at hand – the EU Structural Funds (see Beugelsdijk and Eijffinger, 2005; Ederveen et al., 2006, for country-level evidence as well as Becker et al., 2013; Breidenbach et al., 2019; Cappelen et al., 2003; Fratesi and Perucca, 2014; Gagliardi and Percoco, 2017; Rodríguez-Pose and Garcilazo, 2015, for regional analyses). These studies widely suggest that regional conditioning factors matter and – as also emphasised in Iammarino et al. (2019) – that public policy measures thus should be more tailored and attuned to differences in regional structures. However, despite this growing evidence on the importance of the regional context for funding success, very little is known about the role of conditional effects in the German regional policy context so far.

Based on this novel contribution, three central research questions can be formulated: 1) To what extent do economic responses to regional policy funding depend on underlying conditioning factors such as a region's absorptive capacity and economic freedom? 2) Does this potential conditionality of policy effects vary across the different socio-economic outcome variables covered in our small-scale regional economic system? 3) Do conditional effects also arise in the context of different funding instruments of the GRW, i.e. do the identified transmission channels of investment support to private firms and public infrastructure support work differently in specific regional contexts? Providing answers to these three questions can be seen as particularly helpful for policy makers as it can effectively contribute to future policy design or, as Fratesi and Wishlade (2017, p. 819) phrase it: *"[...] knowing that some policies have a greater impact in certain contexts can provide a basis for more efficient use of funds*". Particularly in times of stagnating or even decreasing funding volumes for regional policy in the EU and Germany, this analysis may guide policy makers on creating fertile regional conditions that can improve funding effectiveness or focusing the available funds on regions with higher effectiveness. Finally, the empirical approach presented here may be seen as a blueprint for the analysis of regional policy effectiveness in other countries or at the EU level.

The remainder of this paper proceeds as follows. Section 3.2 provides a brief overview of recent empirical studies related to our empirical identification strategy. Section 3.3 presents the underlying theory and develops research hypotheses on the role of regional conditioning factors for policy effectiveness. Thereafter, the econometric approach (Section 3.4) and the data (Section 3.5) are introduced. Section 3.6 presents the empirical results together with a series of robustness tests. Finally, Section 3.7 summarises and concludes the paper.

3.2 State of debate

The regional policy in focus, the GRW, is the most relevant and financially powerful policy framework in Germany to accelerate the general development of economically suffering and poorly developed regions. In doing so, the GRW includes financial means from the European Regional Development Fund (ERDF) and primarily seeks to spur local private physical capital investment activities as well as to improve the local infrastructure (e.g. Alecke et al., 2012, 2013; Eberle et al., 2019). Alecke et al. (2012, 2013) and Eberle et al. (2019) show that GRW investment grants are particularly allocated to the economic weaker regions in the Eastern part of Germany.[39]

So far, little is known about the conditional effects of German regional policy as regional heterogeneities are mainly disregarded in the empirical evaluation literature on regional funding effectiveness.[40] Some first explorative evidence on the role of the regional context is – to a limited extent – reported by Röhl and von Speicher (2009), who correlate regional growth and GRW funding for data on 113 East German regions over the period 1996-2006 using a four-type classification of regional settlement structures as conditioning factor. While the authors find positive correlations for all four different types of German regions on sectoral gross value added (GVA) in the manufacturing sector, their magnitude is observed to differ across region types with the highest effect observed for highly agglomerated regions followed by rural areas (Röhl and von Speicher, 2009). The study of Rhoden (2016) runs a cross-sectional analysis for 402 German regions over the aggregated time period 2000-2012. Different from Röhl and von Speicher (2009), however, Rhoden

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[39] For additional details on the institutional setup, the connection to EU structural funds (ERDF) and the budgetary framework of GRW funding, we refer to studies of Alecke et al. (2012, 2013) and Eberle et al. (2019).

[40] Prior empirical GRW studies include Alecke et al. (2012, 2013), Alecke and Untiedt (2007), Blien et al. (2003), Dettmann et al. (2016), Eberle et al. (2019), Eckey and Kosfeld (2005), Eggert et al. (2007), Mitze et al. (2015), Rhoden (2016), Röhl and von Speicher (2009), Schalk and Untiedt (2000) and von Ehrlich and Seidel (2015). Eberle et al. (2019) provide a detailed survey of methods, used data and results of this studies.

(2016) does not find evidence for significant differences in the relation between GRW funding and regional growth across region types with different settlement structure.

Looking beyond the scarce literature on German regional policy, there is a growing international literature that stresses the role of the conditional effects in the working of public funding and transfer programmes (e.g. Becker et al., 2013; Beugelsdijk and Eijffinger, 2005; Breidenbach et al., 2019; Burnside and Dollar, 2000; Cappelen et al., 2003; Ederveen et al., 2006; Fratesi and Perucca, 2014; Gagliardi and Percoco, 2017; Rodríguez-Pose and Garcilazo, 2015, see Table A3.1 for additional information). Most closely related to the scope of this study is the large evaluation literature on EU Structural Funds effectiveness. Ederveen et al. (2006) analyse the conditional effects of EU Structural Funds on national economic growth using institutional quality (institutional quality index, inflation, trust, openness and corruption) as important national context indicator. The authors conclude that EU funding has higher effects in countries with proper institutions, a higher openness and less corruption (Ederveen et al., 2006). Beugelsdijk and Eijffinger (2005) consider the degree of corruption of countries and conclude, different from Ederveen et al. (2006), that the results do not indicate significant effects of the national degree of corruption on GDP growth.

At the regional level, Cappelen et al. (2003) analyse the conditional effects of EU Structural Funds for NUTS1/NUTS2 regions in 10 EU countries over the period 1980 to 1997 by means of changing sample design: Specifically, the authors contrast the estimation results for the full sample of regions with a restricted sample which excludes regions from Spain, Greece and Portugal. The results point to stronger effects of EU Structural Funds in the restricted sample, thus indicating a more efficient use of EU Structural Funds in regions within a more advanced economic environment (Cappelen et al., 2003).

More recent studies on EU Structural Funds effectiveness further refine the use of conditioning factors by employing measures for the absorptive capacity of regions (Becker et al., 2013), regional territorial capital (Fratesi and Perucca, 2014), regional government quality (Breidenbach et al., 2019; Rodríguez-Pose and Garcilazo, 2015) and settlement structure (Gagliardi and Percoco, 2017).[41] Becker et al. (2013) analyse the conditional EU funding effectiveness for NUTS2 regions over three different multi-annual funding periods between 1989 and 2006. As conditioning factor the authors employ different measures for the regions' absorptive capacity, proxied by human capital endowments and the quality of government. The authors find that a sufficient level of regional absorptive capacity is crucial for translating Objective 1 payment from the EU Structural Funds into higher per capita GDP growth and investment rates. Similarly, the authors find that social capital, proxied through voter turnout at European Parliamentary Elections, has a similar conditioning role on the effectiveness of EU regional policy in different regional contexts (Becker et al., 2013).

The findings by Becker et al. (2013) are supported by Fratesi and Perucca (2014) as well as Rodríguez-Pose and Garcilazo (2015) and Breidenbach et al. (2019) indicating that the presence of territorial capital in the region and a high quality of government increase policy effectiveness. Gagliardi and Percoco (2017) show that regional settlement structures also matter for funding efficiency as economic growth triggered by Objective 1 payment is found to be most significant in rural regions close to a city. This result, which points at the role played by access to agglomeration forces in the geographical proximity to large urban agglomerations as a means to productively use

[41] Iammarino et al. (2019) also emphasise the importance of institutions as driver for economic development. Di Cataldo and Monastiriotis (2018) analyse the influence of the congruence between the regional need and fund allocation in the UK. The authors find evidence that a vertical misalignment measure has no influence on regional GDP growth, while a horizontal misalignment measure indicates negative growth effects. They claim to address regional disadvantages by providing more tailored policy measures (Di Cataldo and Monastiriotis, 2018).

funding inputs, is broadly in line with earlier findings for German GRW funding as reported by Röhl and von Speicher (2009).[42]

3.3 Theoretical considerations and research hypotheses

Consistent with the well-established literature on VAR modelling, we deliberately keep the theoretical underpinnings of our regional economic model at a minimum. Specifically, we use elements from growth theory to highlight variable selection and to formulate research hypotheses, while we avoid making (false) assumption on the functional relationship among certain variables in the system. To start with, we specify a regional production function (e.g. Eberle et al., 2019) as

$$Y_i(t) = K_i(t)^{\alpha} H_i(t)^{\beta} Z(t)_i^{\gamma} (A_i(t) L_i(t))^{1-\alpha-\beta-\gamma}. \tag{3.1}$$

In Equation (3.1), $Y_i(t)$ expresses output of region *i* at time period *t*, $H_i(t)$ indicates regional human capital, while $K_i(t)$ and $Z_i(t)$ are private and public physical capital stocks, respectively, $A_i(t)$ denotes the regional level of technology and $L_i(t)$ is labour.[43] Based on Crihfield et al. (1995), diminishing returns to capital are assumed ($\alpha + \beta + \gamma < 1$) and production is homogenous of degree one in $K_i(t)$, $H_i(t)$, $Z(t)_i$ and $L_i(t)$. In addition, technology $A_i(t)$ is considered as public good and labour-augmenting (e.g. Mankiw et al., 1992). By multiplying Equation (3.1) with P_i^{-1}, where P_i defines the economically active population (henceforth workforce), we can state the production function in intensive form as

$$y_i(t) = k_i(t)^{\alpha} h_i(t)^{\beta} z_i(t)^{\gamma} (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma}. \tag{3.2}$$

[42] Most of the above findings for the conditional effects of EU regional policy are also consistent with the broader international literature on funding and transfer programmes (e.g. Burnside and Dollar, 2000, or Suárez Serrato and Wingender, 2016).

[43] Following Eberle et al. (2019), we define $L_i(t)$ as: $L_i(t) = \lambda_i(t) \times P_i(0)e^{n_i t}$. Based on this definition, $P_i(t)$ expresses the economically active population at the age of 15 to 64 years that grows exogenously with the rate n_i and $\lambda_i(t)$ represents the ratio of employed population ($L_i(t)/P_i(t)$), which is constant in the long-run perspective (Eberle et al., 2019).

While Equation (3.2) describes a production process where private and public inputs are combined to create $y_i(t)$, the dynamics of a regional economy is typically much more complex and characterised by mutual feedback relationships. We capture this dynamics by specifying additional functional equations for each input variable included in Equation (3.2). This results in a six variable system including GDP per workforce (y_i), the human (h_i), private physical (k_i) as well as public physical capital (z_i) per workforce, regional technology (A_i) and the employment rate (λ_i).[44]

The central objective of this analysis is to shed light on the *conditional* effects of changes in the GRW investment support to private firms and local public infrastructure on the economic growth dynamics of a regional economic system (implied primary target variables of GRW funding are the private physical and public physical capital investment rates). As the literature review has shown, these differences may chiefly depend on the regions' ability to transform (public) inputs productively into output, in other words, regions should have a sufficiently high absorptive capacity. As Becker et al. (2013) argue, an essential dimension of absorptive capacity relates to the regions' equipment with human capital as a low amount of high skilled workers in the region may cause a low return on public funding: "A particularly interesting source of heterogeneity in transfer treatment response is the *absorptive capacity* of recipients" (Becker et al., 2013, p. 30). A similar argumentation holds for the case of the region's technology level. One way to include these latter effects in the dynamic presentation of a regional economic system, as outlined above, is to extent the underlying equations for private and public physical capital accumulation as stated in Eberle et al. (2019) by an efficiency parameter θ_i as

[44] Interpretable regional data for the physical capital stocks (private and public) and the technological level is unavailable. For this reason, we apply data for private ($s_{k,i}$) and public physical capital investments ($s_{z,i}$) and the patent rate as proxy for the regional technological growth rate (g_i) (e.g. Eberle et al., 2019).

$$\frac{\dot{k}_i}{k_i} = \theta_i \, [s_{k,i} \, (k_i(t)^{\alpha-1} \, h_i(t)^{\beta} \, z_i(t)^{\gamma} \, (A_i(t)\lambda_i(t))^{1-\alpha-\beta-\gamma})] - (n_i+\delta) \tag{3.3}$$

and

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

δ denotes the depreciation rate of k_i and z_i, respectively, and θ_i measures the degree of region *i*'s ability to use investments efficiently, e.g. due to the level of available absorptive capacity. This implies that the real share of saved and invested income $s_{k,i}$ and $s_{z,i}$ depends – among other efficiency enhancing regional conditions – on the region's absorptive capacity: A fully efficient region ($\theta_i = 1$) exploits the complete saved income and follows the predicted growth path of the Solow model (e.g. Mankiw et al., 1992). Conversely, regions with lower levels of absorptive capacity ($\theta_i < 1$) are not able to fully exploit the total saved income due to inefficiencies.

Consequentially, these differences in the growth rate of private and public capital stocks have additional effects on the remaining variables of the system (see Eberle et al., 2019 for a detailed exposition of this issue). In addition, the moderating role of absorptive capacity for a region's development path may also run through additional channels such as efficient learning and knowledge diffusion, thereby affect the regions' technology, employment and output growth (e.g. Roper and Love, 2006).

Taken together, the following hypothesis (*H*) on the role of absorptive capacity for regional economic development can be formulated:

> **H3.1:** *Regional policy has larger effects in regions with higher levels of (technological and entrepreneurial)* ***absorptive capacity*** *as these regions experience higher returns on public and private physical capital investments. Together with further transmission channels such*

as efficient learning and knowledge diffusion, this carries over into positive socio-economic development.

Another strand of the theoretical and empirical growth literature stresses the role of institutional quality and economic freedom as an important conditioning factor for economic development. At the country level, the institutional environment (economic freedom) is found to be a key driver for human capital investment (Feldmann, 2017) and economic growth (e.g. Doucouliagos and Ulubasoglu, 2006, or Williamson and Mathers, 2011). Based on a meta-analysis of the contemporaneous empirical literature on the nexus between economic freedom and growth, Doucouliagos and Ulubasoglu (2006) find evidence for an overall positive direct connection between the national economic freedom and economic growth together with a positive indirect effect running through the stimulation of physical capital. Although institutional characteristics are typically more homogeneous at the regional level, Bologna et al. (2016) for the United States and Spruk and Kešeljević (2018) for Germany have recently shown that a higher regional economic freedom is associated with a higher per capita income and economic growth. Accordingly, it can be expected that economic freedom acts as a similar catalyst for regional economic development as absorptive capacity does, mainly by increasing the regional efficiency in utilising physical investments, labour market capacities and the available knowledge stock. That said, we refer to parameter θ_i in Equation (3.3) also as a proxy for the economic freedom of region *i* and thus we can extend H3.1 to the case of economic freedom as:

H3.2: *Regional policy has larger effects in regions with higher levels of* ***economic freedom*** *as these regions experience higher returns on public and private physical capital investments. Together with further transmission channels such as efficient learning and knowledge diffusion, this carries over into positive socio-economic development.*

3.4 Identification and econometric strategy

3.4.1 Pre-estimation – identification strategy

In the empirical estimations, we aim at comparing the regional economic effects of GRW funding for regions with low and high levels of absorptive capacity and economic freedom. In a first step, we therefore construct composite indicators for both concepts and group regions into subsamples based on the median of both indicators. As a robustness check to this type of regional classification, we also partition regions along the quintiles of the distribution in order detect potential non-linearities in the moderating role of absorptive capacity and economic freedom for funding effectiveness. Moreover, to warrant comparability to previous GRW studies (Röhl and von Speicher, 2009, and Rhoden, 2016), we also group regions into subsamples on the basis of region type categories offered by the *Federal Institute for Research on Building, Urban Affairs and Spatial Development* (BBSR) as an additional robustness check.[45]

In order to measure regional absorptive capacity as a multi-dimensional construct, we follow Becker et al. (2013) who identify regional human capital (education) as a central conditioning factor for the region's ability to efficiently transform inputs into regional output. Additionally, Baldwin and Okubo (2006) argue that the most efficient firms typically tend to sort themselves into urban agglomerations, while public subsidies mainly attract the less efficient firms to relocate to the periphery. Hence, we use the population density as second measure for regional absorptive capacity as we expect that firm productivity is higher in urban compared to rural regions. Similarly, the regional patent intensity and start-up rates in high-tech, medium high-tech manufacturing sectors and knowledge intensive services (KIS) are used as further input factors for the construction

[45] The BBSR groups regions according to their settlement structure in 258 labour market regions (Status: 31.12.2014). 118 (45.74 %) of the labour market regions are classified as urban regions, 61 (23.64 %) as rural regions with some agglomeration tendencies (intermediate regions) and 79 (30.62 %) as rural regions.

of a composite indicator for regional absorptive capacity. We interpret these variables as proxies for the efficient use of knowledge stocks and high business dynamics.

With regard to the measurement of economic freedom, we essentially use the regions' overall tax revenues, regional public debt levels and the share of public employment as key input factors identified in the related literature (e.g. Bologna et al., 2016; Potrafke, 2013; Spruk and Kešeljević, 2018). Additionally, we include voter turnout at federal elections as an indicator related to the regions' social capital, i.e. the predisposition to exert individual rights (Becker et al., 2013). The latter variable can also be linked the large literature on individual rights and economic freedom. While government ideology could be considered as a further source for differences in economic freedom (i.e. right-wing governments are typically found to propagate higher economic freedom), Potrafke (2013) has shown for German federal states that this relationship only holds for West Germany but cannot be extended to East Germany. Since East German regions are significant recipients of GRW funding, we do not include the shares of votes for right-wing parties as an additional indicator in order to avoid a too strong overlap between the policy variable and the conditioning factor.[46]

In order to construct (synthetic) composite indicators for absorptive capacity and economic freedom, we apply principal component analysis (PCA).[47] Groups of regions with high and low levels of absorptive capacity and economic freedom are then partitioned according the moments of the distribution of both indicators (median, quintiles).

[46] Please note that analysing the conditional effects according to a corruption index using regional data for only one country is difficult. On the one hand, the differences within a country are expected to be much smaller as between countries and, on the other hand, it is difficult to collect such data on a small-scale regional level in Germany.

[47] Individual components are normalised to takes values between 0 and 1 prior to PCA application in order to correct for possibly exorbitant variation in the various components (see Spruk and Kešeljević, 2018, for additional information).

3.4.2 Estimation – SpPVAR approach and IRF analysis

Based on this subsampling strategy, we run regressions for each selected group of regions using a six equation SpPVAR model including the following variables (in logarithmic transformation): GRW funding intensity {**lgrw**}, higher education rate {**lhk**}, patent rate {**lpat**}, physical capital investment rate {**linvq**}, employment rate {**lemp**} and GDP per workforce {**lgdp**}. As shown in Eberle et al. (2019), this econometric approach allows us to adequately deal with the system's inherent space-time dynamics, the presence of feedback effects among variables and the existence of indirect impact channels of GRW funding. In its reduced form, each equation of the VAR model for the vector of dependent variables **y** = {**lgrw**, **lhk**, **lpat**, **linvq**, **lemp**, **lgdp**} has the following basic structure

$$\mathbf{y}_{it} = \boldsymbol{\mu}_i + \boldsymbol{\tau}_t + \mathbf{B}_1\,\mathbf{y}_{i,t-1} + \mathbf{B}_2\,\mathbf{W}\mathbf{y}_{i,t-1} + \boldsymbol{\varepsilon}_{it}, \tag{3.4}$$

where $\boldsymbol{\mu}_i$ are region- and $\boldsymbol{\tau}_t$ are time-specific fixed effects (controls, e.g., for the business cycle and macroeconomic shocks), while $\mathbf{B}_1$ $\{\beta_1, \ldots, \beta_6\}$ and $\mathbf{B}_2$ $\{\beta_7, \ldots, \beta_{12}\}$ denotes a set of reduced-form coefficients of the six time- ($\mathbf{y}_{i,t-1}$) and time-space lagged ($\mathbf{W}\mathbf{y}_{i,t-1}$) endogenous variables and $\boldsymbol{\varepsilon}_{it}$ denotes the reduced-form error term (e.g. Eberle et al., 2019 for additional information).[48] In Section 3.6, we will use IRFs together with standard error belts calculated on the basis of Monte Carlo simulations (Love and Zicchino, 2006) to graphically analyse the responses of regional economic variables to a positive (structural) shock in the GRW intensity. We keep the technical description

[48] Regression models are estimated with a bias-corrected fixed-effects estimator (see Everaert and Pozzi, 2007). Please note that the included spatial lag variables $\mathbf{W}\mathbf{y}_{i,t-1}$ are only included to identify unbiased estimates for the time-lagged variables $\mathbf{y}_{i,t-1}$ and spatially indirect effects are not analysed. Moreover, the included spatial lag variable $\mathbf{W}\mathbf{y}_{i,t-1}$ for the of the particular dependent variable is biased in our fixed effects model. Thus, we perform a robustness check by excluding $\mathbf{W}\mathbf{y}_{t-1}$ from the specific dependent variable in the models using the median and BBSR classification for subdivision. The results of the robustness check show that the bias is negligible and does not influence the estimation results and IRF analysis.

of the structural SpPVAR model at a minimum here (a technical exposition is given in Eberle et al., 2019, as a precursor to this analysis).

Finally, it is important to note that we use a structural SpPVAR approach to properly identify policy effects by imposing the following causal ordering of variables in the model

$$\mathbf{lgrw_t} \longrightarrow \mathbf{lhk_t} \longrightarrow \mathbf{lpat_t} \longrightarrow \mathbf{linvq_t} \longrightarrow \mathbf{lemp_t} \longrightarrow \mathbf{lgdp_t}.$$

The arrows indicate the direction of causality. Specifically, variables more on the left side (e.g. GRW funding) are allowed to contemporaneously affect variables to their right (at time *t*), while feedback effects from the latter to the former variables can only take place with a time lag (*t+1*). That said, the chosen causal ordering defines the GRW policy as the most exogenous variable in the regional economic system (provided that funding modalities are unaffected in the very short-run perspective). Likewise, GDP is the most endogenous variable, which is determined by all input factors in period *t*. Feedback effects from GDP to these input factors are only allowed to happen in period *t+1* (e.g. Eberle et al., 2019).

3.4.3 Post-estimation – *t*-tests

In order to detect statistical differences between regional subgroups in the estimated responses to a GRW shock in our SpPVAR model, we run a series of ex-post *t*-tests for each sample period *t* as

$$t_t = \frac{\mathrm{IRF_{low}} - \mathrm{IRF_{high}}}{\sqrt{\frac{\mathrm{sd^2_{low}}}{\mathrm{N_{low}}} + \frac{\mathrm{sd^2_{high}}}{\mathrm{N_{high}}}}}, \tag{3.5}$$

where IRF_{low} is the estimated response in below median regions in *t*, IRF_{high} is the estimated response in above median regions in year *t*; sd_{low} and sd_{high} denote the associated standard deviations (calculated from the simulated error bands) and N_{low} and N_{high} is the number of repetitions (= 200) in the Monte Carlo simulations. While the null hypothesis of these tests is that the estimated IRFs between regions with low and high levels of absorptive capacity (economic freedom) do not differ, a rejection of the null hypothesis indicates that the regional effects of GRW funding are sensitive to the regional context. Our identification and econometric strategy is summarised in Figure 3.1.

Figure 3.1 Summary of identification approach and estimation strategy

Pre-estimation

Principal component analysis (PCA)

Calculation of absorptive capacity and economic freedom indicators
Building of subsamples according to the indicators

Estimation

Estimation of subsample specific VAR models

IRF analysis

Post-estimation

Comparing of subsample specific responses by using t-tests

3.5 Data and PCA analysis

The empirical analysis is conducted for 258 German labour market regions over the time period 2000-2011. Labour market regions have been chosen as units of analysis as they depict the *de facto* administrative level used by German regional policy to decide on the eligibility of GRW funding receipt (Deutscher Bundestag, 2014). Variables used for the SpPVAR specification have been gathered from different data sources as shown in Table A3.2 in the Appendix. All variables are used in logarithmic transformation.

Table 3.1 Summary statistics of variables in SpPVAR model, 2000-2011

Variable	Mean	Standard Deviation	Min	Max
bip	49341.59	12938.38	22936.38	116626.4
emp	0.6141	0.0901	0.3902	0.9473
hk	0.0566	0.0291	0.0155	0.2067
invq	0.0254	0.0167	0.0027	0.2240
pat	0.0067	0.0052	0	0.0356
grw_ind	0.0012	0.0028	0	0.0576
grw_infra	0.0004	0.0014	0	0.0337
grw	0.0016	0.0037	0	0.0761
w_bip	54087.27	12065.66	28247.57	93912.85
w_emp	0.6456	0.0556	0.4803	0.8291
w_hk	0.0700	0.0253	0.0224	0.1649
w_invq	0.0235	0.0092	0.0057	0.0932
w_pat	0.0069	0.0038	0.0004	0.0210
w_grw_ind	0.0010	0.0019	0	0.0179
w_grw_infra	0.0004	0.0008	0	0.0111
w_grw	0.0014	0.0025	0	0.0216

Notes: t = 12; i = 258; N = 3096. Variables are normalised according to Table A3.2. Summary statistics are presented before taking the ln and detrending variables. For estimation, zero values are replaced by a very small number before taking the ln. See Table A3.2 for variable descriptions and source information.

Moreover, we calculate spatial lags for all variables included in the VAR model in order to control for spatial autocorrelation across variables. The employment and human capital rate together with their spatial lags have been detrended as they have shown signs for non-stationarity (see Im et al., 2003 for the applied test procedure). Table 3.1 reports summary statistics for the variables.

A description of the underlying variables used to conduct the synthetic composite indicators for absorptive capacity and economic freedom is given in Table A3.3. In order to ensure the predeterminedness of absorptive capacity and economic freedom as conditioning factor for GRW effectiveness, both composite indicators have been constructed for the initial (pre-)sample period in 2000.[49]

[49] Only the variable public employment is based on observations in 2006 due to a structural break in the public employment statistics and regional voter turnouts are taken from the federal parliament elections in 1998. See Table A3.3 for details.

The PCA-based factor loadings used to construct two composite indicators for absorptive capacity (Z^{AC}) and economic freedom (Z^{EF})[50] are shown below, where ~ indicates that the variables have been standardised:

Z^{AC} = 0.5108 (~ higher education rate) + 0.3893 (~ patent rate) + 0.4315 (~ population density) + 0.2953 (~ start-up rate high-tech sectors) + 0.5605 (~ start-up rate KIS)

Z^{EF} = 0.5549 (~ overall tax revenues) + 0.3772 (~ public debt) - 0.2726 (~ public employment) + 0.6896 (~ voter turnout)

The reported factor loadings are based on the first principal component, which is typically used as the best synthetic indicator that combines or condenses the information originally dispersed over the input factors (e.g. Spruk and Kešeljević, 2018). As the PCA results show, the indicator for the absorptive capacity is positively correlated with all input factors in 2000, where the highest weights are given to the regions' human capital endowment and KIS start-up rate. In line with Spruk and Kešeljević (2018), the PCA results for economic freedom show that the synthetic indicator positively correlates with tax revenues, public debt levels and voter turnout, while higher levels of public employment are associated with a lower degree of economic freedom. Moreover, if we calculate a simple correlation coefficient ρ for both indicator scores, the result ($\rho = 0.3901$) shows that this correlation is positive but small and thus that both indicates capture different dimensions of regional context conditions.

The regional absorptive capacity is primarily high in urban labour market regions – such as Berlin, Munich, Hamburg, Frankfurt (Main) or Düsseldorf – while rural labour markets bring out lower

[50] Due to data issues (see Table A3.3), factor loadings are calculated without the labour market regions Hamburg, Bremen, Bremerhaven and Berlin.

levels of absorptive capacity. Conversely, the economic freedom indicator emphasises considerable differences between Eastern and Western German labour markets, with a dominant concentration of higher levels of economic freedom in Western Germany (see Figure A3.1).

3.6 Empirical results

The presentation of empirical results is primarily based on a graphical IRF analysis. Statistical inference can be made on the basis of the plotted standard error belts. By partitioning our sample as outlined above, the main focus rests on a comparison of economic responses to a one-period GRW shock in regions with high (blue lines) and low (grey lines) indicator values. It is important to note that the initial GRW shock at time $t = 0$ is measured in terms of a positive, one-period increase in the GRW funding intensity by one standard deviation (henceforth: GRW shock).[51] This implies that GRW shocks are subsample-specific. However, when we use *t*-test to detect systematic differences in the estimated responses across groups, we work with “comparable” GRW shock as a robustness check (that is, the initial shock for regions in the ‘high’ group is rescaled to equal the percentage shock for regions in the ‘low’ group). We report the empirical results for regional economic responses to changes in the overall GRW funding intensity here; separate estimation results for disaggregated funding volumes of GRW industry and GRW infrastructure support can be found in the Appendix. The main findings of our IRF analysis, based on the estimated SpPVAR model, are summarised in Table 3.2 and will be discussed in the following.

[51] Responses are measured relative to the standard deviation (in %).

Table 3.2 Summary of statistically significant findings from IRF analysis in SpPVAR model

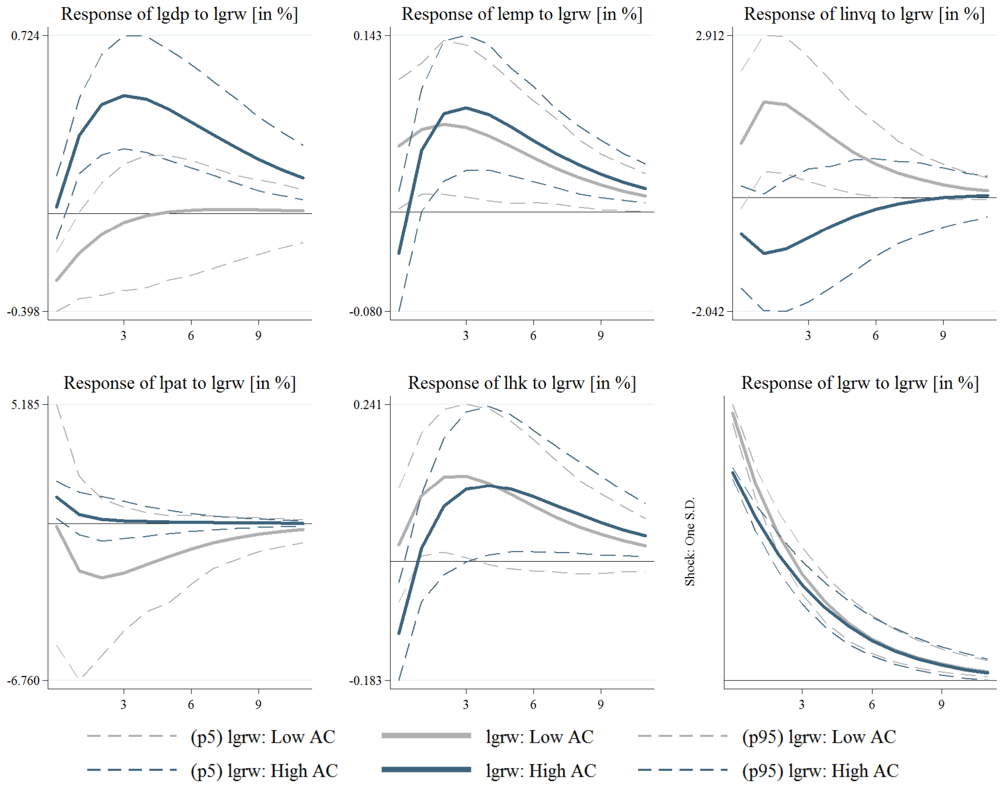
			lgdp	**lemp**	**linvq**	**lpat**	**lhk**
Absorptive Capacity	**GRW industry funding**	Low AC	-	+	+		
		High AC	+	+	-	+	-
		Diff. (see Table A3.4)	**H**		**L**		L
	GRW infrastructure funding	Low AC		+		-	+
		High AC	+	+			+
		Diff. (see Table A3.4)	H		L	H	
	Overall GRW funding	Low AC	-	+	+		+
		High AC	+	+		+	- +
		Diff. (see Table A3.4)	**H**	L	**L**		L
Economic Freedom	**GRW industry funding**	Low EF	-		+	-	+
		High EF	+	+		+	
		Diff. (see Table A3.5)	**H**	**H**	**L**	**H**	
	GRW infrastructure funding	Low EF			+	-	+
		High EF	+	+	-		+
		Diff. (see Table A3.5)		H	**L**		
	Overall GRW funding	Low EF	-		+	-	+
		High EF	+	+		+	
		Diff. (see Table A3.5)	**H**	**H**	**L**	**H**	

Notes: + indicates short-term (less than 4 years during the considered time period) and + long-term (at least 4 years) *significant* positive effects, - indicates short-term and - long-term *significant* negative effects. L denotes short-term (less than 4 years during the considered time period) and **L** long-term (at least 4 years) *significant* higher economic responses in regions with a low indicator score, H (short-term) and **H** (long-term) indicates *significant* higher economic responses in regions with a high indicator score.

3.6.1 Absorptive capacity

Figure 3.2 illustrates the regional economic responses to a one-period shock (increase) in the overall GRW funding intensity for regions with high and low levels of absorptive capacity (median classification). The reactions of the employment and human capital rate to a one-period increase in overall GRW funding are quite similar for type of regions (blue and grey lines in Figure 3.2): we observe a statistically significant increase in the employment rate and a positive response in the region's human capital rate. Hence, higher intensities of overall GRW funding are associated with a higher employment and human capital rate – independent of the absorptive capacity in the regions. When we test for significant differences in the response rate across regions with high and low absorptive capacity, the results from period-specific *t*-tests point at a higher response of the employment and human capital rate for regions with low absorptive capacity in the short run (Table A3.4).

Figure 3.2 IRFs for one-period shock in overall GRW intensity, high/low levels of absorptive capacity (AC)

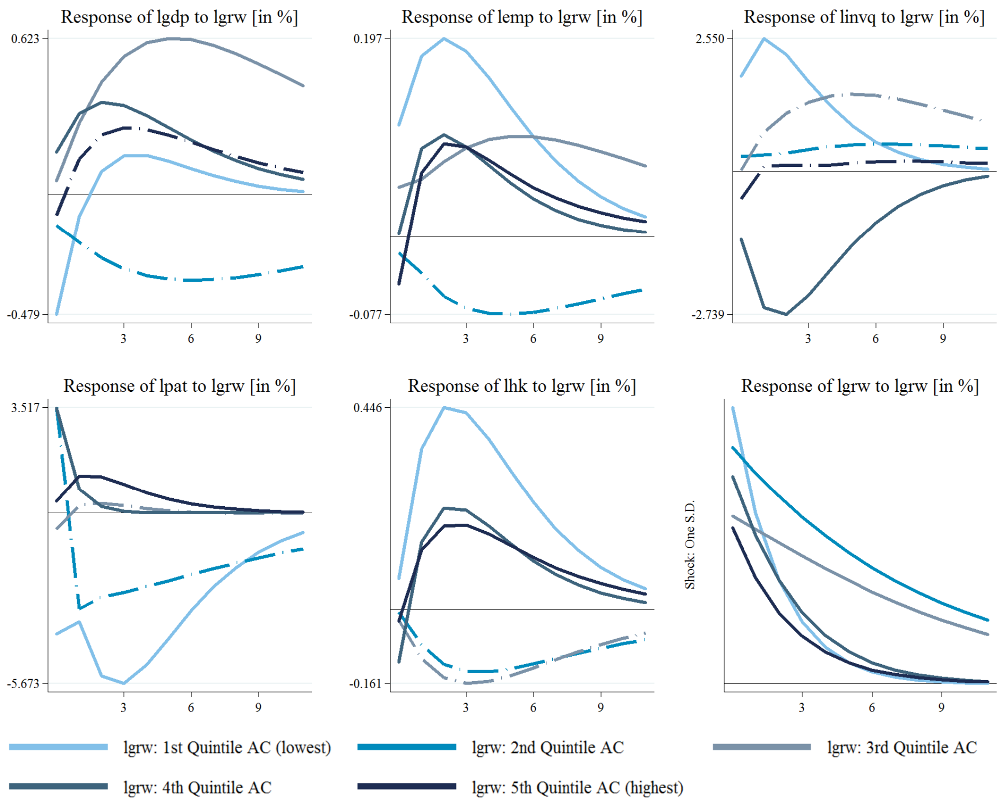


Notes: The solid lines illustrate the estimated IRF for each subsample and the corresponding dashed lines show the 95% confidence intervals that were calculated by performing Monte Carlo simulations with 200 repetitions. Subsamples are portioned by the median value of absorptive capacity. The associated regression results of the underlying SpPVAR models are available upon request.

In regions with high absorptive capacity, an increase in the overall GRW funding is further associated with a significant increase in the region's GDP per workforce and the patent activity. Conversely, overall GRW funding appears to trigger private investments only in regions with low levels of absorptive capacity. This IRF heterogeneity hints at the fact that alternative transmission channels of funding operate in different regional contexts: While a traditional funding channel, mainly running through an increase in the private sector investment rate, play a dominant role in regions with a low absorptive capacity, regions with a high absorptive capacity mainly benefit through a knowledge-based funding channel, which also appears to increase the region's GDP. Finally, the results of the *t*-test analysis underline significant differences in the responses of the GDP per workforce and the investment rate across regions with high and low levels of absorptive capacity (see Table A3.4 in the Appendix for details).

In order to better identify potential non-linearities in the moderating role of absorptive capacity for regional GRW funding effects, we also classify regions in five subgroups according to the quintiles of the indicator's distribution. This allows us to gain more insights into the effectiveness of GRW funding in different regional contexts. We focus on a graphical presentation of the results for a one-period shock in the overall GRW intensity and reduce the information content in Figure 3.3 (i.e. solid lines denote statistically significant responses, while the non-solid lines indicate non-significant responses). The quintile-based subsample estimation results confirm the main results from above and additionally provide some refined information. First, again all significant findings for effects on employment rate and human capital are positive. However, insignificant effects are rather found in the middle quintiles (the second and third quintile for human capital and second quintile for the employment rate). This suggests that GRW funding increases employment and human capital especially in regions with very low or very high absorptive capacity through different transmission channels. The quintile-based findings for the response of private investment and patent activity also match with our above findings: Private investment is triggered by GRW funding only in the regions with the lowest absorptive capacity, while it has a negative impact on regions of the fourth quintile (high absorptive capacity). The regional patent activity appears to benefit from GRW funding in regions with high absorptive capacity (fourth and fifth quintile) and is negatively correlated with GRW funding in regions with very low absorptive capacity.

Figure 3.3 Quintile-based IRFs for one-period shock in overall GRW intensity, absorptive capacity (AC)



Notes: The solid lines illustrate statistically significant IRFs, while the dashed lines illustrate statistically non-significant IRFs. The associated regression results of the underlying SpPVAR models are available upon request.

The results for the response of GDP are mixed. At least, we find significant positive effects (third and fourth quintile) or no significant effects, so that GRW funding is, with exception of quintile 2, in sum positively correlated with regional GDP development.[52] There is no clear tendency in the differences between the subsamples so that we avoid over-interpreting these results. However, carefully speaking, the findings indicate that traditional funding channels which mainly target the firms' physical investment rate as intermediate output variable are rather less effective compared to knowledge-based funding channels.

[52] Please note that the response is significant negative in the year of the funding increase for the first quintile.

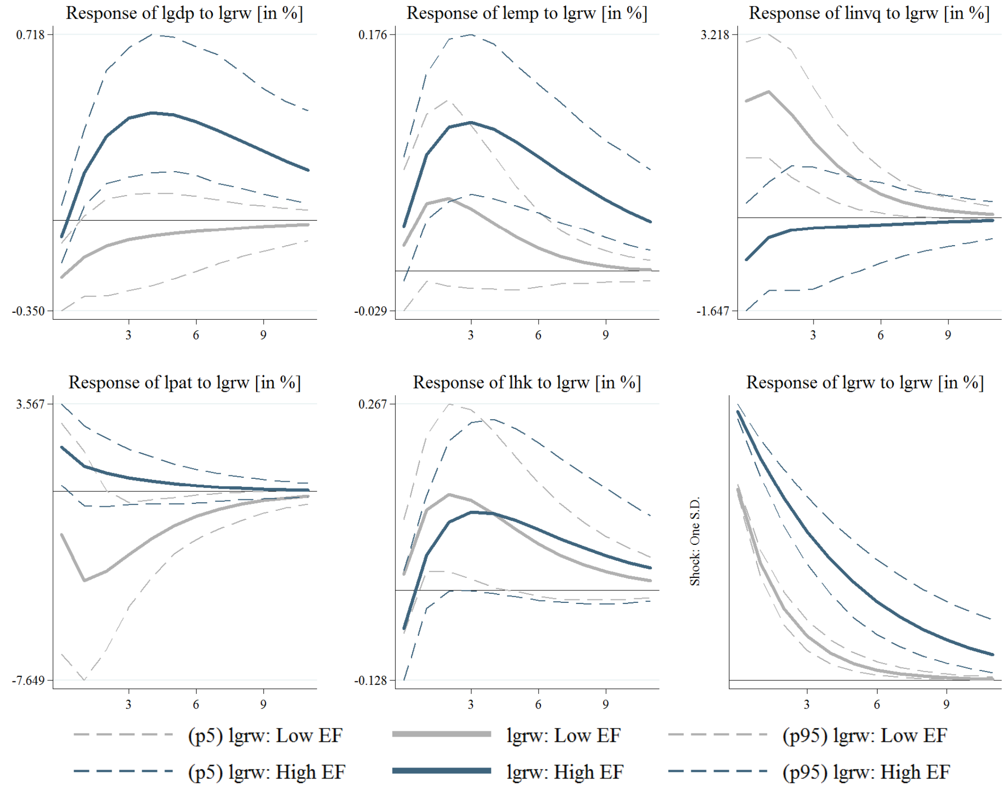
Our findings for the two GRW policy fields in focus (GRW industry and infrastructure support) reveal only little differences in the underlying transmission channels: That is, GRW industry funding has a larger impact on private investment and the region's patent activity, while GRW infrastructure funding is mainly associated with a rise in the region's human capital intensity. Both components of GRW funding influence GDP and employment in a similar way (see Figure A3.2 in the Appendix for details).

3.6.2 Economic freedom

If we separate regions according to high and low levels of economic freedom (median classification), the IRF results in Figure 3.4 show that we only observe a moderate level of group heterogeneity in the effects of a GRW shock on employment and human capital. Specifically, we observe that the estimated IRFs are positive for both groups, although the effects on the employment rate are statistically insignificant for regions with low economic freedom and also significantly lower compared to regions with a high level of economic freedom (see *t*-tests in Table A3.5 for details).

Moreover, the effects on GDP, patent activity and private investment differ significantly across groups: overall GRW funding has a significant positive effect on GDP and the patent activity in regions with high economic freedom, while it has a positive effect on private investment and negative effect on patent activity in regions with low economic freedom (Figure 3.4). These differences are also emphasised by the *t*-test analysis, which reveals that the magnitudes of the estimated responses differ significantly across the subgroups (Table A3.5). In terms of the direction of effects, the IRF results are quite similar to the finding for absorptive capacity, although the regions in the subsamples are quite different. This is an interesting outcome of our estimations and will be further discussed below.

Figure 3.4 IRFs for one-period shock in overall GRW intensity, high/low levels of economic freedom (EF)



Notes: The solid lines illustrate the estimated IRF for each subsample and the corresponding dashed lines show the 95% confidence intervals that were calculated by performing Monte Carlo simulations with 200 repetitions. Subsamples are portioned by the median value of economic freedom. The associated regression results of the underlying SpPVAR models are available upon request.

Figure 3.5 reports quintile-specific IRFs for a shock in the overall GRW intensity when the degree of economic freedom varies across quintiles. Similar to the findings for subgroups according to absorptive capacity, the employment rate benefits from GRW funding especially in regions with very high and very low economic freedom. Regions with high values in both indicators – absorptive capacity and economic freedom – are West German regions, while the regions with low values in both indicators are mainly the economically weak regions in East Germany together with East Bavaria. These regions seem to benefit most from GRW funding in terms of a rising employment rate.

In contrast to the subsample results for absorptive capacity, however, only regions with a low level of economic freedom show a statistically significant positive correlation between GRW funding and the human capital rate. The IRFs for regions with higher economic freedom are similar in size but statistically insignificant. Statistically significant positive effects on the patent activity arise only in the fifth quintile (highest economic freedom), while the effects are negative in the lowest three quintiles (significant for the lowest quintile). Thus, in East Bavaria and in regions in East Germany with low values in both indicators, GRW funding has negative effects on the patent activity, while the patent activity is increased especially in supported West German regions.

GRW funding and GDP per workforce are positively associated mainly in regions with high economic freedom.[53] In combination with the observed patterns for the absorptive capacity classification, GRW funding is positively associated with GDP development in regions in West Germany; however, positive effects may also arise in East German regions with low economic freedom when the level of absorptive capacity is sufficiently high.

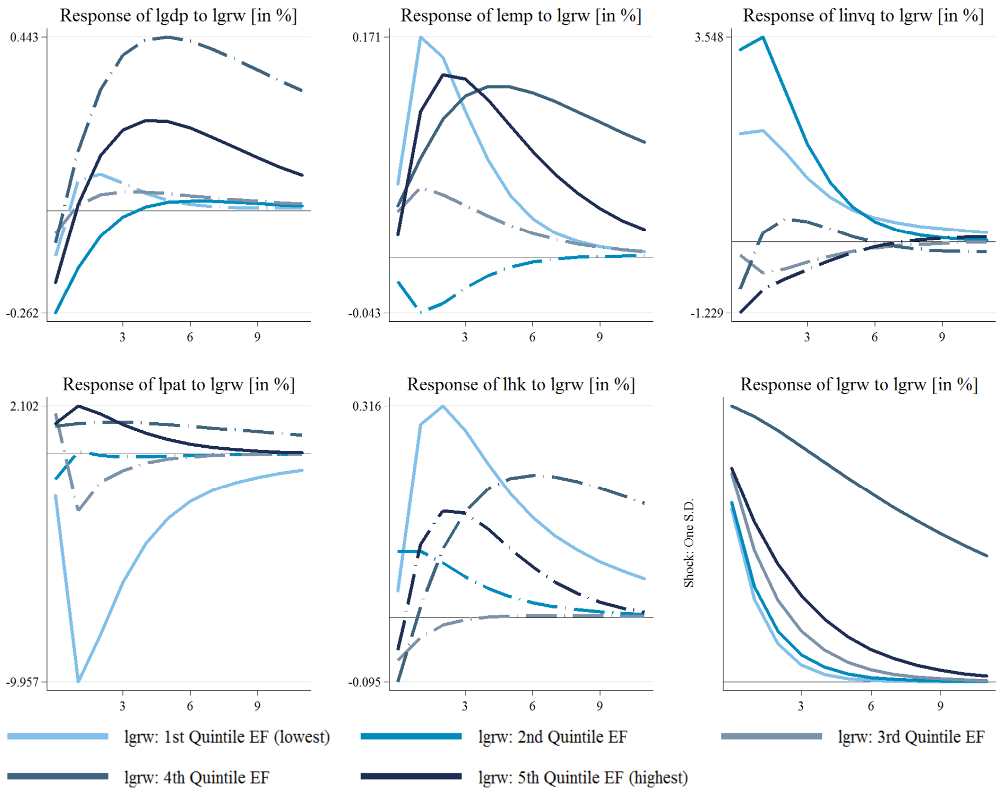
An opposite empirical picture emerges for the response of private investment to GRW funding conditional on the observed level of economic freedom: Here, only regions with lower economic freedom seem to benefit, significant positive effects are only found for the two lowest quintiles. Combining this with the result that GRW funding increases private investments most in regions with very low absorptive capacity, the economically weak regions in West Germany (North-East of Bavaria) and regions with low absorptive capacity and economic freedom in East Germany seem to benefit most in this way.

Regarding disaggregated results for GRW industry and infrastructure funding, we again find only little differences in the working of the two main pillars of German regional policy: the effects on GDP per workforce, the employment rate and, different to the analysis using the classification

[53] Please note that the response is significant negative in the year of the funding increase for the fifth quintile.

according to the absorptive capacity, the investment rate are very similar for both policy instruments. However, only GRW industry funding has a significant positive effect on the region's patent activity, while GRW infrastructure funding affects the human capital rate in both subsamples (see Figure A3.3).[54]

Figure 3.5 Quintile-based IRFs for one-period shock in overall GRW intensity, economic freedom (EF)



Notes: The solid lines illustrate statistically significant IRFs, while the dashed lines illustrate statistically non-significant IRFs. The associated regression results of the underlying SpPVAR models are available upon request.

[54] We have also used a classification of regions according to their settlement structure as an additional robust check (Figure A3.4 in the Appendix). For the most part, the empirical results support a significant regional heterogeneity as indicated by differences in absorptive capacity and economic freedom. The findings show that the private sector investment rate is positively affected only for rural regions (all GRW funding measures) and negative in urban regions for GRW infrastructure funding, while human capital is positively affected especially in intermediate regions (applies for all GRW funding measures). The employment rate is positively affected by all kinds of GRW funding in urban and rural regions (GRW infrastructure funding). Finally, the patent activity is positively correlated with GRW funding in urban or intermediate regions. GRW funding only has a significant positive effect on the regional GDP per workforce in urban regions.

3.7 Conclusions and policy implications

This paper has analysed the role of regional absorptive capacity and economic freedom for the ability of regions to use regional policy funding effectively for economic development. We have used data for Germany's most important regional policy instrument, the "Joint Task for the Improvement of Regional Economic Structures" in the period 2000-2011 for our empirical investigation. In the empirical analysis, we have applied a structural SpPVAR approach and have used associated IRF analysis to track the effects of regional policy on the functioning of a regional economic system for various subsamples of region types. These subsamples have been created on the basis of moments (median, quintiles) of the distribution for two synthetic composite indicators proxying regional absorptive capacity and economic freedom. Moreover, we have used ex-post *t*-tests to determine significant differences between the estimated average responses across subsamples.

Our empirical results shed new light on the multifaceted dimension of the GRW policy and underline the importance of regional context conditions for policy effectiveness. While we find evidence for the working of a traditional funding channel for regions with low levels of absorptive capacity and economic freedom, mainly working through an increased investment rate, no evidence is found for growth enhancing effects of this transmission channel in these regions (e.g. measured in terms of GDP per workforce). In contrast, GRW funding is found to boost GDP per workforce through a knowledge-based funding channel in regions with a high absorptive capacity and economic freedom. Furthermore, both kinds of regions show a higher employment rate as a reaction to GRW funding, but this effect is strongest in the regions with high and very low indicator values for absorptive capacity and economic freedom. In general, our findings hint at the complementary role of both composite indicators as fertile soil for policy effectiveness.

Based on the empirical findings, we see two main policy implications. First, GRW is a multifaceted policy that i) affects several economic variables simultaneously and ii) has heterogeneous effects in different regional contexts. Accordingly, an assessment of the effective use of public funding chiefly depends on the specific policy objective in focus. However, the results of our structural SpPVAR suggest that traditional policy impact channels of German regional policy (e.g. via increased private sector investment rates) are less effective to stimulate regional economic growth compared to knowledge-based transmission channels. The latter funding channel is particularly significant for regions with a high level of absorptive capacity and economic freedom.

Secondly, in times of decreasing GRW funding volumes, regional context factors, including the absorptive capacity and economic freedom, should come to the fore of policy makers as a fertile ground for the implementation of policy objectives. As such, proper institutional designs and initiatives that are able to positively affect these context conditions may yield a higher return to public spending than compensating for lack of these regional 'assets' through large-scale funding schemes. While good-functioning regional institutions, educational opportunities, low bureaucratic hurdles, a dynamic entrepreneurship community and a local civil society can surely contribute to such positive regional context conditions, more research is needed to fully understand the fundamental mechanisms that drive their interplay with policy instruments to support the socio-economic development of regions in the long run.

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A3. Appendix

Table A3.1 Recent empirical studies on the conditional effects of investment and transfer programmes

Authors	Policy	Geographical scale	Conditional effects are measured by	Conditional effects
Röhl and von Speicher (2009)	GRW	Regional (Germany)	Four different types of agglomeration (settlement structure)	Highest effects in agglomerations, followed by rural areas.
Rhoden (2016)	GRW	Regional (Germany)	Four different types of agglomeration (settlement structure)	No different effects in different types of agglomeration.
Cappelen et al. (2003)	EU Structural Funds	Regional (Europe)	Economic environment: less developed regions from Spain, Greece and Portugal are excluded in a reduced sample estimation	Higher effects in economic more advanced regions.
Beugelsdijk and Eijffinger (2005)	EU Structural Funds	National (Europe)	Corruption index	No higher effects in less corrupt countries.
Ederveen et al. (2006)	EU Structural Funds	National (Europe)	Institutional quality index, inflation, trust, openness and corruption	Higher effects in countries with adequate institutions.
Becker et al. (2013)	EU Structural Funds	Regional (Europe)	Absorptive capacity, quality of government	Higher effects in regions with an adequate absorptive capacity (human capital endowment, quality of government)
Fratesi and Perucca (2014)	EU Structural Funds	Regional (Central and Eastern Europe)	Territorial capital	A higher regional territorial capital increases the effectiveness of structural funds regarding GDP growth.
Rodríguez-Pose and Garcilazo (2015)	EU Structural Funds	Regional (Europe)	Quality of government	Beyond a certain threshold, quality of government increases the efficacy of regional structural funds.
Gagliardi and Percoco (2017)	EU Structural Funds	Regional (Europe)	Settlement structures	The effects of EU Objective 1 investments on GDP per capita is higher in intermediate as well as rural regions that are located close to a city.
Breidenbach et al. (2019)	EU Structural Funds	Regional (Europe)	Institutional (government) quality	Positive correlation between the funding effects and government quality.
Burnside and Dollar (2000)	Foreign aid	National (Latin America. Asia and Africa)	Index of Openness, budget surplus and inflation rate	Higher effects in countries with a good policy environment.
Suárez Serrato and Wingender (2016)	Federal spending United States	Counties (Unites States)	Faster- and slower-growing counties	Higher returns to federal spending on income and employment in poorer counties.

Table A3.2 Variables description and data sources variables used in SpPVAR analysis

Variable	Description	Data source
lgdp	Nominal GDP per economically active working population defined as: [GDP in € / (Population aged 15 to 64 years × Participation rate)] Note: Population data is based on the census 1987. Till 2011, the participation rate is based on the same population data. From 2011, the participation rate is calculated based on population data of the census 2011.	GDP: Arbeitskreis "Volkswirtschaftliche Gesamtrechnungen der Länder" (Status: August 2015) Population aged 15 to 64 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 physical capital investment rate (industry investments in the manufacturing, mining and quarrying sector) defined as: [Industry Investments in € / GDP in €] Note: Missing values are 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 defined as: [Employees with university degree / (Population aged 15 to 64 years × Participation rate)] Note: We assume that possible data imperfections regarding the qualification of employees are random.	Institute for Employment Research (IAB), Nuremberg
lemp	Employment rate defined as: [Employees total / (Population aged 15 to 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lpat	Patent rate 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) defined as: [GRW funding volumes in € / GDP in €]	Federal Office for Economic Affairs and Export Control (BAFA)
w_X (controls)	Spatial lags are calculated using the STATA command *splagvar* (in absolute values for each variable). After that, the constructed spatial lag variables are normalised and ln-transformed identical to the non-spatial variables.	

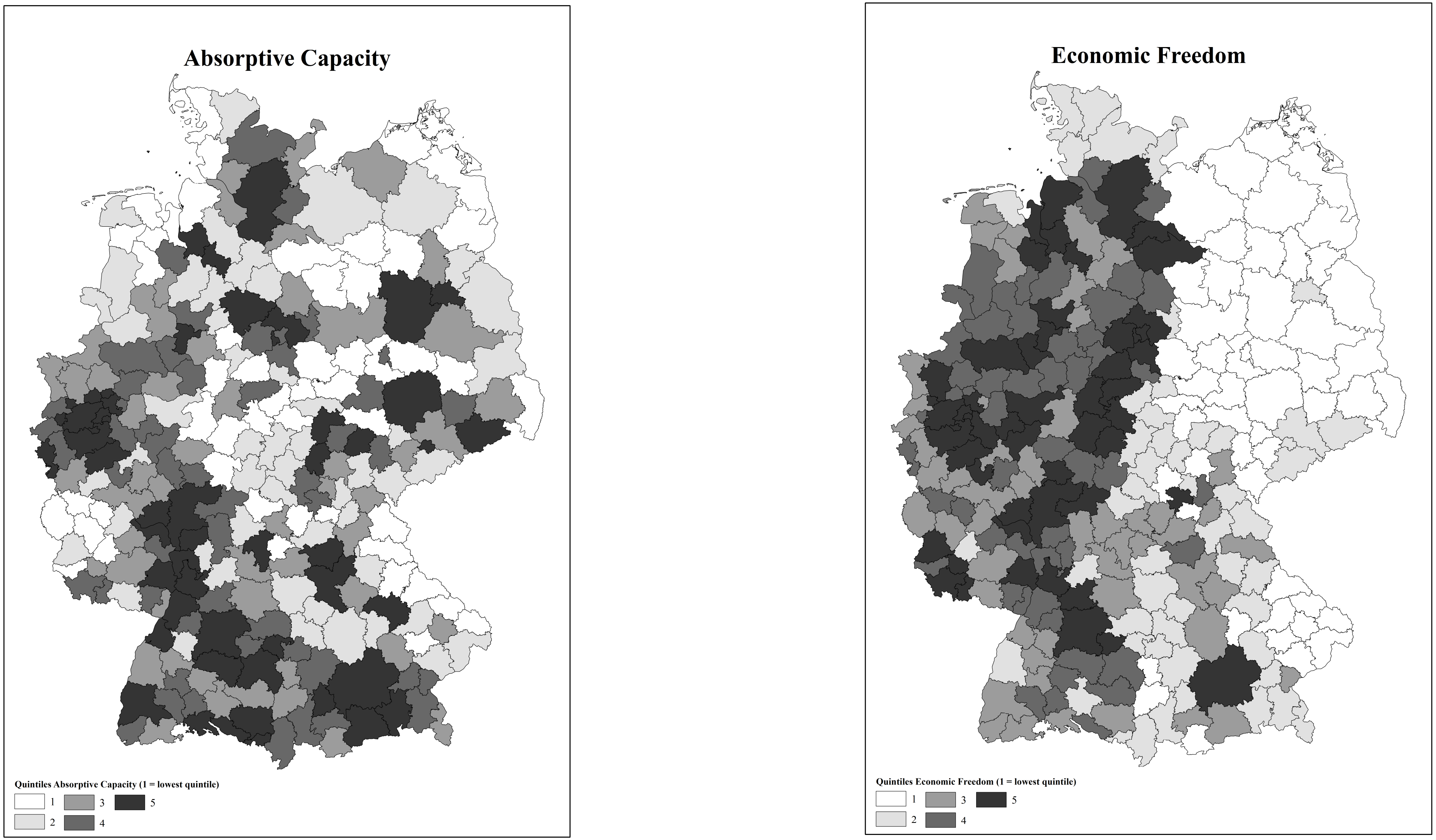
Notes: All variables are used in logarithmic transformation.

Table A3.3 Variables description and data sources used for PCA analysis

Variable	Description	Data source
	Absorptive Capacity	
Higher education rate	Employees with university degree / (Population aged 15 to 64 years × Participation rate)	see Table A3.2
Patent rate	Patents / GDP in Mio. €	see Table A3.2
Population density	(Population aged 15 to 64 years × Participation rate) / area (in km^2)	Area in km^2: Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR)
Start-up rate high-technology and medium-high-technology sectors	Start-ups high-technology and medium-high-technology sectors / (Population aged 15 to 64 years × Participation rate)	Mannheimer Unternehmenspanel (2015), Centre for European Economic Research (ZEW)
Start-up rate total knowledge intensive activities sectors	Start-ups total knowledge intensive activities sectors / (Population aged 15 to 64 years × Participation rate)	Mannheimer Unternehmenspanel (2015), Centre for European Economic Research (ZEW)
	Economic Freedom	
Overall tax revenues	Overall tax revenue in € / population	Realsteuervergleich des Bundes und der Länder / Indikatoren und Karten zur Raum und Stadtentwicklung (INKAR)
Public debts*	Reserve bank credit in € / population	Statistik über Schulden des Bundes und der Länder / Indikatoren und Karten zur Raum und Stadtentwicklung (INKAR) Amt für Statistik Berlin-Brandenburg
Public employment*	Employees of the municipality / population (10.000)	Personalstandsstatistik der Länder, Gemeinden und Gemeindeverbände / Indikatoren und Karten zur Raum und Stadtentwicklung (INKAR) Statistische Ämter des Bundes und der Länder
Voter turnout	Second votes / people eligible to vote (in %)	Allgemeine Bundestagswahlstatistik des Bundes und der Länder / Indikatoren und Karten zur Raum und Stadtentwicklung (INKAR)

Notes: * No data is available for the districts of the city states Hamburg, Bremen and Berlin. The labour market regions Hamburg, Bremen and Bremerhaven comprise more administrative districts than the particular city district itself, for which reason interpretable values exist for these labour market regions (underestimation is possible). To approximate values for Berlin, public employment includes employees of municipalities and of the federal state, while the public debts are measured for the federal state Berlin. Please note that the labour markets regions comprising city states are excluded for the calculation of the factor loadings.

Figure A3.1 Distribution of absorptive capacity and economic freedom across German labour market regions (quintiles)



Notes: Own calculations. See main text and Table A3.3 for details on composite indicator calculation. Quintiles of distribution are shown for 258 local labour markets in Germany.

Table A3.4 *t*-tests for differences in the estimated average response to a GRW shock between regions with high and low levels of absorptive capacity

Initial GRW shock in subsamples: one *sample-specific* standard deviation													
		GRW industry funding				GRW infrastructure funding				Overall GRW funding			
Time	**Re-sponse var.**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	1.8602	**0.0318**	0.9682	0.0636	1.5036	0.0667	0.9333	0.1335	1.9375	**0.0267**	0.9733	0.0534
1	lhk	1.0205	0.1540	0.8460	0.3081	1.0968	0.1367	0.8633	0.2734	1.0657	0.1436	0.8564	0.2872
2	lhk	0.5364	0.2960	0.7040	0.5920	0.8274	0.2042	0.7958	0.4085	0.4903	0.3121	0.6879	0.6242
3	lhk	0.3586	0.3601	0.6399	0.7201	0.6702	0.2516	0.7484	0.5031	0.2036	0.4194	0.5806	0.8387
4	lhk	0.2587	0.3980	0.6020	0.7960	0.5427	0.2938	0.7062	0.5877	0.0328	0.4869	0.5131	0.9739
5	lhk	0.1985	0.4214	0.5786	0.8428	0.4267	0.3349	0.6651	0.6699	-0.0844	0.5336	0.4664	0.9328
6	lhk	0.1552	0.4384	0.5616	0.8767	0.3317	0.3701	0.6299	0.7403	-0.1755	0.5696	0.4304	0.8608
7	lhk	0.1228	0.4512	0.5488	0.9024	0.2352	0.4071	0.5929	0.8142	-0.2498	0.5986	0.4014	0.8028
8	lhk	0.0958	0.4619	0.5381	0.9238	0.1486	0.4410	0.5590	0.8820	-0.3081	0.6209	0.3791	0.7581
9	lhk	0.0762	0.4697	0.5303	0.9393	0.0716	0.4715	0.5285	0.9430	-0.3506	0.6369	0.3631	0.7261
10	lhk	0.0605	0.4759	0.5241	0.9518	0.0027	0.4989	0.5011	0.9979	-0.3926	0.6526	0.3474	0.6949
11	lhk	0.0488	0.4805	0.5195	0.9611	-0.0570	0.5227	0.4773	0.9546	-0.4229	0.6637	0.3363	0.6726
12	lhk	0.0409	0.4837	0.5163	0.9674	-0.1065	0.5424	0.4576	0.9152	-0.4357	0.6683	0.3317	0.6633
0	lpat	0.1891	0.4251	0.5749	0.8501	-1.6751	0.9526	**0.0474**	0.0947	-0.3923	0.6525	0.3475	0.6950
1	lpat	-0.6377	0.7380	0.2620	0.5240	-1.2411	0.8924	0.1076	0.2153	-0.8929	0.8138	0.1862	0.3725
2	lpat	-0.8812	0.8106	0.1894	0.3788	-2.4348	0.9923	**0.0077**	**0.0153**	-1.1873	0.8821	0.1179	0.2358
3	lpat	-1.0421	0.8510	0.1490	0.2980	-2.0881	0.9813	**0.0187**	**0.0374**	-1.3346	0.9086	0.0914	0.1828
4	lpat	-1.1342	0.8713	0.1287	0.2574	-1.6115	0.9461	0.0539	0.1079	-1.3745	0.9150	0.0850	0.1701
5	lpat	-1.1731	0.8793	0.1207	0.2415	-1.2925	0.9015	0.0985	0.1969	-1.2563	0.8951	0.1049	0.2097
6	lpat	-1.1640	0.8774	0.1226	0.2451	-1.0759	0.8587	0.1413	0.2826	-1.2338	0.8910	0.1090	0.2180
7	lpat	-1.1324	0.8709	0.1291	0.2581	-0.9229	0.8217	0.1783	0.3566	-1.2355	0.8913	0.1087	0.2174
8	lpat	-1.0536	0.8537	0.1463	0.2927	-0.8150	0.7922	0.2078	0.4155	-1.1426	0.8731	0.1269	0.2539
9	lpat	-1.0145	0.8445	0.1555	0.3110	-0.6935	0.7558	0.2442	0.4884	-1.0793	0.8594	0.1406	0.2811
10	lpat	-0.9847	0.8373	0.1627	0.3254	-0.6017	0.7261	0.2739	0.5477	-0.9741	0.8347	0.1653	0.3306
11	lpat	-0.9429	0.8268	0.1732	0.3463	-0.5400	0.7052	0.2948	0.5895	-0.8788	0.8100	0.1900	0.3800
12	lpat	-0.8474	0.8013	0.1987	0.3973	-0.5132	0.6959	0.3041	0.6081	-0.7874	0.7843	0.2157	0.4315
0	linvq	1.5773	0.0578	0.9422	0.1155	0.4656	0.3209	0.6791	0.6417	1.7512	**0.0403**	0.9597	0.0807
1	linvq	3.2298	**0.0007**	0.9993	**0.0013**	1.7014	**0.0448**	0.9552	0.0897	2.7944	**0.0027**	0.9973	**0.0055**
2	linvq	2.9540	**0.0017**	0.9983	**0.0033**	1.5803	0.0574	0.9426	0.1148	2.5168	**0.0061**	0.9939	**0.0122**
3	linvq	2.7199	**0.0034**	0.9966	**0.0068**	1.2691	0.1026	0.8974	0.2052	2.1385	**0.0165**	0.9835	**0.0331**
4	linvq	2.3913	**0.0086**	0.9914	**0.0173**	0.8002	0.2120	0.7880	0.4241	1.8203	**0.0347**	0.9653	0.0695
5	linvq	2.0586	**0.0201**	0.9799	**0.0402**	0.3376	0.3679	0.6321	0.7358	1.4800	0.0698	0.9302	0.1397
6	linvq	1.7099	**0.0440**	0.9560	0.0881	-0.0005	0.5002	0.4998	0.9996	1.2155	0.1124	0.8876	0.2249
7	linvq	1.4258	0.0773	0.9227	0.1547	-0.2213	0.5875	0.4125	0.8250	1.0082	0.1570	0.8430	0.3140
8	linvq	1.1859	0.1182	0.8818	0.2364	-0.3332	0.6304	0.3696	0.7391	0.7954	0.2134	0.7866	0.4269
9	linvq	0.9677	0.1669	0.8331	0.3338	-0.4110	0.6593	0.3407	0.6813	0.6210	0.2675	0.7325	0.5350
10	linvq	0.7716	0.2204	0.7796	0.4408	-0.4520	0.6743	0.3257	0.6515	0.4719	0.3186	0.6814	0.6372
11	linvq	0.6126	0.2702	0.7298	0.5405	-0.4561	0.6757	0.3243	0.6486	0.3337	0.3694	0.6306	0.7388
12	linvq	0.4712	0.3189	0.6811	0.6377	-0.4598	0.6770	0.3230	0.6459	0.2197	0.4131	0.5869	0.8262
0	lemp	1.1472	0.1260	0.8740	0.2520	0.3171	0.3757	0.6243	0.7513	2.0216	**0.0219**	0.9781	0.0439
1	lemp	0.1536	0.4390	0.5610	0.8780	-0.8436	0.8003	0.1997	0.3994	0.3738	0.3544	0.6456	0.7088
2	lemp	0.0245	0.4902	0.5098	0.9805	-0.7820	0.7827	0.2173	0.4347	-0.1696	0.5673	0.4327	0.8654
3	lemp	0.0905	0.4640	0.5360	0.9280	-0.5175	0.6974	0.3026	0.6051	-0.3220	0.6262	0.3738	0.7476
4	lemp	0.1895	0.4249	0.5751	0.8498	-0.1940	0.5769	0.4231	0.8462	-0.3700	0.6442	0.3558	0.7116
5	lemp	0.2965	0.3835	0.6165	0.7670	0.0560	0.4777	0.5223	0.9554	-0.3952	0.6535	0.3465	0.6929
6	lemp	0.3780	0.3528	0.6472	0.7056	0.1837	0.4272	0.5728	0.8544	-0.4107	0.6592	0.3408	0.6815
7	lemp	0.4335	0.3325	0.6675	0.6649	0.1949	0.4228	0.5772	0.8456	-0.4232	0.6638	0.3362	0.6724
8	lemp	0.4681	0.3200	0.6800	0.6400	0.1343	0.4466	0.5534	0.8932	-0.4387	0.6694	0.3306	0.6611
9	lemp	0.4718	0.3186	0.6814	0.6373	0.0511	0.4797	0.5203	0.9593	-0.4413	0.6704	0.3296	0.6593
10	lemp	0.4906	0.3120	0.6880	0.6239	-0.0388	0.5154	0.4846	0.9691	-0.4418	0.6706	0.3294	0.6589
11	lemp	0.4966	0.3099	0.6901	0.6197	-0.1204	0.5479	0.4521	0.9042	-0.4371	0.6689	0.3311	0.6623
12	lemp	0.4915	0.3117	0.6883	0.6234	-0.1874	0.5743	0.4257	0.8515	-0.4401	0.6700	0.3300	0.6601
0	lgdp	-2.7546	0.9969	**0.0031**	**0.0061**	-1.3947	0.9181	0.0819	0.1639	-2.8183	0.9975	**0.0025**	**0.0051**
1	lgdp	-3.2450	0.9994	**0.0006**	**0.0013**	-1.7433	0.9590	**0.0410**	0.0821	-3.4058	0.9996	**0.0004**	**0.0007**
2	lgdp	-2.5925	0.9951	**0.0049**	**0.0099**	-1.4597	0.9274	0.0726	0.1452	-2.8523	0.9977	**0.0023**	**0.0046**
3	lgdp	-2.1269	0.9830	**0.0170**	**0.0340**	-1.1979	0.8842	0.1158	0.2317	-2.4665	0.9930	**0.0070**	**0.0141**
4	lgdp	-1.8336	0.9663	**0.0337**	0.0675	-1.0299	0.8482	0.1518	0.3037	-2.1763	0.9849	**0.0151**	**0.0301**
5	lgdp	-1.5990	0.9447	0.0553	0.1106	-0.8923	0.8136	0.1864	0.3728	-2.0342	0.9787	**0.0213**	**0.0426**
6	lgdp	-1.4007	0.9190	0.0810	0.1621	-0.8381	0.7988	0.2012	0.4025	-1.8803	0.9696	**0.0304**	0.0608
7	lgdp	-1.2542	0.8947	0.1053	0.2105	-0.7791	0.7818	0.2182	0.4364	-1.7907	0.9630	**0.0370**	0.0741
8	lgdp	-1.1434	0.8732	0.1268	0.2536	-0.7486	0.7727	0.2273	0.4546	-1.6951	0.9546	**0.0454**	0.0908
9	lgdp	-1.0513	0.8531	0.1469	0.2938	-0.7187	0.7636	0.2364	0.4727	-1.5931	0.9440	0.0560	0.1119
10	lgdp	-0.9846	0.8373	0.1627	0.3254	-0.6833	0.7526	0.2474	0.4948	-1.5008	0.9329	0.0671	0.1342
11	lgdp	-0.9074	0.8176	0.1824	0.3648	-0.6515	0.7424	0.2576	0.5151	-1.4299	0.9232	0.0768	0.1535
12	lgdp	-0.8266	0.7955	0.2045	0.4090	-0.6320	0.7361	0.2639	0.5278	-1.3458	0.9104	0.0896	0.1791

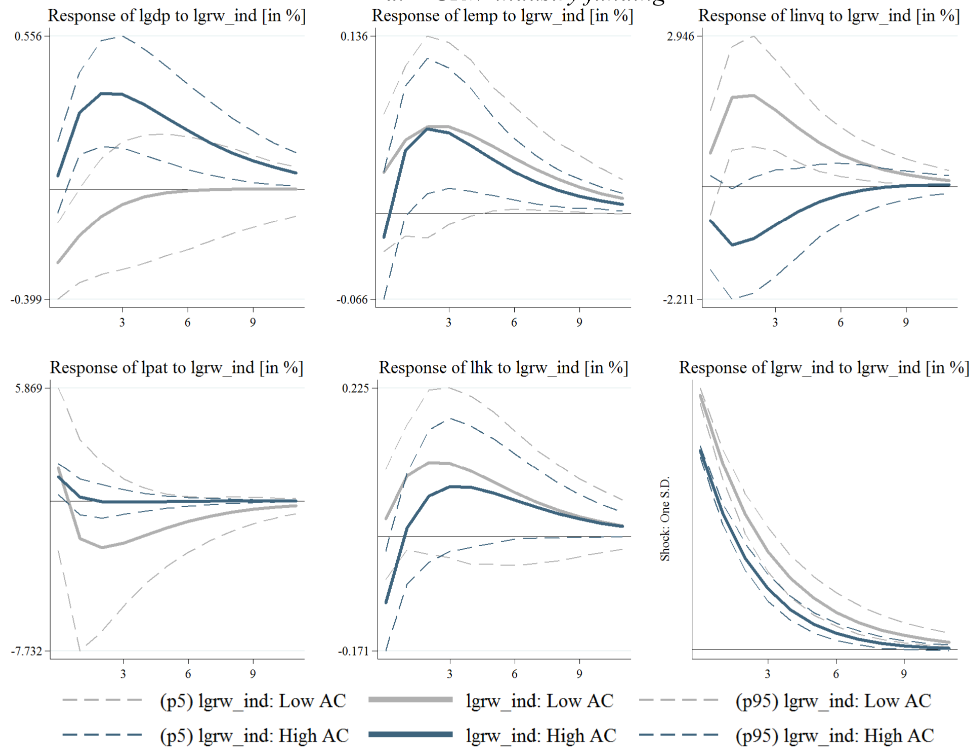
Table A3.4 continued

		Initial GRW shock in subsamples: same percentage*											
		GRW industry funding				GRW infrastructure funding				Overall GRW funding			
Time	**Re-sponse var.**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	2.0012	**0.0230**	0.9770	**0.0461**	1.3896	0.0827	0.9173	0.1654	2.1182	**0.0174**	0.9826	**0.0348**
1	lhk	0.8598	0.1952	0.8048	0.3904	0.5164	0.3029	0.6971	0.6059	0.8759	0.1908	0.8092	0.3816
2	lhk	0.3231	0.3734	0.6266	0.7468	0.2661	0.3952	0.6048	0.7903	0.2006	0.4205	0.5795	0.8411
3	lhk	0.1315	0.4477	0.5523	0.8954	0.1831	0.4274	0.5726	0.8549	-0.0977	0.5389	0.4611	0.9222
4	lhk	0.0377	0.4850	0.5150	0.9700	0.1355	0.4462	0.5538	0.8923	-0.2599	0.6025	0.3975	0.7951
5	lhk	-0.0155	0.5062	0.4938	0.9877	0.0876	0.4651	0.5349	0.9302	-0.3677	0.6434	0.3566	0.7133
6	lhk	-0.0498	0.5199	0.4801	0.9603	0.0344	0.4863	0.5137	0.9726	-0.4506	0.6738	0.3262	0.6525
7	lhk	-0.0735	0.5293	0.4707	0.9414	-0.0237	0.5095	0.4905	0.9811	-0.5145	0.6964	0.3036	0.6072
8	lhk	-0.0891	0.5355	0.4645	0.9290	-0.0816	0.5325	0.4675	0.9350	-0.5593	0.7118	0.2882	0.5763
9	lhk	-0.1011	0.5402	0.4598	0.9195	-0.1369	0.5544	0.4456	0.8912	-0.5849	0.7205	0.2795	0.5589
10	lhk	-0.1088	0.5433	0.4567	0.9134	-0.1906	0.5755	0.4245	0.8490	-0.6193	0.7320	0.2680	0.5360
11	lhk	-0.1133	0.5451	0.4549	0.9099	-0.2293	0.5906	0.4094	0.8188	-0.6400	0.7387	0.2613	0.5225
12	lhk	-0.1163	0.5463	0.4537	0.9075	-0.2600	0.6025	0.3975	0.7950	-0.6341	0.7368	0.2632	0.5264
0	lpat	0.0563	0.4776	0.5224	0.9551	-1.6036	0.9452	0.0548	0.1096	-0.4915	0.6883	0.3117	0.6233
1	lpat	-0.6485	0.7415	0.2585	0.5170	-1.2878	0.9007	0.0993	0.1986	-0.9231	0.8217	0.1783	0.3565
2	lpat	-0.8677	0.8070	0.1930	0.3861	-2.3824	0.9912	**0.0088**	**0.0177**	-1.1850	0.8816	0.1184	0.2367
3	lpat	-1.0218	0.8463	0.1537	0.3075	-2.0700	0.9805	**0.0195**	**0.0391**	-1.3195	0.9061	0.0939	0.1877
4	lpat	-1.1134	0.8669	0.1331	0.2662	-1.6064	0.9455	0.0545	0.1090	-1.3576	0.9123	0.0877	0.1753
5	lpat	-1.1546	0.8755	0.1245	0.2490	-1.2850	0.9002	0.0998	0.1995	-1.2466	0.8934	0.1066	0.2133
6	lpat	-1.1484	0.8742	0.1258	0.2515	-1.0697	0.8573	0.1427	0.2854	-1.2260	0.8895	0.1105	0.2209
7	lpat	-1.1201	0.8683	0.1317	0.2633	-0.9207	0.8211	0.1789	0.3578	-1.2282	0.8899	0.1101	0.2201
8	lpat	-1.0452	0.8517	0.1483	0.2966	-0.8145	0.7921	0.2079	0.4159	-1.1379	0.8721	0.1279	0.2559
9	lpat	-1.0086	0.8431	0.1569	0.3138	-0.6949	0.7562	0.2438	0.4875	-1.0772	0.8590	0.1410	0.2820
10	lpat	-0.9805	0.8363	0.1637	0.3274	-0.6043	0.7270	0.2730	0.5460	-0.9742	0.8347	0.1653	0.3305
11	lpat	-0.9404	0.8262	0.1738	0.3476	-0.5437	0.7065	0.2935	0.5869	-0.8813	0.8107	0.1893	0.3787
12	lpat	-0.8465	0.8011	0.1989	0.3978	-0.5170	0.6973	0.3027	0.6055	-0.7909	0.7853	0.2147	0.4295
0	linvq	1.5876	0.0566	0.9434	0.1132	0.4392	0.3304	0.6696	0.6608	1.7584	**0.0397**	0.9603	**0.0794**
1	linvq	3.1017	**0.0010**	0.9990	**0.0021**	1.6431	0.0506	0.9494	0.1012	2.7328	**0.0033**	0.9967	**0.0066**
2	linvq	2.8202	**0.0025**	0.9975	**0.0050**	1.5275	0.0637	0.9363	0.1274	2.4189	**0.0080**	0.9920	**0.0160**
3	linvq	2.5439	**0.0057**	0.9943	**0.0113**	1.2007	0.1153	0.8847	0.2306	2.0208	**0.0220**	0.9780	**0.0440**
4	linvq	2.2164	**0.0136**	0.9864	**0.0272**	0.7484	0.2273	0.7727	0.4546	1.6978	**0.0452**	0.9548	0.0903
5	linvq	1.8853	**0.0301**	0.9699	0.0601	0.3007	0.3819	0.6181	0.7638	1.3543	0.0882	0.9118	0.1764
6	linvq	1.5390	0.0623	0.9377	0.1246	-0.0295	0.5118	0.4882	0.9765	1.0959	0.1369	0.8631	0.2738
7	linvq	1.2610	0.1040	0.8960	0.2080	-0.2450	0.5967	0.4033	0.8066	0.8869	0.1878	0.8122	0.3757
8	linvq	1.0328	0.1512	0.8488	0.3023	-0.3541	0.6383	0.3617	0.7234	0.6776	0.2492	0.7508	0.4984
9	linvq	0.8193	0.2066	0.7934	0.4131	-0.4281	0.6656	0.3344	0.6688	0.5104	0.3050	0.6950	0.6100
10	linvq	0.6280	0.2652	0.7348	0.5303	-0.4727	0.6817	0.3183	0.6367	0.3669	0.3570	0.6430	0.7139
11	linvq	0.4684	0.3199	0.6801	0.6397	-0.4799	0.6842	0.3158	0.6316	0.2361	0.4067	0.5933	0.8135
12	linvq	0.3281	0.3715	0.6285	0.7430	-0.4836	0.6855	0.3145	0.6290	0.1277	0.4492	0.5508	0.8985
0	lemp	1.1141	0.1330	0.8670	0.2659	0.1228	0.4512	0.5488	0.9023	1.9645	**0.0251**	0.9749	0.0502
1	lemp	-0.1058	0.5421	0.4579	0.9158	-1.4342	0.9239	0.0761	0.1523	0.0418	0.4833	0.5167	0.9667
2	lemp	-0.2689	0.6059	0.3941	0.7881	-1.4210	0.9220	0.0780	0.1561	-0.5407	0.7055	0.2945	0.5890
3	lemp	-0.2261	0.5894	0.4106	0.8213	-1.1665	0.8779	0.1221	0.2441	-0.7097	0.7609	0.2391	0.4783
4	lemp	-0.1304	0.5518	0.4482	0.8963	-0.7868	0.7841	0.2159	0.4319	-0.7550	0.7746	0.2254	0.4507
5	lemp	-0.0348	0.5139	0.4861	0.9723	-0.4581	0.6764	0.3236	0.6471	-0.7820	0.7827	0.2173	0.4347
6	lemp	0.0550	0.4781	0.5219	0.9562	-0.2477	0.5977	0.4023	0.8045	-0.7855	0.7837	0.2163	0.4326
7	lemp	0.1270	0.4495	0.5505	0.8990	-0.1436	0.5570	0.4430	0.8859	-0.7898	0.7849	0.2151	0.4301
8	lemp	0.1809	0.4283	0.5717	0.8566	-0.1250	0.5497	0.4503	0.9006	-0.7884	0.7845	0.2155	0.4309
9	lemp	0.2129	0.4157	0.5843	0.8315	-0.1549	0.5615	0.4385	0.8770	-0.7701	0.7792	0.2208	0.4417
10	lemp	0.2443	0.4036	0.5964	0.8071	-0.2028	0.5803	0.4197	0.8394	-0.7556	0.7748	0.2252	0.4503
11	lemp	0.2634	0.3962	0.6038	0.7924	-0.2530	0.5998	0.4002	0.8004	-0.7286	0.7667	0.2333	0.4666
12	lemp	0.2744	0.3920	0.6080	0.7839	-0.2952	0.6160	0.3840	0.7680	-0.7194	0.7638	0.2362	0.4723
0	lgdp	-2.5242	0.9940	**0.0060**	**0.0120**	-1.5646	0.9408	0.0592	0.1185	-2.4891	0.9934	**0.0066**	**0.0132**
1	lgdp	-3.3716	0.9996	**0.0004**	**0.0008**	-2.1075	0.9822	**0.0178**	**0.0357**	-3.5813	0.9998	**0.0002**	**0.0004**
2	lgdp	-2.7807	0.9972	**0.0028**	**0.0057**	-1.7465	0.9593	**0.0407**	0.0815	-3.1135	0.9990	**0.0010**	**0.0020**
3	lgdp	-2.3357	0.9900	**0.0100**	**0.0200**	-1.4026	0.9192	0.0808	0.1615	-2.7466	0.9969	**0.0031**	**0.0063**
4	lgdp	-2.0519	0.9796	**0.0204**	**0.0408**	-1.1855	0.8817	0.1183	0.2365	-2.4607	0.9929	**0.0071**	**0.0143**
5	lgdp	-1.8140	0.9648	**0.0352**	0.0704	-1.0176	0.8452	0.1548	0.3095	-2.3131	0.9894	**0.0106**	**0.0212**
6	lgdp	-1.6074	0.9456	0.0544	0.1088	-0.9392	0.8259	0.1741	0.3482	-2.1468	0.9838	**0.0162**	**0.0324**
7	lgdp	-1.4463	0.9256	0.0744	0.1489	-0.8605	0.8050	0.1950	0.3900	-2.0402	0.9790	**0.0210**	**0.0420**
8	lgdp	-1.3265	0.9073	0.0927	0.1854	-0.8215	0.7941	0.2059	0.4119	-1.9223	0.9724	**0.0276**	0.0553
9	lgdp	-1.2207	0.8885	0.1115	0.2229	-0.7792	0.7818	0.2182	0.4363	-1.8086	0.9644	**0.0356**	0.0713
10	lgdp	-1.1471	0.8740	0.1260	0.2520	-0.7352	0.7687	0.2313	0.4626	-1.7057	0.9556	**0.0444**	0.0888
11	lgdp	-1.0604	0.8552	0.1448	0.2896	-0.6953	0.7564	0.2436	0.4873	-1.6201	0.9470	0.0530	0.1060
12	lgdp	-0.9634	0.8320	0.1680	0.3360	-0.6676	0.7476	0.2524	0.5048	-1.5232	0.9357	0.0643	0.1285

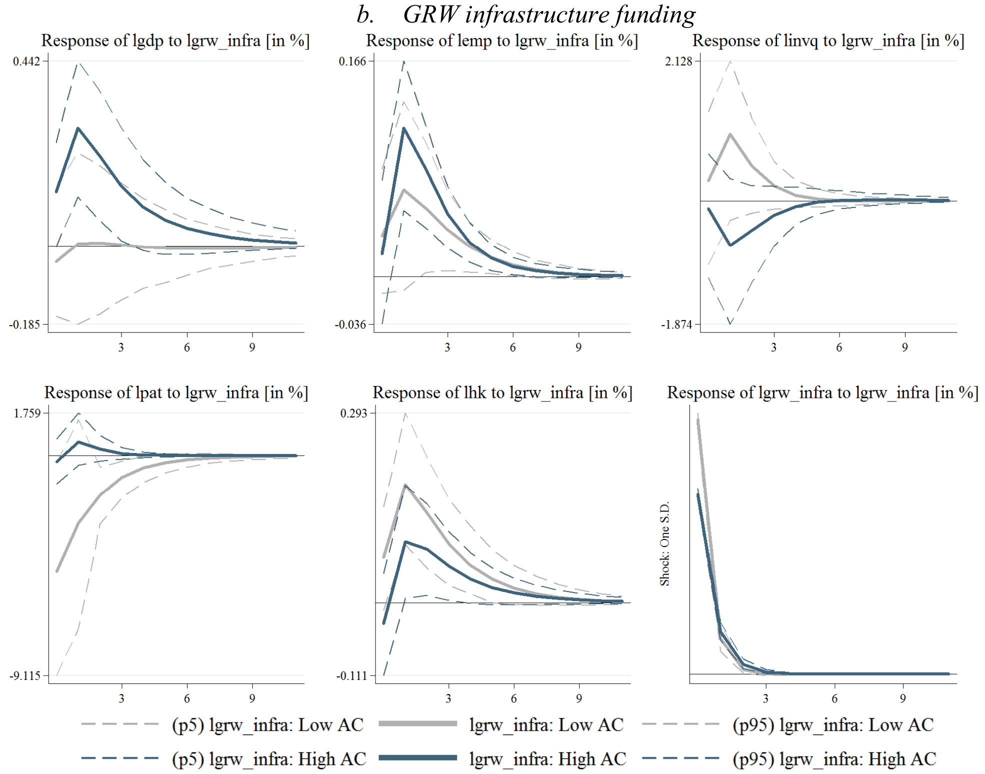
Notes: diff = mean(low_regions) - mean(high_regions); H0: diff = 0; degrees of freedom = 398. *Initial shock in high value regions is rescaled to the amount of the initial shock in low value regions.

Figure A3.2 IRFs for one-period shock in GRW components, high/low levels of absorptive capacity (AC)

a. GRW industry funding



b. GRW infrastructure funding



Notes: The solid lines illustrate the estimated IRF for each subsample and the corresponding dashed lines show the 95% confidence intervals that were calculated by performing Monte Carlo simulations with 200 repetitions. Subsamples are portioned by the median value of absorptive capacity. The associated regression results of the underlying SpPVAR models are available upon request.

Table A3.5 *t*-tests for differences in the estimated average responses to a GRW shock between regions with high and low levels of economic freedom

		Initial GRW shock in subsamples: one *sample-specific* standard deviation											
		GRW industry funding				**GRW infrastructure funding**				**Overall GRW funding**			
Time	**Re-sponse var.**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	1.4491	0.0741	0.9259	0.1481	0.3100	0.3784	0.6216	0.7568	1.1384	0.1278	0.8722	0.2557
1	lhk	1.1563	0.1241	0.8759	0.2483	-0.1866	0.5740	0.4260	0.8520	0.8462	0.1990	0.8010	0.3979
2	lhk	0.6633	0.2537	0.7463	0.5075	-0.1169	0.5465	0.4535	0.9070	0.4088	0.3414	0.6586	0.6829
3	lhk	0.4110	0.3407	0.6593	0.6813	0.1496	0.4406	0.5594	0.8812	0.1627	0.4354	0.5646	0.8709
4	lhk	0.2369	0.4064	0.5936	0.8128	0.4055	0.3427	0.6573	0.6853	-0.0112	0.5045	0.4955	0.9910
5	lhk	0.1184	0.4529	0.5471	0.9058	0.6103	0.2710	0.7290	0.5420	-0.1429	0.5568	0.4432	0.8864
6	lhk	0.0257	0.4898	0.5102	0.9795	0.7418	0.2293	0.7707	0.4586	-0.2432	0.5960	0.4040	0.8079
7	lhk	-0.0464	0.5185	0.4815	0.9630	0.7906	0.2148	0.7852	0.4296	-0.3173	0.6244	0.3756	0.7512
8	lhk	-0.0984	0.5392	0.4608	0.9216	0.8242	0.2052	0.7948	0.4103	-0.3686	0.6437	0.3563	0.7126
9	lhk	-0.1385	0.5550	0.4450	0.8899	0.8044	0.2108	0.7892	0.4216	-0.4019	0.6560	0.3440	0.6879
10	lhk	-0.1680	0.5667	0.4333	0.8667	0.7864	0.2161	0.7839	0.4321	-0.4270	0.6652	0.3348	0.6696
11	lhk	-0.1907	0.5756	0.4244	0.8488	0.7575	0.2246	0.7754	0.4492	-0.4485	0.6730	0.3270	0.6541
12	lhk	-0.1974	0.5782	0.4218	0.8436	0.7036	0.2410	0.7590	0.4821	-0.4504	0.6737	0.3263	0.6527
0	lpat	-0.4359	0.6684	0.3316	0.6632	-1.2024	0.8850	0.1150	0.2299	-1.1807	0.8808	0.1192	0.2384
1	lpat	-1.6456	0.9497	0.0503	0.1006	-0.6952	0.7563	0.2437	0.4873	-1.5667	0.9410	0.0590	0.1180
2	lpat	-2.0114	0.9775	**0.0225**	**0.0450**	-1.6169	0.9467	0.0533	0.1067	-1.8856	0.9700	**0.0300**	0.0601
3	lpat	-2.2876	0.9887	**0.0113**	**0.0227**	-1.5026	0.9331	0.0669	0.1337	-2.1503	0.9839	**0.0161**	**0.0321**
4	lpat	-2.1922	0.9855	**0.0145**	**0.0289**	-1.2905	0.9012	0.0988	0.1976	-2.0780	0.9808	**0.0192**	**0.0383**
5	lpat	-2.1443	0.9837	**0.0163**	**0.0326**	-1.1795	0.8806	0.1194	0.2389	-2.0250	0.9782	**0.0218**	**0.0435**
6	lpat	-1.9072	0.9714	**0.0286**	0.0572	-1.0213	0.8461	0.1539	0.3078	-1.8307	0.9661	**0.0339**	0.0679
7	lpat	-1.6672	0.9519	**0.0481**	0.0963	-0.9224	0.8216	0.1784	0.3569	-1.6279	0.9478	0.0522	0.1043
8	lpat	-1.4896	0.9314	0.0686	0.1371	-0.8624	0.8055	0.1945	0.3890	-1.4466	0.9256	0.0744	0.1488
9	lpat	-1.3382	0.9092	0.0908	0.1816	-0.7881	0.7845	0.2155	0.4311	-1.3008	0.9030	0.0970	0.1941
10	lpat	-1.1995	0.8845	0.1155	0.2311	-0.7568	0.7752	0.2248	0.4496	-1.1563	0.8759	0.1241	0.2482
11	lpat	-1.0224	0.8464	0.1536	0.3072	-0.7459	0.7719	0.2281	0.4562	-1.0161	0.8449	0.1551	0.3102
12	lpat	-0.8972	0.8149	0.1851	0.3702	-0.7128	0.7618	0.2382	0.4764	-0.8874	0.8123	0.1877	0.3754
0	linvq	3.2228	**0.0007**	0.9993	**0.0014**	1.9503	**0.0259**	0.9741	0.0518	3.3220	**0.0005**	0.9995	**0.0010**
1	linvq	2.9957	**0.0015**	0.9985	**0.0029**	2.5416	**0.0057**	0.9943	**0.0114**	2.9425	**0.0017**	0.9983	**0.0034**
2	linvq	2.2660	**0.0120**	0.9880	**0.0240**	2.5710	**0.0053**	0.9947	**0.0105**	2.1610	**0.0156**	0.9844	**0.0313**
3	linvq	1.9624	**0.0252**	0.9748	0.0504	2.5661	**0.0053**	0.9947	**0.0107**	1.7971	**0.0365**	0.9635	0.0731
4	linvq	1.6860	**0.0463**	0.9537	0.0926	2.4302	**0.0078**	0.9922	**0.0155**	1.5555	0.0603	0.9397	0.1206
5	linvq	1.4382	0.0756	0.9244	0.1512	2.0521	**0.0204**	0.9796	**0.0408**	1.3239	0.0931	0.9069	0.1863
6	linvq	1.2314	0.1094	0.8906	0.2189	1.7562	**0.0399**	0.9601	0.0798	1.1123	0.1334	0.8666	0.2667
7	linvq	1.0719	0.1422	0.8578	0.2844	1.3614	0.0871	0.9129	0.1741	0.9665	0.1672	0.8328	0.3344
8	linvq	0.9002	0.1843	0.8157	0.3685	1.0810	0.1402	0.8598	0.2803	0.8053	0.2106	0.7894	0.4212
9	linvq	0.7116	0.2386	0.7614	0.4771	0.8892	0.1872	0.8128	0.3744	0.6628	0.2539	0.7461	0.5079
10	linvq	0.6124	0.2703	0.7297	0.5407	0.7201	0.2360	0.7640	0.4719	0.5659	0.2859	0.7141	0.5718
11	linvq	0.5290	0.2986	0.7014	0.5971	0.6204	0.2677	0.7323	0.5354	0.4886	0.3127	0.6873	0.6254
12	linvq	0.4703	0.3192	0.6808	0.6384	0.5452	0.2930	0.7070	0.5859	0.4278	0.3345	0.6655	0.6690
0	lemp	-0.2441	0.5964	0.4036	0.8073	-0.4964	0.6900	0.3100	0.6199	-0.3427	0.6340	0.3660	0.7320
1	lemp	-0.5107	0.6951	0.3049	0.6098	-1.8825	0.9698	**0.0302**	0.0605	-0.7264	0.7660	0.2340	0.4680
2	lemp	-0.7056	0.7596	0.2404	0.4808	-2.0381	0.9789	**0.0211**	**0.0422**	-0.9564	0.8303	0.1697	0.3395
3	lemp	-0.9619	0.8317	0.1683	0.3367	-1.8479	0.9673	**0.0327**	0.0654	-1.2537	0.8947	0.1053	0.2107
4	lemp	-1.2015	0.8849	0.1151	0.2303	-1.4852	0.9309	0.0691	0.1383	-1.5191	0.9352	0.0648	0.1295
5	lemp	-1.4569	0.9270	0.0730	0.1459	-1.0689	0.8571	0.1429	0.2858	-1.8017	0.9638	**0.0362**	0.0724
6	lemp	-1.7187	0.9568	**0.0432**	0.0864	-0.7056	0.7596	0.2404	0.4809	-2.0208	0.9780	**0.0220**	**0.0440**
7	lemp	-1.8828	0.9698	**0.0302**	0.0605	-0.4569	0.6760	0.3240	0.6480	-2.1240	0.9829	**0.0171**	**0.0343**
8	lemp	-1.9622	0.9748	**0.0252**	0.0504	-0.2917	0.6147	0.3853	0.7706	-2.1918	0.9855	**0.0145**	**0.0290**
9	lemp	-1.9655	0.9750	**0.0250**	0.0500	-0.2087	0.5826	0.4174	0.8348	-2.1631	0.9844	**0.0156**	**0.0311**
10	lemp	-1.9184	0.9721	**0.0279**	0.0558	-0.1625	0.5645	0.4355	0.8710	-2.0114	0.9775	**0.0225**	**0.0450**
11	lemp	-1.8797	0.9696	**0.0304**	0.0609	-0.1417	0.5563	0.4437	0.8874	-1.9275	0.9727	**0.0273**	0.0546
12	lemp	-1.8252	0.9656	**0.0344**	0.0687	-0.1307	0.5520	0.4480	0.8961	-1.7616	0.9605	**0.0395**	0.0789
0	lgdp	-1.2563	0.8951	0.1049	0.2097	-1.5796	0.9425	0.0575	0.1150	-1.4986	0.9326	0.0674	0.1348
1	lgdp	-2.2395	0.9872	**0.0128**	**0.0257**	-1.2518	0.8943	0.1057	0.2114	-2.5168	0.9939	**0.0061**	**0.0122**
2	lgdp	-2.1797	0.9851	**0.0149**	**0.0299**	-1.0104	0.8435	0.1565	0.3129	-2.4384	0.9924	**0.0076**	**0.0152**
3	lgdp	-2.1992	0.9858	**0.0142**	**0.0284**	-0.8001	0.7879	0.2121	0.4242	-2.4944	0.9935	**0.0065**	**0.0130**
4	lgdp	-2.1689	0.9847	**0.0153**	**0.0307**	-0.6160	0.7309	0.2691	0.5382	-2.4416	0.9925	**0.0075**	**0.0151**
5	lgdp	-2.1472	0.9838	**0.0162**	**0.0324**	-0.5127	0.6958	0.3042	0.6085	-2.4672	0.9930	**0.0070**	**0.0140**
6	lgdp	-2.1079	0.9822	**0.0178**	**0.0357**	-0.4385	0.6694	0.3306	0.6613	-2.4319	0.9923	**0.0077**	**0.0155**
7	lgdp	-2.0333	0.9787	**0.0213**	**0.0427**	-0.3770	0.6468	0.3532	0.7064	-2.2711	0.9882	**0.0118**	**0.0237**
8	lgdp	-1.9291	0.9728	**0.0272**	0.0544	-0.3358	0.6314	0.3686	0.7372	-2.2474	0.9874	**0.0126**	**0.0252**
9	lgdp	-1.8513	0.9676	**0.0324**	0.0649	-0.2954	0.6161	0.3839	0.7679	-2.1775	0.9850	**0.0150**	**0.0300**
10	lgdp	-1.7747	0.9616	**0.0384**	0.0767	-0.2690	0.6060	0.3940	0.7881	-2.0388	0.9789	**0.0211**	**0.0421**
11	lgdp	-1.7103	0.9560	**0.0440**	0.0880	-0.2472	0.5976	0.4024	0.8049	-1.8432	0.9670	**0.0330**	0.0660
12	lgdp	-1.5826	0.9428	0.0572	0.1143	-0.2315	0.5915	0.4085	0.8170	-1.7489	0.9595	**0.0405**	0.0811

Table A3.5 continued

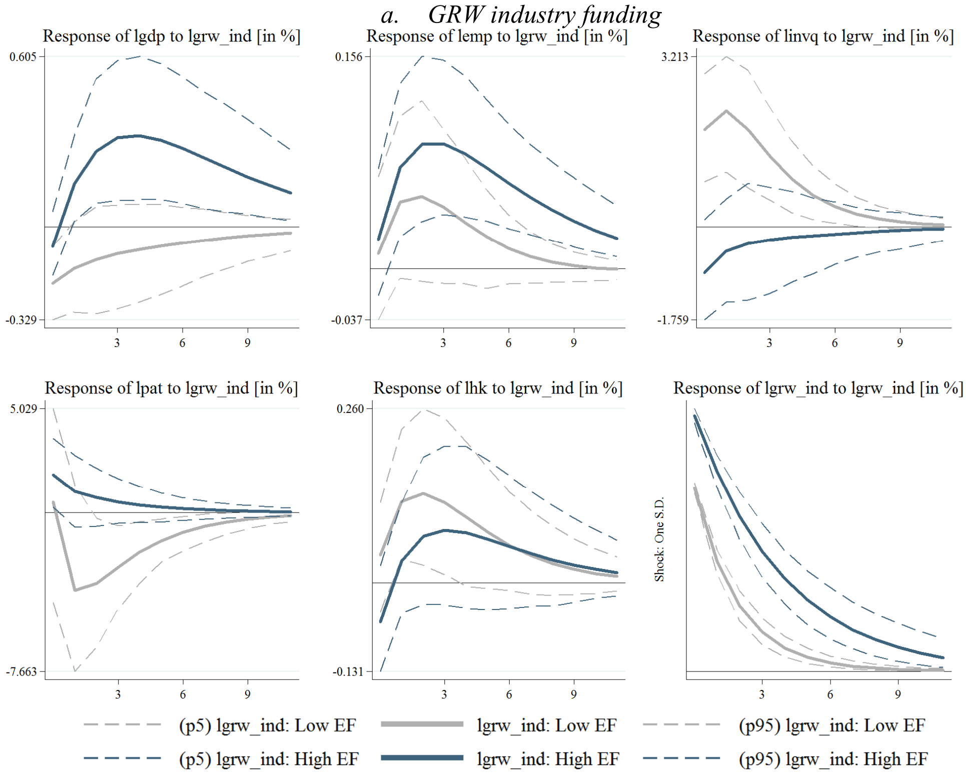
Initial GRW shock in subsamples: same percentage*

		GRW industry funding				GRW infrastructure funding				Overall GRW funding			
Time	**Re-sponse var.**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	1.3847	0.0835	0.9165	0.1669	0.3377	0.3679	0.6321	0.7358	1.0392	0.1497	0.8503	0.2994
1	lhk	1.4325	0.0764	0.9236	0.1528	-0.0590	0.5235	0.4765	0.9530	1.1645	0.1225	0.8775	0.2449
2	lhk	0.9860	0.1624	0.8376	0.3247	0.0037	0.4985	0.5015	0.9970	0.7918	0.2145	0.7855	0.4290
3	lhk	0.7297	0.2330	0.7670	0.4660	0.2539	0.3999	0.6001	0.7997	0.5510	0.2910	0.7090	0.5819
4	lhk	0.5315	0.2977	0.7023	0.5954	0.4894	0.3124	0.6876	0.6248	0.3583	0.3601	0.6399	0.7203
5	lhk	0.3952	0.3464	0.6536	0.6929	0.6760	0.2497	0.7503	0.4994	0.2038	0.4193	0.5807	0.8386
6	lhk	0.2803	0.3897	0.6103	0.7794	0.7926	0.2142	0.7858	0.4285	0.0715	0.4715	0.5285	0.9431
7	lhk	0.1785	0.4292	0.5708	0.8584	0.8256	0.2048	0.7952	0.4095	-0.0374	0.5149	0.4851	0.9702
8	lhk	0.0969	0.4614	0.5386	0.9229	0.8490	0.1982	0.8018	0.3964	-0.1239	0.5493	0.4507	0.9015
9	lhk	0.0352	0.4859	0.5141	0.9719	0.8215	0.2059	0.7941	0.4119	-0.1904	0.5754	0.4246	0.8491
10	lhk	-0.0133	0.5053	0.4947	0.9894	0.7975	0.2128	0.7872	0.4257	-0.2424	0.5957	0.4043	0.8086
11	lhk	-0.0518	0.5206	0.4794	0.9587	0.7642	0.2226	0.7774	0.4452	-0.2854	0.6123	0.3877	0.7755
12	lhk	-0.0783	0.5312	0.4688	0.9376	0.7071	0.2400	0.7600	0.4799	-0.3115	0.6222	0.3778	0.7555
0	lpat	-0.2730	0.6075	0.3925	0.7850	-1.2312	0.8905	0.1095	0.2190	-1.0345	0.8492	0.1508	0.3015
1	lpat	-1.5982	0.9446	0.0554	0.1108	-0.7036	0.7590	0.2410	0.4821	-1.5075	0.9338	0.0662	0.1325
2	lpat	-1.9964	0.9767	**0.0233**	**0.0466**	-1.6386	0.9490	0.0510	0.1021	-1.8563	0.9679	**0.0321**	0.0642
3	lpat	-2.3131	0.9894	**0.0106**	**0.0212**	-1.5100	0.9341	0.0659	0.1318	-2.1597	0.9843	**0.0157**	**0.0314**
4	lpat	-2.2413	0.9872	**0.0128**	**0.0256**	-1.2941	0.9018	0.0982	0.1964	-2.1196	0.9827	**0.0173**	**0.0347**
5	lpat	-2.2271	0.9867	**0.0133**	**0.0265**	-1.1835	0.8813	0.1187	0.2373	-2.1030	0.9820	**0.0180**	**0.0361**
6	lpat	-1.9745	0.9755	**0.0245**	**0.0490**	-1.0251	0.8470	0.1530	0.3060	-1.9183	0.9721	**0.0279**	0.0558
7	lpat	-1.7242	0.9573	**0.0427**	0.0854	-0.9268	0.8227	0.1773	0.3546	-1.7124	0.9562	**0.0438**	0.0876
8	lpat	-1.5486	0.9389	0.0611	0.1223	-0.8673	0.8069	0.1931	0.3863	-1.5292	0.9365	0.0635	0.1270
9	lpat	-1.4086	0.9201	0.0799	0.1597	-0.7933	0.7860	0.2140	0.4281	-1.3945	0.9180	0.0820	0.1639
10	lpat	-1.2702	0.8976	0.1024	0.2048	-0.7624	0.7769	0.2231	0.4463	-1.2585	0.8955	0.1045	0.2090
11	lpat	-1.0869	0.8611	0.1389	0.2778	-0.7519	0.7737	0.2263	0.4526	-1.1197	0.8682	0.1318	0.2635
12	lpat	-0.9578	0.8306	0.1694	0.3388	-0.7187	0.7636	0.2364	0.4727	-0.9835	0.8370	0.1630	0.3260
0	linvq	3.3278	**0.0005**	0.9995	**0.0010**	1.9404	**0.0265**	0.9735	0.0530	3.4894	**0.0003**	0.9997	**0.0005**
1	linvq	3.2160	**0.0007**	0.9993	**0.0014**	2.5492	**0.0056**	0.9944	**0.0112**	3.1882	**0.0008**	0.9992	**0.0015**
2	linvq	2.4938	**0.0065**	0.9935	**0.0130**	2.5810	**0.0051**	0.9949	**0.0102**	2.4028	**0.0084**	0.9916	**0.0167**
3	linvq	2.2048	**0.0140**	0.9860	**0.0280**	2.5713	**0.0052**	0.9948	**0.0105**	2.0586	**0.0201**	0.9799	**0.0402**
4	linvq	1.9080	**0.0286**	0.9714	0.0571	2.4439	**0.0075**	0.9925	**0.0150**	1.7982	**0.0365**	0.9635	0.0729
5	linvq	1.6354	0.0514	0.9486	0.1028	2.0473	**0.0206**	0.9794	**0.0413**	1.5428	0.0618	0.9382	0.1237
6	linvq	1.4077	0.0800	0.9200	0.1600	1.7481	**0.0406**	0.9594	0.0812	1.3097	0.0955	0.9045	0.1911
7	linvq	1.2198	0.1116	0.8884	0.2233	1.3527	0.0885	0.9115	0.1769	1.1369	0.1281	0.8719	0.2563
8	linvq	1.0219	0.1537	0.8463	0.3074	1.0756	0.1414	0.8586	0.2828	0.9449	0.1726	0.8274	0.3453
9	linvq	0.8028	0.2113	0.7887	0.4226	0.8881	0.1875	0.8125	0.3750	0.7708	0.2207	0.7793	0.4413
10	linvq	0.6839	0.2472	0.7528	0.4944	0.7215	0.2355	0.7645	0.4710	0.6522	0.2573	0.7427	0.5147
11	linvq	0.5844	0.2796	0.7204	0.5593	0.6243	0.2664	0.7336	0.5328	0.5599	0.2879	0.7121	0.5759
12	linvq	0.5112	0.3048	0.6952	0.6095	0.5514	0.2908	0.7092	0.5816	0.4840	0.3143	0.6857	0.6286
0	lemp	-0.1116	0.5444	0.4556	0.9112	-0.4200	0.6626	0.3374	0.6747	-0.1277	0.5508	0.4492	0.8985
1	lemp	-0.0975	0.5388	0.4612	0.9224	-1.7204	0.9569	**0.0431**	0.0861	-0.2495	0.5984	0.4016	0.8031
2	lemp	-0.2590	0.6021	0.3979	0.7958	-1.8664	0.9686	**0.0314**	0.0627	-0.4458	0.6720	0.3280	0.6560
3	lemp	-0.4885	0.6872	0.3128	0.6255	-1.6820	0.9533	**0.0467**	0.0934	-0.7190	0.7637	0.2363	0.4726
4	lemp	-0.7390	0.7698	0.2302	0.4604	-1.3318	0.9082	0.0918	0.1837	-1.0055	0.8424	0.1576	0.3153
5	lemp	-1.0134	0.8442	0.1558	0.3115	-0.9340	0.8246	0.1754	0.3509	-1.3208	0.9063	0.0937	0.1873
6	lemp	-1.3256	0.9071	0.0929	0.1857	-0.5971	0.7246	0.2754	0.5508	-1.6156	0.9465	0.0535	0.1070
7	lemp	-1.5540	0.9395	0.0605	0.1210	-0.3722	0.6450	0.3550	0.7099	-1.8299	0.9660	**0.0340**	0.0680
8	lemp	-1.7134	0.9563	**0.0437**	0.0874	-0.2288	0.5904	0.4096	0.8191	-1.9645	0.9749	**0.0251**	0.0502
9	lemp	-1.7842	0.9624	**0.0376**	0.0752	-0.1592	0.5632	0.4368	0.8736	-2.0061	0.9772	**0.0228**	**0.0455**
10	lemp	-1.7864	0.9626	**0.0374**	0.0748	-0.1225	0.5487	0.4513	0.9026	-1.9091	0.9715	**0.0285**	0.0570
11	lemp	-1.7799	0.9621	**0.0379**	0.0759	-0.1073	0.5427	0.4573	0.9146	-1.8580	0.9680	**0.0320**	0.0639
12	lemp	-1.7471	0.9593	**0.0407**	0.0814	-0.1005	0.5400	0.4600	0.9200	-1.7178	0.9567	**0.0433**	0.0866
0	lgdp	-1.6248	0.9475	0.0525	0.1050	-1.5057	0.9335	0.0665	0.1329	-1.8937	0.9705	**0.0295**	0.0590
1	lgdp	-2.1841	0.9852	**0.0148**	**0.0295**	-1.1483	0.8742	0.1258	0.2515	-2.4080	0.9918	**0.0082**	**0.0165**
2	lgdp	-2.0600	0.9800	**0.0200**	**0.0400**	-0.9294	0.8234	0.1766	0.3533	-2.2438	0.9873	**0.0127**	**0.0254**
3	lgdp	-2.0745	0.9807	**0.0193**	**0.0387**	-0.7336	0.7682	0.2318	0.4636	-2.2866	0.9886	**0.0114**	**0.0227**
4	lgdp	-2.0506	0.9795	**0.0205**	**0.0410**	-0.5610	0.7124	0.2876	0.5751	-2.2473	0.9874	**0.0126**	**0.0252**
5	lgdp	-2.0261	0.9783	**0.0217**	**0.0434**	-0.4640	0.6785	0.3215	0.6429	-2.2742	0.9883	**0.0117**	**0.0235**
6	lgdp	-2.0007	0.9770	**0.0230**	**0.0461**	-0.3959	0.6538	0.3462	0.6924	-2.2627	0.9879	**0.0121**	**0.0242**
7	lgdp	-1.9473	0.9739	**0.0261**	**0.0522**	-0.3402	0.6330	0.3670	0.7339	-2.1567	0.9842	**0.0158**	**0.0316**
8	lgdp	-1.8677	0.9687	**0.0313**	0.0625	-0.3026	0.6188	0.3812	0.7624	-2.1528	0.9840	**0.0160**	**0.0319**
9	lgdp	-1.8103	0.9645	**0.0355**	0.0710	-0.2657	0.6047	0.3953	0.7906	-2.0966	0.9817	**0.0183**	**0.0367**
10	lgdp	-1.7378	0.9585	**0.0415**	0.0830	-0.2418	0.5955	0.4045	0.8090	-1.9806	0.9758	**0.0242**	**0.0483**
11	lgdp	-1.6804	0.9532	**0.0468**	0.0937	-0.2221	0.5878	0.4122	0.8243	-1.8135	0.9647	**0.0353**	0.0705
12	lgdp	-1.5613	0.9404	0.0596	0.1193	-0.2081	0.5824	0.4176	0.8352	-1.7258	0.9574	**0.0426**	0.0852

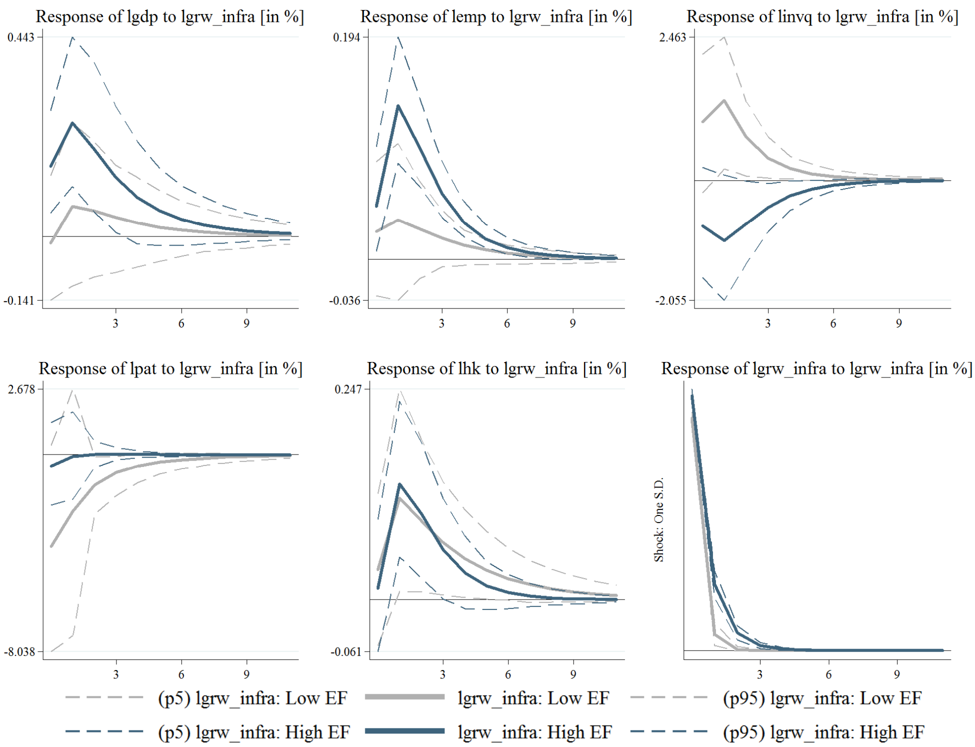
Notes: diff = mean(low_regions) - mean(high_regions); H0: diff = 0; degrees of freedom = 398. *Initial shock in high value regions is rescaled to the amount of the initial shock in low value regions.

Figure A3.3 IRFs for one-period shock in GRW components, high/low levels of economic freedom (EF)

a. GRW industry funding



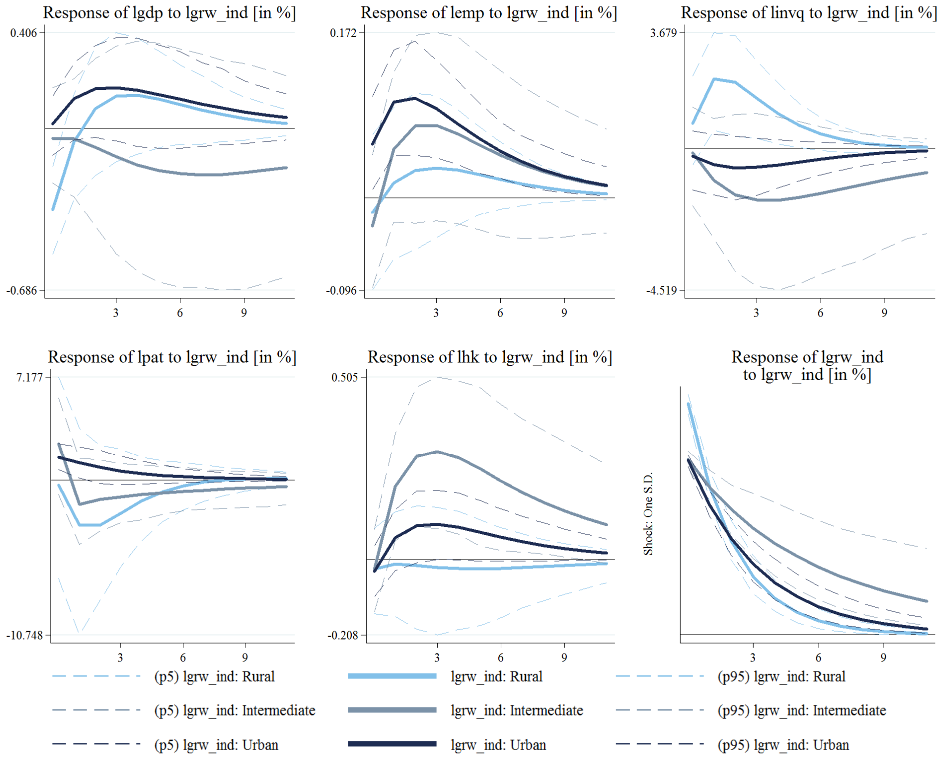
b. GRW infrastructure funding



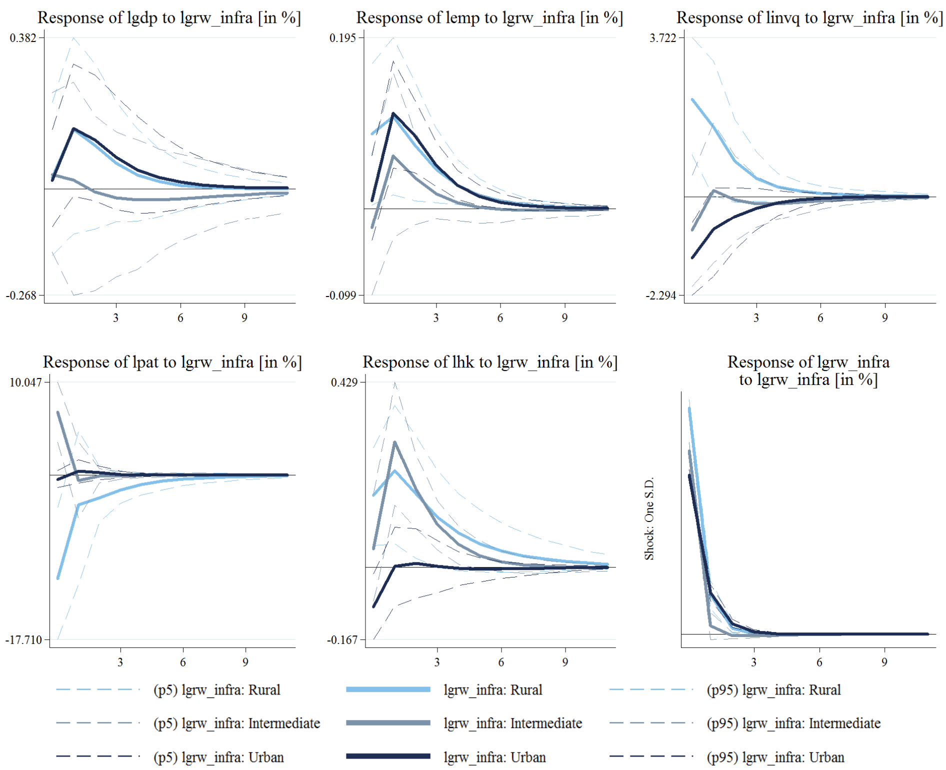
Notes: The solid lines illustrate the estimated IRF for each subsample and the corresponding dashed lines show the 95% confidence intervals that were calculated by performing Monte Carlo simulations with 200 repetitions. Subsamples are portioned by the median value of economic freedom. The associated regression results of the underlying SpPVAR models are available upon request.

Figure A3.4 IRFs for one-period shocks in GRW intensity, BBSR classification for regions with different settlement structure

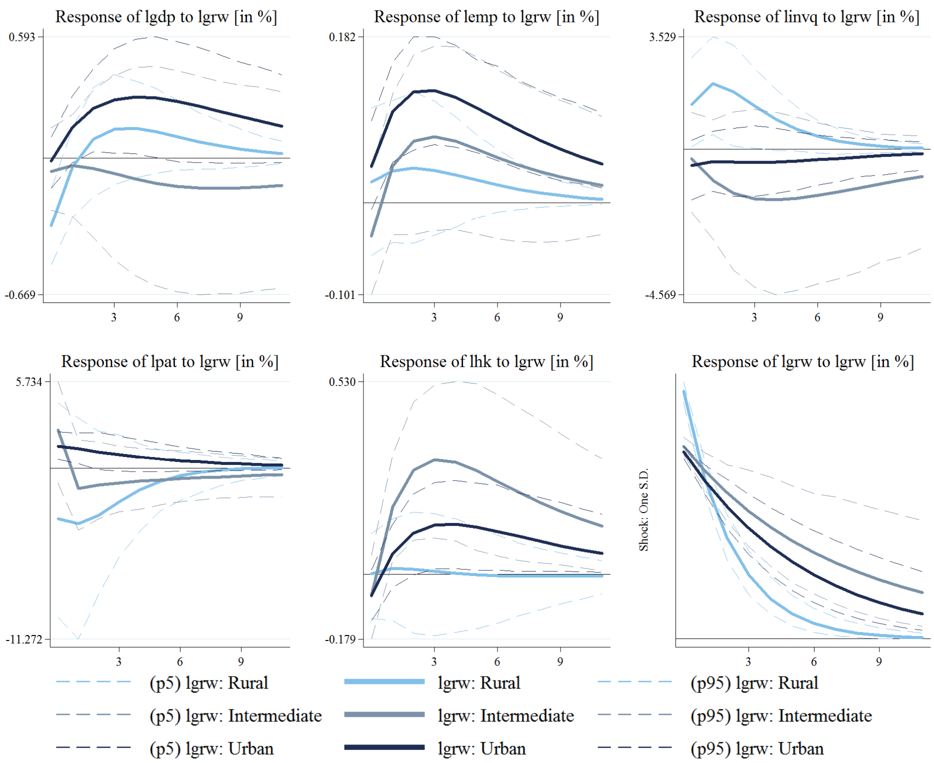
a. GRW industry funding



b. GRW infrastructure funding



c. Overall GRW funding



Notes: The solid lines illustrate the estimated IRF for each subsample and the corresponding dashed lines show the 95% confidence intervals that were calculated by performing Monte Carlo simulations with 200 repetitions. Subsamples are portioned by the classification of the BBSR (Status: 31.12.2014) with *Rural* = Population density < 100 Pop./km^2, *Intermediate* = Population density < 150 Pop./km^2 ≥ 100, *Urban* = Population density ≥ 150 Pop./ km^2. The associated regression results of the underlying SpPVAR models are available upon request.

4. Economic effects of regional fiscal equalisation – Empirical evidence from German labour market regions

Notes: The paper was submitted to *Journal of Economics and Statistics* (20 April 2019). A related version of the paper was published as *Working Papers on Innovation and Space* (Vol. 01.19).

Abstract: Regional fiscal equalisation in Germany aims to reduce fiscal disparities by allocating financial resources to less promising regions. This paper aims to analyse potential economic secondary effects of regional fiscal equalisation on several economic in- and output variables. Additionally, the paper examines the potential regional characteristics to influence the transformation of fiscal inputs into economic outcomes. Lastly, I compare the effects of fiscal equalisation to these of the major German structural funding programme. The findings generally reveal a significant positive effect of fiscal equalisation on the regional employment rate. Moreover, the findings suggest different transmission channels of fiscal equalisation in East and West Germany. Particularly, I find higher effects in right-wing CDU/CSU preferring regions on the employment, human capital and private sector investment rate. Finally, while structural funding affects more economic variables significantly, the magnitude of the estimated economic responses of fiscal equalisation compared to these of German structural funding are not statistically different.

Keywords: Evaluation, fiscal equalisation, regional economic growth, political ideology, SpPVAR, impulse response functions

JEL Classification: C33, E62, R11, R58, O47

4.1 Introduction

Many regional policy measures explicitly aim to foster the economic progress of rather less affluent regions to warrant equal living conditions and economic balance. To this end, a large amount of public money is spent in terms of structural investment programmes to trigger economic development in less promising regions – examples are the cohesion policy of the EU (e.g. European Commission, 2017) or, in Germany, the Joint Task for the Improvement of Regional Economic Structures (GRW) (e.g. Brachert et al., 2018; Deutscher Bundestag, 2014).

However, besides structural funding, further important regional policy measures are fiscal equalisation schemes. In Germany, fiscal equalisation is provided across federal states (Länderfinanzausgleich) as well as across municipalities within a federal state. This paper sheds light on the latter equalisation scheme, which is of particular political interest as it provides a high funding volume each year and is thus a crucial income source for German regional authorities. Between 2000 and 2011, on average, 23.51 billion Euro in unconditional formula-based grants (Schlüsselzuweisungen) – the key funding mechanism for regional financial compensation – was provided annually to German municipalities.[55] The basic purpose of regional equalisation is to provide financial resources to needier municipalities to perpetuate the supply of public goods by explicitly considering the financial capacity and needs for fund allocation (e.g. Albouy, 2012; Lenk et al., 2013). Thus, regional equalisation bridges financial gaps and features a distinct redistributive function of public financial resources (see Lenk et al., 2013, for German regional fiscal equalisation).

Despite the economic relevance as important income source and the high annual financial volume, empirical evaluations of the economic effects of German regional fiscal equalisation are sparse

[55] Please note that this figures are based on own calculations using data from the *Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR)* (see Table A4.1).

(e.g. Henkel et al., 2018; Kalb, 2010; Lehmann and Wrede, 2019). That said, economic implications are hardly known, especially regarding potential economic secondary effects, which are interpreted in this paper as additional (inadvertent) effects of an increase in formula-based grants on other economic variables in the regional production system – such as the per capita income, patent, investment, human capital and employment rate.

The purpose of the paper at hand is to contribute to the scientific and political discussion by transferring a simultaneous equation approach suggested by Eberle et al. (2019) to an evaluation exercise of the regional fiscal equalisation scheme. The applied econometric approach provides multifaceted insights in the working and the transmission channels of German fiscal equalisation and explicitly detects direct and indirect effects among the variables in the regional production system. This is, to the author's knowledge, the first study regarding regional fiscal equalisation that applies this methodological approach. In doing so, the first question of interest is: Do fiscal equalisation grants trigger economic development via secondary effects?

Second, studies evaluating structural and cohesion funds increasingly emphasise the relevance of conditioning factors (e.g. quality of government) as driver for an efficient use of public spending (Fratesi and Wishlade, 2017). Building upon this burgeoning string of literature, the second research question asks whether potential secondary effects are uniform across regions or rather depend on political-economic conditions. To this end, German regions are subdivided according to a rather general (Eastern and Western German regions) as well as to a more specific (government ideologies) measure of political structures. Finally, in contrast to regional fiscal equalisation, the GRW programme can be considered as more industry-oriented policy measure (Deutscher Bundestag, 2014). In order to provide a profound comparison of the two regional policies, the last research question raises the discussion as to whether or not the economic effects differ between regional fiscal equalisation and the GRW programme.

The findings show significant positive (unconditional) effects on regional employment, while further economic variables are unaffected by an increase in the formula-based grant intensity in the basic model. Furthermore, I find evidence for slightly different transmission channels of regional fiscal equalisation in Eastern and Western German regions. In addition, an increase in the formula-based grant intensity leads to statistically significantly higher effects on the employment, human capital and private sector investment rate in regions that mainly support the rather pro-business and right-wing conservative parties Christian Democratic Party (CDU) and Christian Social Party (CSU). Lastly, while the differences in the estimated economic effects of fiscal equalisation and the GRW are not significant, the GRW triggers not only significant positive effects on the employment rate but also on the GDP and human capital.

The remainder of the paper is organised as follows. In the next section, I provide information on the basic setup of regional fiscal equalisation in Germany and discuss the state of academic debate (Section 4.2). In Section 4.3, theoretical considerations and research hypotheses are presented, while Section 4.4 shortly describes the econometric strategy and data. Section 4.5 analyses the economic effects of German regional fiscal equalisation and Section 4.6 summarises and concludes.

4.2 The German regional fiscal equalisation scheme

4.2.1 Institutional setup

German fiscal equalisation is implemented at the federal level (Länderfinanzausgleich) as well as on the regional level, where equalisation is provided across municipalities within a federal state. The paper on hand is focused on the regional fiscal equalisation scheme, where the responsibility of detailed design and implementation is incumbent upon the particular federal state. The scheme aims to improve the financial resources of municipalities within a specific federal state to guarantee a sufficient endowment of public goods, especially by allocating funds predominantly to economic weaker municipalities with the highest need – indicating a highly redistributive character (Lenk et al., 2013).

Municipalities are the lowest level of regional government in Germany, notwithstanding they generally have notable autonomy (e.g. Kalb, 2010). Buettner and Holm-Hadulla (2008) name three general income sources of German municipalities: First, municipalities receive a share of income taxes and valued-added tax (VAT). Second, they raise local business and land taxes. Finally, they gain from fiscal transfers allocated by the federal state government. The distribution of these funds is, on the one hand, based on the fiscal capacity and, on the other hand, on the fiscal need of municipalities. If fiscal capacity exceeds fiscal need, no equalisation funds are provided (abundant municipality) and they are net contributors. Conversely, if fiscal need is in excess of financial capacity, equalisation funds are provided to balance a flexible part of this difference (Buettner and Holm-Hadulla, 2008). As explained by Lenk et al. (2013), the detailed setup and conceptualization differs across German federal states. However, the approximation of the financial conditions in the municipalities generally follows the above presented structure, i.e. counting the financial capacity against the financial need. To this end, the unconditional formula-based grants are the key funds for financial compensation of economically weaker municipalities and their use is most widely unconstrained. This implies that municipalities are free to make use of the formula-based grants according to their preferences (Lenk et al., 2013). As regional fiscal equalisation is also provided in many other countries according to a similar basis of calculation, the results of this study are, to some extent, also transferable to countries with similar equalisation schemes.

4.2.2 State of debate

Based on the seminal work by Buchanan (1950), empirical studies predominantly focus on the effects of fiscal equalisation on migration patterns and an efficient fund allocation.[56] Albouy (2012) applies data from Canadian provinces in 2001 to analyse the efficiency and equity purposes of the Canadian federal grant system. The author concludes that the grants increase public expenditures only moderately and thus miss the efficiency criterion. Moreover, federal grants are allocated to provinces with higher earnings and realised incomes, which is also contrary to the implied equity purpose (Albouy, 2012). Lehmann and Wrede (2019) adapt the empirical approach of Albouy (2012) to analyse the efficiency and equity aim of fiscal equalisation in the German state Bavaria. Their findings suggest that fiscal equalisation hampers efficiency, but satisfies equity conditions as the grants are allocated to regions with rather low income levels (productivity) and low realised incomes (Lehmann and Wrede, 2019).

Using data from the state of Baden-Württemberg from 1990 to 2004, Kalb (2010) analyses the effects of equalisation grants on regional technical efficiency. The author argues that an increase in equalisation grants raises technical inefficiency and results in a waste of public resources in supported regions (Kalb, 2010).

Henkel et al. (2018) apply a general equilibrium model and compare the present political reality with fiscal transfers to the counterfactual scenario without transfers across federal states and municipalities by using data from 411 German administrative districts (Landkreise). The results point to vast migration waves in the counterfactual situation without fiscal equalisation. Approximately 3.2 million people would move from present recipient regions to more productive regions, resulting in a considerable increase of national labour productivity (5.8 %) and GDP per capita (3.7 %). The

[56] I refer to the study by Albouy (2012) for a comprehensive listing of these studies.

implied net migration is 32 times higher than the net migration in Germany observed between 2000 and 2010. Moreover, public goods quality would diverge across regions. Conversely, national welfare would only increase moderately, because more productive regions already suffer from an over-congestion that would worsen. Therefore, fiscal equalisation may hamper national GDP per capita and labour productivity gains, but not welfare gains (Henkel et al., 2018).

In the context of these heterogeneous results, the next section presents the conceptual background of the study, the ensuing variable selection and discusses the expected economic effects of fiscal equalisation.

4.3. The effects of fiscal equalisation: theoretical background

To this end, various theories of economic growth (Mankiw et al., 1992; Rivera-Batiz and Romer, 1991; Romer, 1990) are used to select variables for the empirical analysis and to derive hypotheses regarding the anticipated outcomes of an increase in the formula-based grant intensity. I presume the following regional production function for each German region *i*

$$Y_i = K_i^{\alpha} H_i^{\beta} Z_i^{\gamma} (A_i (\lambda_i P_i))^{1-\alpha-\beta-\gamma}, \quad (4.1)$$[57]

which can be rewritten in terms of the economically active population (henceforth: workforce) as

$$y_i = k_i^{\alpha} h_i^{\beta} z_i^{\gamma} (A_i \lambda_i)^{1-\alpha-\beta-\gamma}. \quad (4.2)$$

Based on Equation (4.2), private k_i and public physical capital z_i, human capital h_i, technology A_i as well as the employment rate λ_i are the economic input factors to produce regional output per

[57] Y_i is the regional output, K_i denotes private physical and H_i human capital, Z_i is the public physical capital, A_i denotes the regional level of technology, while λ_i is the constant gross employment rate ($\lambda_i = L_i/P_i$), where L_i denotes labour and P_i describes the economically active population (15 to 64 years), which grows exogenously with n_i (see Eberle et al., 2019, for additional details).

workforce y_i and determine the theory-based variable selection for the applied vector-autoregressive (VAR) model in this paper.[58]

4.3.1 Unconditional effects

In this section, the theory-based hypothesis regarding the first research question is derived: Do fiscal equalisation grants trigger economic development via secondary effects? The general dynamics of the public capital stock z_i in region *i* can be expressed as (e.g. Eberle et al., 2019)

$$\frac{\dot{z}_i}{z_i} = s_{z,i}(k_i^{\alpha}\, h_i^{\beta}\, z_i^{\gamma-1}\, (A_i\lambda_i)^{1-\alpha-\beta-\gamma}) - (n_i+\delta), \tag{4.3}$$

where $s_{z,i}$ denotes the investment rate in the public capital stock and δ is the depreciation rate of public capital. Consequentially, an exogenous change in the formula-based grants directly affects the investment rate $s_{z,i}$ in Equation (4.3), which enables a region to provide a higher amount of public capital to the resident industry. The increase of the public investment rate may be higher if fiscal transfers induce additional public expenditures (efficiency purpose according to Albouy, 2012). Furthermore, changes of public investments may have additional secondary effects on further economic variables in Equation (4.2).

At first, I consider potential (short-run) effects on the gross employment rate λ_i.[59] Fiscal equalisation may have short-run effects on the labour input in regions as it affects (public-sector) labour demand and migration patterns. As outlined by Henkel et al. (2018), fiscal transfers make initially poorer regions more attractive and either induce immigration or reduce emigration, respectively. This assumption is strongly underlined by the implied 32 times higher net migration rate in the

[58] Due to the unavailability of adequate regional data, I use the private $s_{k,i}$ and public physical capital investment rate $s_{z,i}$ instead of the respective capital stocks k_i and z_i. For the same reason, instead of the regional technological level A_i, the technological growth rate g_i is used for empirical analysis (e.g. Eberle et al., 2019).

[59] Major growth models do not regard the labour dynamics in detail and, instead, assume that labour L_i grows exogenously (e.g. Mankiw et al., 1992) or is constant (e.g. Rivera-Batiz and Romer, 1991; Romer, 1990) in the long run.

hypothetical case without any fiscal equalisation payments (Henkel et al., 2018). Thus, an increase in the formula-based grant intensity is expected to positively affect regional migration behaviour, which leads to a higher labour supply and regional employment rate in the short run.

Second, the dynamics of physical capital k_i and human capital h_i are similar to the dynamics of public capital in Equation (4.3) (e.g. Mankiw et al., 1992). For this reason, an increase in the public investment rate is expected to have no effects on the fixed private sector physical capital investment rate $s_{k,i}$. However, due to efficiency gains, a positive change in the public investment rate may have positive secondary effects on the accumulation of human capital h_i. However, in regard to the anticipated influence of formula-based grants on migration patterns, the effects on the human capital also depend on the influence on the migration behaviour of high-skilled workers.

Third, following the endogenous growth approaches by Romer (1990) or Rivera-Batiz and Romer (1991), regional technological growth g_i depends on the input factors (e.g. human capital, physical capital, labour) that are assigned to the research sector. Consequently, the effects on technological growth are ex-ante rather unclear and depend on the contingent development of other input factors.

Finally, changes in the regional GDP per workforce can be written as a function of changes in regional input variables (see Equation 4.2)

$$\frac{\dot{y}_i}{y_i} = (1-\alpha-\beta-\gamma)\,\frac{\dot{A}_i}{A_i} + (1-\alpha-\beta-\gamma)\,\frac{\dot{\lambda}_i}{\lambda_i} + \alpha\frac{\dot{k}_i}{k_i} + \beta\frac{\dot{h}_i}{h_i} + \gamma\frac{\dot{z}_i}{z_i}. \tag{4.4}$$

Merging the presented arguments in this section, the first research hypothesis is:

> ***Hypothesis 4.1:*** *An increase of the formula-based grant intensity directly affects public investments $s_{z,i}$ and subsequently triggers positive secondary effects on the regional employment rate λ_i, human capital h_i and GDP per workforce y_i, while the effects on the patent*

intensity g_i are expected to be rather moderate. Moreover, no effects on the private sector physical capital investment rate $s_{k,i}$ are presumed.

4.3.2 Conditional effects: the influence of political-economic structures

With regard to the second research question, I question if economic outcomes of regional fiscal equalisation depend on the political-economic structure. To this end, I expand Equation (4.3) to (e.g. Eberle et al., 2018)

$$\frac{\dot{z}_i}{z_i} = \psi_i \, [s_{z,i}(k_i^{\alpha} \, h_i^{\beta} \, z_i^{\gamma-1} \, (A_i\lambda_i)^{1-\alpha-\beta-\gamma})] - (n_i+\delta), \tag{4.5}$$

where ψ_i indicates a parameter with a fixed value between 0 and 1 that influences the efficiency of public investments and, consequently, the degree of subsequent secondary effects emanated by public capital investments. Simply speaking, a higher value of ψ_i implies a higher share of efficiently used public investments (e.g. Eberle et al., 2018).

One conditional factor that may influence the value of ψ_i is the political-economic structure (ideology).[60] The theory of partisan politics argues that effects of macroeconomic policies are influenced by politicians and party ideologies (Hibbs, 1977). Based on this argumentation, I apply two measures for political-economic structures and ideologies in Germany.

At first, I compare the effects of fiscal equalisation between Eastern and Western German regions.[61] Due to the German division till the year 1990, both parts of former divided Germany developed

[60] In the context of EU structural and cohesion funds, Rodríguez-Pose and Garcilazo (2015) conclude that the quality of government positively affects returns on (public) investments and regional growth.

[61] Please note that a comparison between Eastern and Western German regions does not only consider political differences, it rather includes a wide range of differing (political-)economic conditions. For example, after the German reunification, GDP per capita and labour productivity differed considerably between Eastern and Western regions (e.g. Barrell and te Velde, 2000). Moreover, by analysing new business performances in East and West Germany, Fritsch (2004) argues that the political-economic system in Eastern Germany left marks that still affects economic activities.

contrarious political-economic systems, with democracy and a market economy in Western and communism and a centrally planned economy in Eastern Germany (e.g. Fritsch, 2004). This is reflected by a different party system and fragmentation in East and West Germany after reunification – for example due to the popularity of the Party of Democratic Socialism (PDS, today ‘Die Linke’) in Eastern Germany (Kitschelt, 2003). Kitschelt (2003) shows that in Eastern Germany the share of votes for social parties in the federal elections 1998 and 2002 are higher than for rather conservative and pro-business parties. I relate the differing political-economic structures in former divided Germany to the regional fiscal equalisation scheme and hypothesise:

> ***Hypothesis 4.2:*** *The anticipated effects in hypothesis 4.1 are assumed to primarily apply for Western German regions as these regions support rather pro-business parties and are more effective to transform public investments into economic growth (higher ψ_i).*

Second, I analyse the influence of political ideologies in German regions more specified. In line with partisan theories, Potrafke (2011) states that left-wing parties are more focused on the labour base, while, in contrast, right-wing parties rather act in accordance with capital owners. Using data from Western German federal states, Potrafke (2011) examines the effects of political ideologies on public expenditures. The results hint at no significant effects on overall public expenditures on education and cultural affairs. However, by decomposing public expenditures, left-wing parties positively influence public expenditures on schooling, while negatively affect expenditures on cultural affairs. Conversely, rather right-wing parties increase public expenditures on universities. Thus, the findings show evidence that political ideologies and priorities influence budget composition of German federal states (Potrafke, 2011). Pinto and Pinto (2008) find evidence that left-wing governments positively influence the effects of foreign direct investments on wages in Organisation for Economic Co-operation and Development (OECD) countries. Taking these findings into account, I compare the effects in regions that support the rather left-wing Social Democratic Party (SPD) with the effects in right-wing and more pro-business CDU/CSU supporting regions:

Hypothesis 4.3: *With exception of the regional employment rate, the economic effects are expected to be higher in regions supporting the pro-business CDU/CSU party (higher ψ_i).*

4.3.3 Effects of structural funding

The GRW structural funding programme explicitly aims to promote the economic development of the least prosperous German regions, therefore funding is restricted exclusively to these regions. In contrast to the described targets of regional fiscal equalisation, the GRW mainly works via two funding channels: first, by providing grants to firms in order to set incentives for a higher private sector investment rate and, second, by strengthening the local economic infrastructure (Brachert et al., 2018; Deutscher Bundestag, 2014). Consequently, GRW funding is much more industry-orientated compared to regional fiscal equalisation schemes, leading to the fourth hypothesis:

Hypothesis 4.4: *The implied economic effects of regional fiscal equalisation in hypothesis 4.1 are significantly lower compared to economic effects of the more industry-orientated GRW funding programme.*

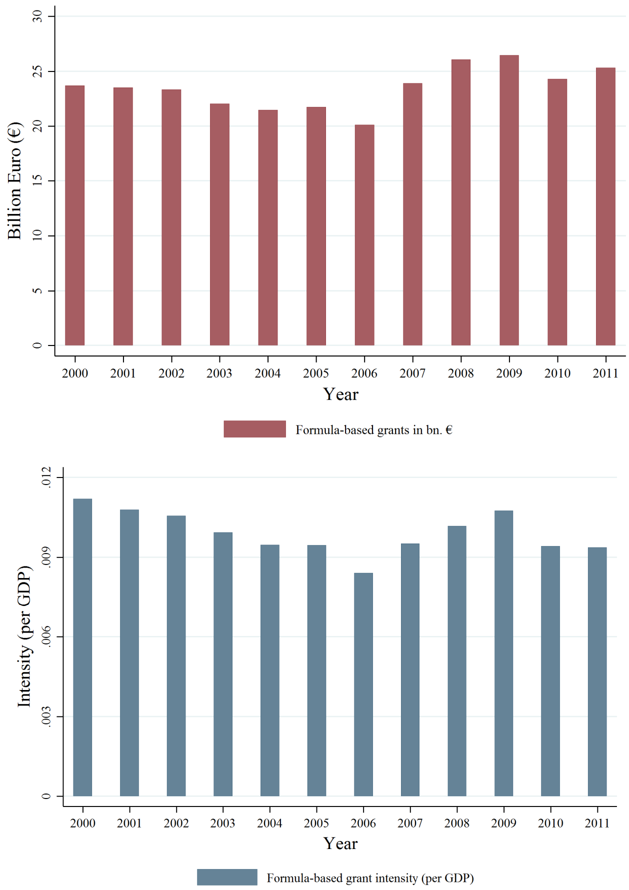
4.4. Data and empirical strategy

4.4.1 Data and variables

I use data for six economic in- and output factors covering the observation period 2000 to 2011. At the municipality level, data is available only inadequately. Therefore, data is collected on the basis of the 402 German districts (Landkreise). Thereupon, I aggregate the districts to 258 labour market regions (Arbeitsmarktregionen) that are defined by the BBSR. Labour market regions explicitly account for economic ties across the small-scale German Kreise (e.g. by regarding commuting traffic) and reduces the risk of measurement errors when constructing normalised variables as, for example, places of work and residence may differ using a classification according to the German Kreise.[62] The applied variables are normalised and converted in logarithmic form as specified in more detail in Table A4.1 in the Appendix.

Figure 4.1 illustrates the annual amount of total formula-based grants as well as the ratio of formula-based grants to GDP (formula-based grant intensity) in Germany. Funding volume and ratio are fairly constant over the covered time period, with a peak in the funding volume of 26.46 billion Euro in 2009 and a ratio of 1.12 % of annual GDP in the year 2000.

Figure 4.1 Annual formula-based grants and formula-based grant intensity, 2000-2011

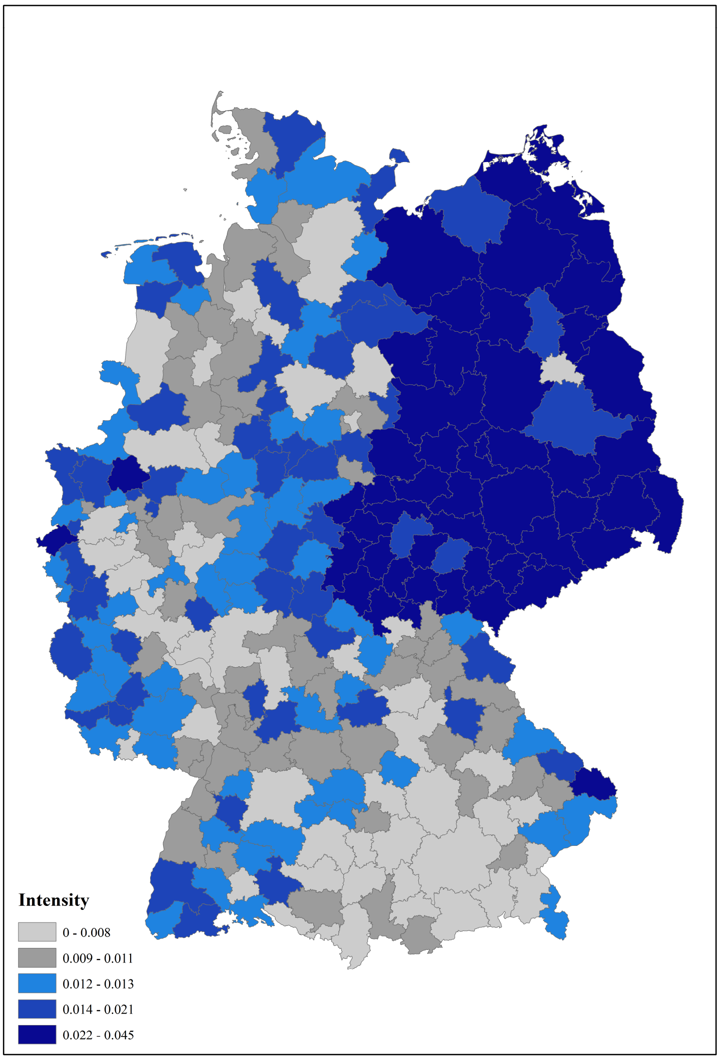


Notes: Own figure (based on data from BBSR).

[62] One potential shortcoming regarding the data for the formula-based grants is related to changed labels of allocated funds within the fiscal equalisation scheme. Regional authorities may receive the same overall amount of allocated funds but under a different label. I assume that these changes are random and add time dummies to the regression models to account for potential effects of these changes in public funding labeling.

Figure 4.2 shows the spatial patterns of the formula-based grant intensity across German labour market regions. The figure illustrates the importance of formula-based grants especially for East Germany, where the ratio of formula-based grants to GDP is considerably higher compared to Western regions.[63]

Figure 4.2 Formula-based grant intensities in German labour market regions, 2000-2011



Notes: Own figure (based on data from BBSR).

[63] In Figure 4.2, the respective ratio for each labour market region is calculated for the entire time period according to the following formula: $Intensity_i = (\sum_{n=2000}^{2011} \text{Formula-based grants}_i) / (\sum_{n=2000}^{2011} GDP_i)$. Moreover, when subdividing the sample in Eastern and Western regions, I compare the economic responses to a funding increase that is equal to one respective standard deviation in each subsample and, additionally, to the same percentage rise in order to account for different formula-based grant intensities in Eastern and Western Germany. The same applies for the comparison of regions with different political ideologies (see Section 4.4).

The five labour market regions with the lowest ratio of formula-based grants to GDP include the economically prosperous regions of Munich and Düsseldorf as well as Berlin, Hamburg and Bremen. Conversely, the five highest ratios appear to be in East Germany, with the highest ratio of 0.0454 in Mansfeld-Südharz (Table 4.1).[64]

Table 4.1 German labour market regions with the highest and the lowest ratio of formula-based grants, 2000-2011

	Labour market region	**Ratio of formula-based grants to GDP**
Low ratio	Berlin	0
	Munich	0.0008
	Düsseldorf	0.0012
	Hamburg	0.0015
	Bremen	0.0023
High ratio	Altenburg	0.0366
	Salzlandkreis	0.0379
	Wittenberg	0.0384
	Stendal	0.0418
	Mansfeld-Südharz	0.0454

Notes: Own calculation (based on data from BBSR).

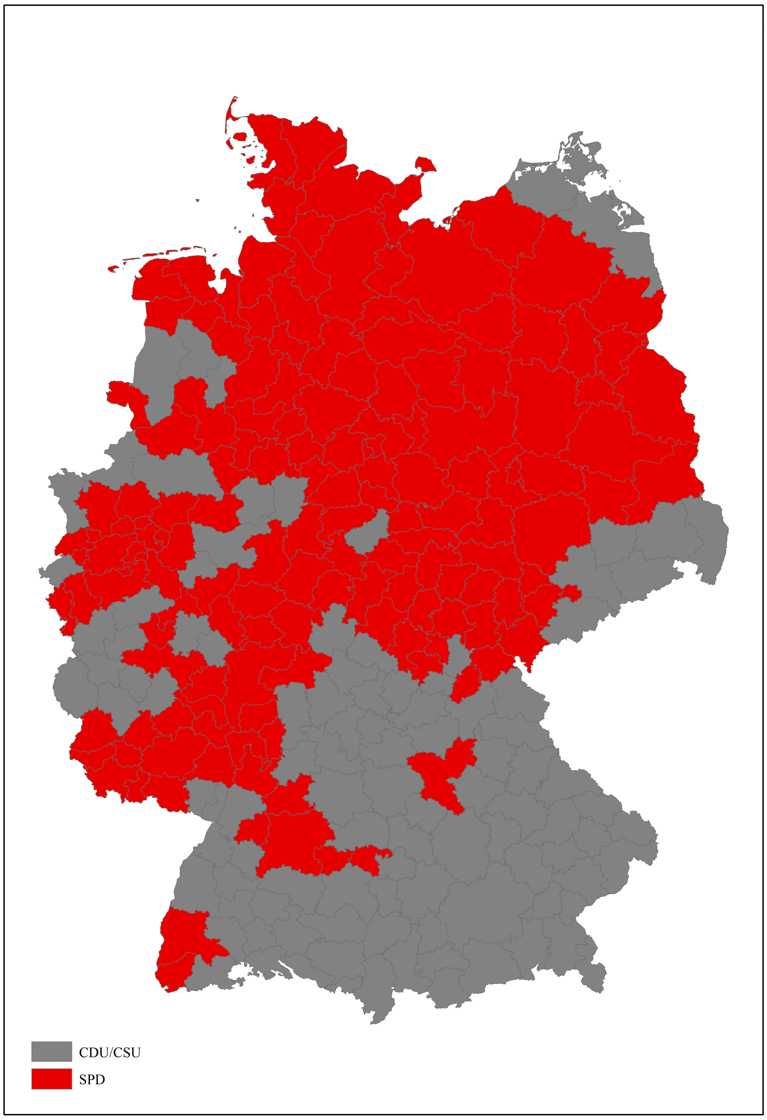
Moreover, I include the spatial lag of each variable to the VAR model and refer to this setup as basic model.[65] Spatial autocorrelation is assumed to be an empirical issue that may result from a divergence between the applied regional scale (labour market regions) and the actual degree of spatial autocorrelation. For this reason, spatial dependencies are not discussed in Section 4.3 but spatial lags are included as control variables to the regressions models.

[64] The lowest ratio is observed for Berlin, which is the only labour market not receiving any formula-based grants in the covered time period. By definition, city states do not have fiscal equalisation. In contrast to the other city states Hamburg and Bremen (Bremerhaven), the small-scale district Berlin is not aligned with other districts to a common labour market. Thus, as shown in Table 4.1, the respective grant intensity is higher than zero in Hamburg and Bremen, but they are also counted among the labour markets with the lowest grant intensities.

[65] A binary first-order neighbourhood matrix is used for the calculation of the spatial relationships (e.g. Eckey and Kosfeld, 2005).

Panel unit root tests according to the approach by Im et al. (2003) show that not all time series are stationary. The non-stationarity applies for the regional gross employment and human capital rate as well as for the spatial lags of these variables (see Table A4.2). Consequently, detrended values are used for estimation. Moreover, the panel unit root test for the formula-based grant intensity indicates stationarity, but impulse response function (IRF) analysis does not work without detrending. Thus, I also use the detrended variable for the formula-based grant intensity in all settings.

Figure 4.3 Spatial patterns highest share of second votes Bundestag elections 1998



Notes: Own figure (based on data from Allgemeine Bundestagswahlstatistik des Bundes und der Länder/ INKAR).

In order to detect potential effects of differences in political-economic structures and ideologies, I initially subdivide the labour market regions in former East and West German regions, while Berlin is excluded from this subdivision. Moreover, the share of second votes for the Bundestag elections in the year 1998 is used as a more specific approximation for the regional political ideology. In doing so, the Bundestag election in the year 1998 is chosen to guarantee predeterminedness of the indicator.[66] Figure 4.3 shows that the SPD reached the highest share of votes in 153 German labour market regions, while the right-wing party CDU/CSU gained the highest share of votes in the remaining 105 regions. This figure also indicates that either the SPD or the CDU/CSU gained the highest share of votes in the 258 German labour market regions in Bundestag elections 1998 and thus allows researchers to analyse the presented left-right ideology (e.g. Potrafke, 2011).[67]

The applied indicator for political ideology may have some drawbacks that are briefly discussed in the following: First, the election behaviour may differ between Bundestag and local elections. Thus, Bundestag elections may not always represent regional government composition perfectly, for which reason the results should be interpreted carefully. However, I assume that the share of second votes for the Bundestag elections is, for the most part, a proper approximation of regional political ideology. Second, one political party is rarely able to govern without coalition partners. However, the regions are subdivided according to the party with the highest share of votes because the major party largely enforce the political agenda and significantly influence the regional government agenda. Third, the respective party with the highest share in 1998 may be replaced by another party in subsequent elections, leading to a misinterpretation of the results. To tackle this

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[66] The subdivision and identification is likely to be exogenous, because parties on this administrative level do not influence the allocation regulations that are made on federal state level.

[67] Correlation coefficient $\rho_{SPD\text{-}East} = 0.2476$ indicates that the correlation between Eastern regions and SPD preferring regions is small, although SPD is slightly more favored in East German regions (Berlin is excluded for calculation). The correlation coefficient indicates an adequate level of independence between the two subsamples.

issue, a robustness check is performed that includes only these regions, where the major party in 1998 also gains the highest shares of votes in the subsequent Bundestag elections 2002 and 2005. Fourth, labour market regions often comprise multiple small-scale administrative districts (Kreise) and the popularity of the SPD and CDU/CSU within one labour market region may differ in the associated districts. Thus, a further robustness test applies only these labour markets regions for analysis, where the leading party has the highest share of votes in all associated administrative districts.

4.4.2 Econometric identification strategy

A simultaneous equation approach allows to analyse the total effects of formula-based grants on all variables in the described economic system by considering diverse transmission channels. Thus, besides direct effects that are usually measured by the estimated coefficient in a single equation approach, the applied VAR setup also accounts for indirect effects among the six variables in the regional system (structural VAR approach, see Rickman, 2010). For example, formula-based grants may affect regional GDP per workforce not directly via the particular coefficient in the GDP equation, but indirectly via an increased human capital or employment rate that, in turn, affect the GDP per workforce.

Based on the theory-based variable selection in Section 4.3, I apply a structural spatial panel VAR model with six equations, comprising the following six endogenous variables: 1) public physical capital investment rate $\mathbf{s_z}$, 2) human capital $\mathbf{h}$, 3) patent intensity $\mathbf{g}$, 4) private physical capital investment rate $\mathbf{s_k}$, gross employment rate $\boldsymbol{\lambda}$, 6) output per workforce $\mathbf{y}$. Based on this, the applied structural spatial panel VAR model can be formulated in matrix notation as (e.g. Eberle et al., 2019)

$$\mathbf{A}\mathbf{y}_t = \mathbf{B}\mathbf{y}_{t-1} + \mathbf{C}\mathbf{W}\mathbf{y}_{t-1} + \mu + \tau_t + \mathbf{D}\mathbf{e}_t, \tag{4.6}$$

where $\mathbf{y}_t$ is a vector that contains the six endogenous variables, **A** is a matrix of contemporaneous parameters, **B** and **C**, respectively, represent matrices of polynomials that connect time lagged as well as time-space lagged variables to contemporaneous variables, μ and τ_t are vectors covering region- and time fixed effects, **D** represents a diagonal matrix connecting the endogenous variables to exogenous shocks and $\mathbf{e}_t$ is a vector of orthogonal errors (e.g. Eberle et al., 2019; Keating, 1992; Mitze et al., 2018; Rickman, 2010).[68] Using the moving average (MA) presentation of the VAR model, total effects of an orthogonal increase in the formula-based grant intensity ($\mathbf{s_z}$) on the remaining economic in- and output factors are calculated and graphically presented. Based on Monte Carlo simulations with 1000 repetitions, confidence intervals are constructed in order to make statements about the significance of the estimated responses (Love and Zicchino, 2006).

Finally, the IRF analysis can be conducted separately for the *isolated* total spatially direct effects (changes in $\mathbf{y}_{t-1}$ on $\mathbf{y}$) and the *isolated* total spatially indirect effects (changes in $\mathbf{Wy}_{t-1}$ on $\mathbf{y}$) (e.g. Eberle et al., 2019). While the focus of the empirical analysis in Section 4.5 is on the computation of the *isolated* total spatially direct effects, response functions of *isolated* total spatially indirect effects are computed in order to test how fiscal equalisation schemes affect the spatial vicinity.

Finally, the presented VAR model is conducted separately for each subsample according to the East-West and SPD-CDU/CSU classification and, ex-post, a *t*-test analysis is applied to test the null hypothesis of no statistical significant differences between the estimated responses (Eberle et al., 2018)

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[68] In order to prevent redundancy, the applied spatial panel VAR is explained only briefly here. A bias-corrected fixed-effects estimator, based on Everaert and Pozzi (2007), is used for estimation of the six equations that are estimated in the reduced-form VAR specification. Detailed information regarding the causal ordering at time *t* to identify the structural parameters **A** and errors $\mathbf{e}_t$ (Choleski decomposition) and further estimation issues are given in the study by Eberle et al. (2019). The formula-based grant intensity is assumed to be the most exogenous variable in the described economic system (assumed ordering: $\mathbf{s_z}$ - $\mathbf{h}$ - $\mathbf{g}$ - $\mathbf{s_k}$ - $\boldsymbol{\lambda}$ - $\mathbf{y}$), implying contemporaneous effects on all other variables at time *t*.

$$t_t = \frac{IRF_{region1} - IRF_{region2}}{\sqrt{\frac{sd^2_{region1}}{N_{region1}} + \frac{sd^2_{region2}}{N_{region2}}}}. \tag{4.7}$$

In Equation (4.7), $IRF_{region1}$ and $IRF_{region2}$, respectively, denote the estimated responses in the two subsamples at year *t*, while $sd_{region1}$ and $sd_{region2}$ are the standard deviations, which are approximated using the constructed confidence intervals. Finally, $N_{region1}$ and $N_{region2}$ express the amount of repetitions in the conducted Monte Carlo simulation (here: N = 1000) (Eberle et al., 2018). I perform a *t*-test analysis using the respective original shock in each subsample that is equal to one respective standard deviation (may differ between the subsamples). In order to control for large differences of these initial shocks, I also conduct a *t*-test analysis comparing the economic responses to an equal shock in terms of the same percentage rise in both subsamples.

4.5 Empirical results

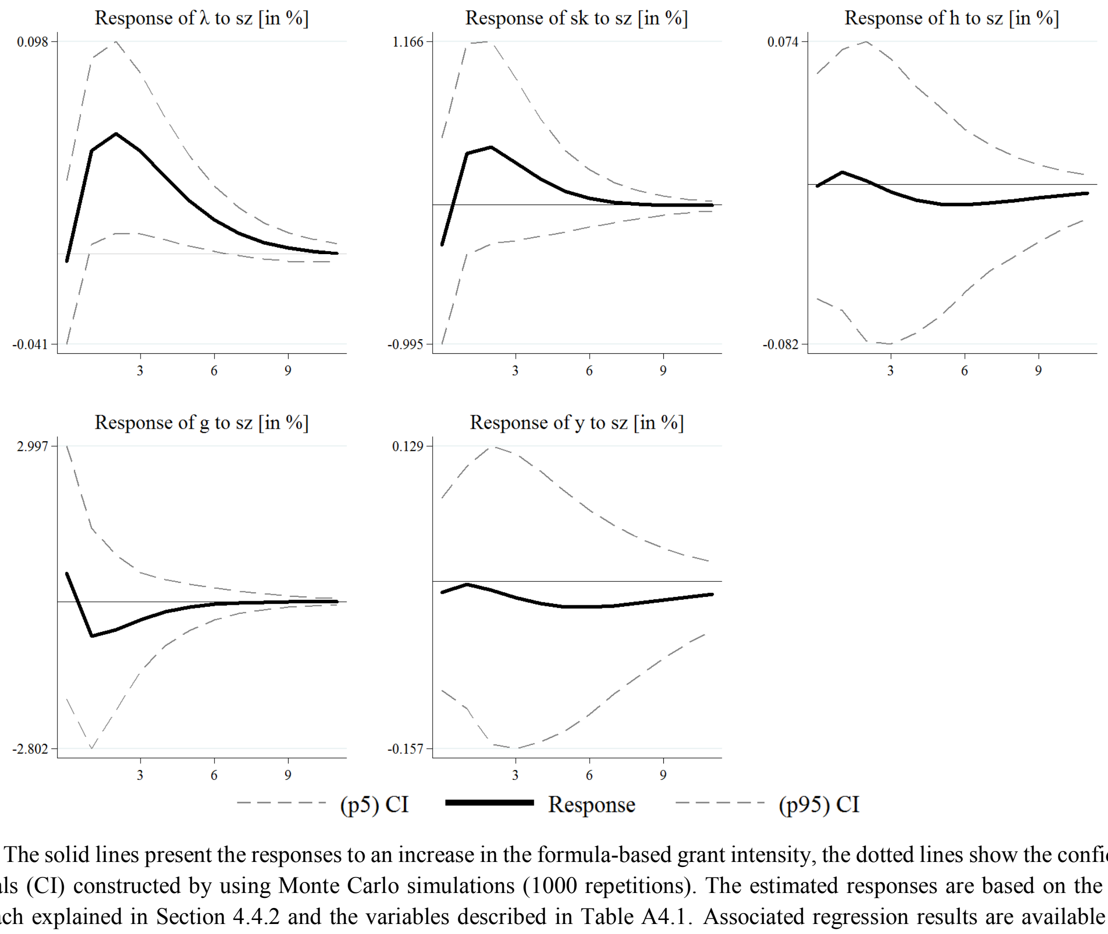
4.5.1 Unconditional effects

I start by analysing the economic effects of a formula-based grant intensity increase ("shock") for the defined set of variables with $\mathbf{y_t} = [s_z, h, g, s_k, \lambda, y_t]$. The continuous lines in Figure 4.4 show the particular response of an economic variable to an increase in the formula-based grant intensity, while the associated dotted lines indicate the constructed error bands. Each response is multiplied by 100 in order to express the estimated effects as a percentage [%].

The estimated response of the regional gross employment rate (λ) implies significant positive effects, which is in line with hypothesis 4.1. The intuition is that formula-based grants may internalise public externalities and have positive effects on the migration behaviour, both leading to a higher labour supply and gross employment rate. Moreover, more financial resources may lead to higher levels of employment especially due to an increasing demand in the public sector. In line with the ex-ante expectations, the estimated magnitude of the private sector physical capital investment rate

(s_k) is small and non-significant. In addition, the plotted IRFs suggest that mainly low-skilled workers are impacted by an increase in the formula-based grant intensity, while the stock of high-skilled workers remains unaffected by a change – expressed by a statistically insignificant response of the human capital (h). That said, the patent intensity (g) displays an insignificant response as well. Finally, an increase in the formula-based funding intensity is not associated with a higher regional GDP per workforce (y). Thus, the positive response of the employment rate appears to be driven predominantly by an increase of low-skilled workers with a rather low average productivity in industrial production.

Figure 4.4 Impulse response function analysis formula-based grants (spatially direct effects), basic model



Notes: The solid lines present the responses to an increase in the formula-based grant intensity, the dotted lines show the confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Subsequently two robustness checks are provided. First, the spatial lag $\mathbf{Wy_{t-1}}$ of the particular dependent variable is excluded in each of the six equations because this variable is supposed to be weakly exogenous and may suffer from a bias in the applied fixed-effects estimator approach (see Figure A4.1 in the Appendix for the results).[69] Second, additive public investments are added as control variable to the regression models (see Figure A4.2 for the results and Table A4.1 for details). The results of the two robustness checks emphasise that neither the exclusion of the particular spatial lag variable nor the inclusion of the public funding intensity of additive public policies leads to serious changes of the plotted IRF results.

Figure A4.3 in the Appendix shows the *isolated* total spatially indirect effects of an increase in the formula-based funding intensity. I use the same initial increase ("shock") in the grant intensity as in Figure 4.4 (basic model) and I assume the same contemporaneous relationship across the six spatial lag variables compared to the non-spatial model (same **A** matrix).[70] The results hint at significant negative effects of an increase in the formula-based grant intensity in neighbouring regions on the grant-intensity in region *i*. This finding suggests that regions are competing for formula-based grants as an increase in the neighbourhood may be indirectly financed by region *i* (by receiving less formula-based grants, respectively). In addition, a shock in neighbouring regions abates much faster than the spatially direct effects and the error belts suggest non-significant effects for all economic variables.

[69] The applied bias-corrected fixed-effects estimator is supposed to correct only for the bias in the time lag of the particular dependent variable $\mathbf{y_{t-1}}$ in each regression model. However, this bias is more severe than the potential bias of $\mathbf{Wy_{t-1}}$ for the respective dependent variable, which is only included as control variable in the basic model.

[70] The definition of the spatial model (see Equation (4.5)) precludes contemporaneous effects from neighbouring regions on $\mathbf{y_t}$, for which reason they are 0 at time *t*.

4.5.2 Conditional effects

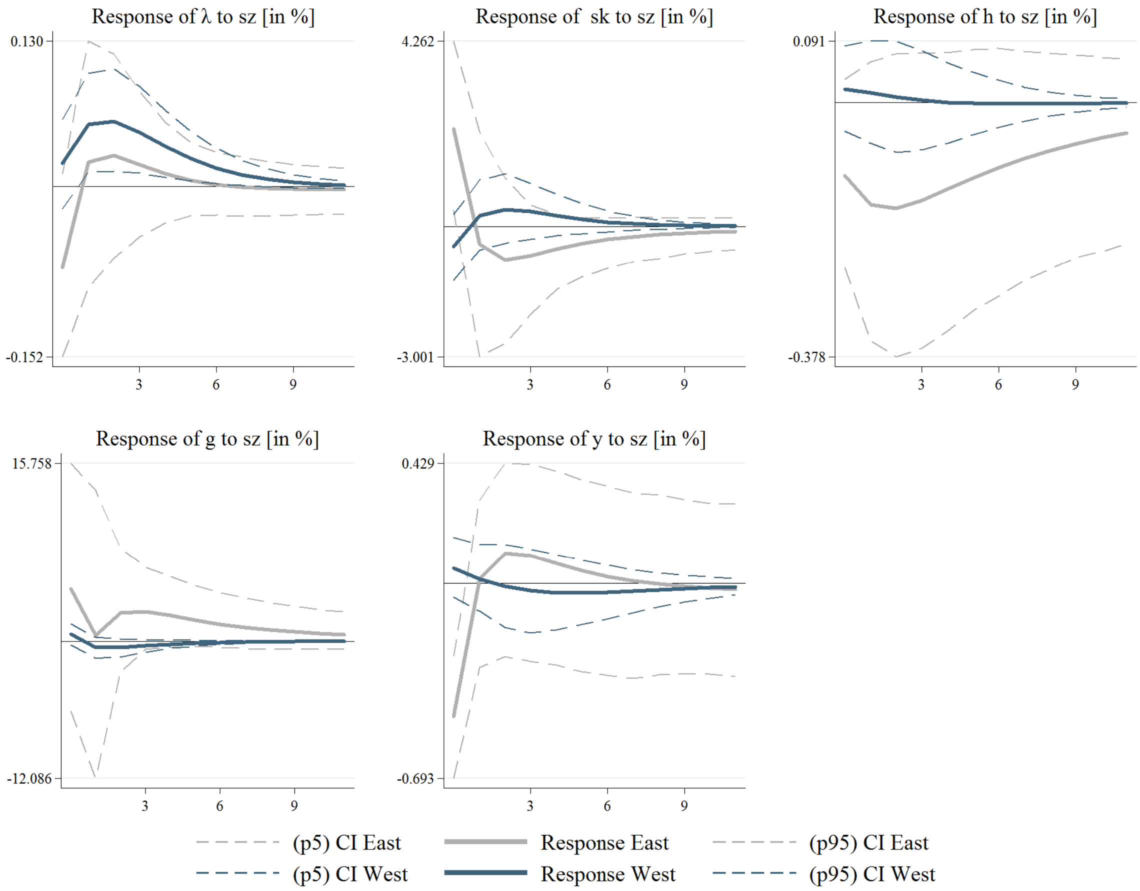
In this section, I split the basic sample into subsamples, starting with comparing the plotted IRFs in Eastern and Western German regions. Due to its special status in divided Germany, Berlin is excluded from analysis. In both setups, the two continuous lines (blue and grey) display the economic responses, while the dotted lines in grey and blue report the associated confidence intervals.

Figure 4.5 shows the responses of Eastern and Western German regions to a shock in the formula-based funding intensity. With regard to the significance and the magnitude of the estimated responses, the results hint at only minor differences for the human capital and the patent intensity between the subsamples. However, the response of the employment rate to an increase in the formula-based grant intensity is significant positive only for Western German regions. Moreover, in the year of the funding increase, the magnitude of the response is also significantly higher in West Germany (if the respective one standard deviation increase is used for the computation, see Table A4.3).

Additionally, the plotted IRFs suggest short-run significant negative effects on the GDP per workforce in East Germany. This finding is also supported by a statistically significantly lower response in the year of the funding increase in Eastern German regions. Conversely, the findings hint at short-run significant positive effects on the private sector physical capital investment rate in Eastern German regions, also reflected by a significant higher magnitude in the year of the funding change. However, this finding is limited to the year of a grant increase.

The described moderate differences may be explained by an unequal conceptualization and implementation of fiscal equalisation as well as by different political ideologies in East and West Germany (hypothesis 4.2). However, one should keep in mind that the economic conditions in both parts of former divided Germany are still different. The marginal productivity of capital may be smaller in West compared to East Germany as regions are closer to their individual steady state level. Thus, Western regions may be more focused on the employment target, while Eastern German regions use the grants primarily to create incentives for firms to raise the private sector investment rate. In addition, average wages are still lower in Eastern German regions, for which reason it may be more complex to influence the migration patterns of employees. The short-run negative response of the GDP per workforce becomes positive in subsequent years, which is why I do not overvalue this finding.

Figure 4.5 Impulse response function analysis formula-based grants, East – West German labour market regions

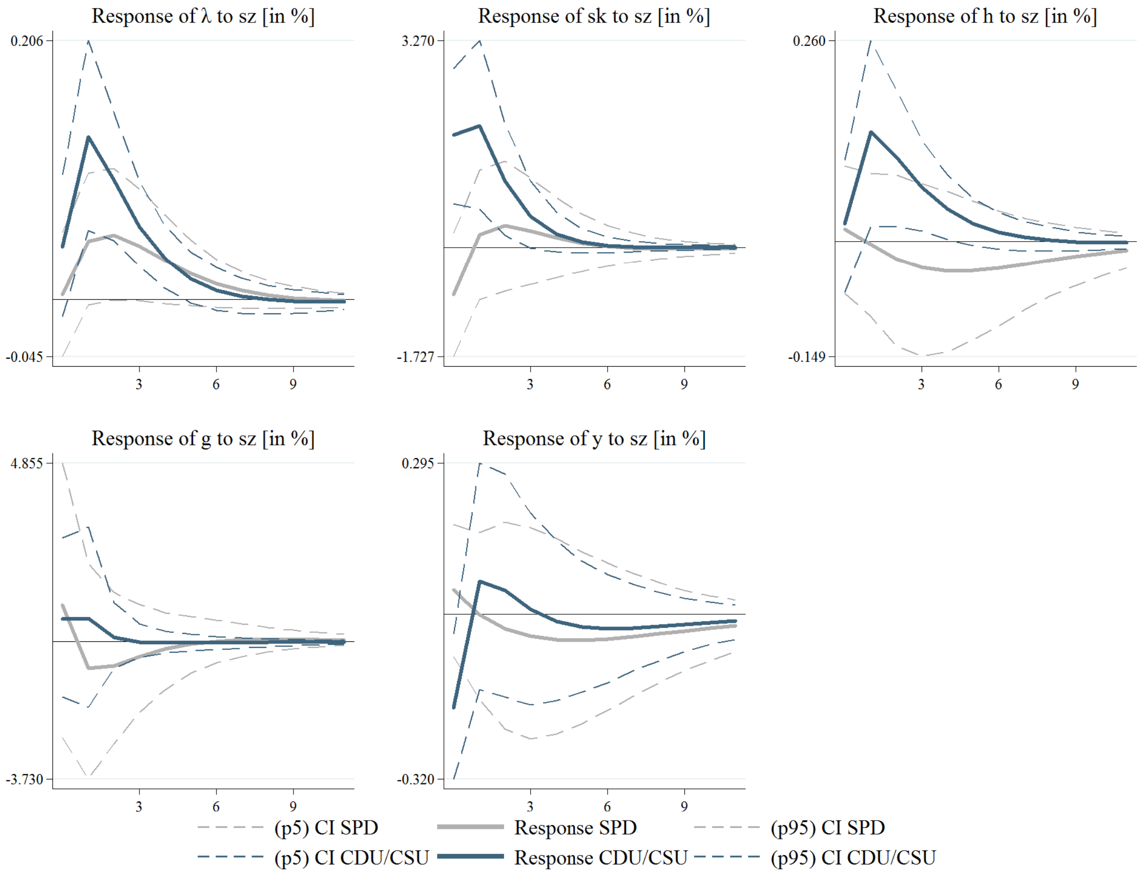


Notes: The solid lines present the responses to an increase in the formula-based grant intensity in East (grey) and West German regions (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

In a second investigation, I deepen the analysis on the influence of political ideologies on the economic responses to an increase in the grant intensity by using the share of votes for German parties.

Figure 4.6 displays the differences in the use of fiscal grants between left-wing SPD and pro-business CDU/CSU preferring regions. The effects in SPD supporting regions are non-significant for all economic in- and output variables, while fiscal equalisation triggers statistically significant positive effects on the employment, human capital and private sector investment rate in CDU/CSU preferring regions. Carefully speaking, regions with a high share of votes for the right-wing and pro-business CDU/CSU transform an increase in the grant intensity not solely to more employment, but also to an increase of high-skilled employment (human capital). Conversely, the findings also suggest short-term negative effects on the GDP per workforce in these regions but the response turns into non-significant positive effects in subsequent years.

Figure 4.6 Impulse response function analysis formula-based grants, Share of votes SPD – CDU/CSU



Notes: The solid lines present the responses to an increase in the formula-based grant intensity in regions with a major share of voters for the SPD (grey) and the CDU/CSU (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

I run several robustness checks for the applied SPD-CDU/CSU classification. At first, I use only these regions, where SPD or CDU/CSU receive the highest shares of votes in the Bundestag elections 1998, 2002 and 2005. Second, I consider only these labour market regions, where either SPD or CDU/CSU receive the highest share of votes 1998 in all inherent small-scale Kreise. The findings for both robustness checks remain robust and almost unchanged (see Figures A4.4 and A4.5). Finally, I use only these regions for analysis, where the SPD or CDU/CSU receive the highest share of votes in all inherent Kreise in the respective Bundestag elections of 1998, 2002 and 2005. The IRF analysis confirms that economic responses in CDU/CSU supporting regions are robust, while the economic responses and associated confidence intervals in SPD supporting regions change to a greater extend in this setting (see Figure A4.6). The findings hint at significant positive effects of an increase in the grant intensity on the employment rate as well as on the regional GDP per workforce in SPD preferring regions. However, the latter finding is only significant in the year of the shock. In subsequent years, the response becomes insignificant and negative. The estimated economic responses in Figure A4.6 are considered as the most robust classification and thus these responses are used to perform a *t*-test analysis. The estimated response of the GDP per workforce is significantly higher in SPD preferring regions in the year of the funding increase, while the results hint at significantly higher (short-term) effects on the regional employment, human capital and investment rate in CDU/CSU supporting regions (see Table A4.4). The conducted analysis emphasises that the findings are partially in line with the formulated expectations in hypothesis 4.3 but statistically significant differences are restricted to single years.

4.5.3 Economic effects of fiscal equalisation compared to structural funding

Finally, this section determines potential differences between fiscal equalisation and the structural funding programme GRW. To this end, I initially estimate the economic effects of an increase in overall GRW funding intensity. In doing so, the funding intensity of remaining public investments is included as control variable.[71] The plotted IRFs in Figure A4.7 illustrate the responses to an increase in the overall GRW and formula-based grant intensity, respectively. The findings support the robustness of the results by Eberle et al. (2019), suggesting statistically significant positive effects of overall GRW investments on the employment and human capital rate as well as on regional GDP per workforce.

Table 4.2 shows the results of *t*-test analysis comparing the estimated economic responses to an increase in the formula-based grant and GRW funding intensity. Using the estimated responses to an initial shock that amounts each to one respective standard deviation (may differ between both subsamples), an increase in the GRW is associated with statistically significantly higher responses of the regional GDP per workforce, employment and human capital rate. The responses of the patent activity and private sector investment rate are not significantly different. However, calculating the economic responses based on a rescaled initial shock (same initial percent rise), the statistically significant differences in the magnitudes of the economic responses diminish. Thus, the findings suggest that GRW funding triggers significant positive effects on more economic variables compared to regional fiscal equalisation but the magnitudes are not higher compared to these of regional fiscal equalisation (hypothesis 4.4 is not confirmed).

[71] This approach is the same as the robustness check regarding formula-based grants illustrated in Figure A4.2.

Table 4.2 *t*-test analysis comparing economic responses to an increase in the formula-based grant and overall GRW intensity (based on Figure A4.7)

Funding increases are one *sample-specific* standard deviation in each subsample						**Funding increases are equal to the same % in each subsample***					
Time	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**Time**	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	0.5125	0.3042	0.6958	0.6084	0	lhk	0.0471	0.4812	0.5188	0.9625
1	lhk	-1.0500	0.8531	0.1469	0.2938	1	lhk	-0.0151	0.5060	0.4940	0.9880
2	lhk	-1.4876	0.9315	0.0685	0.1370	2	lhk	-0.2139	0.5847	0.4153	0.8306
3	lhk	-1.6812	0.9536	**0.0464**	0.0929	3	lhk	-0.3912	0.6521	0.3479	0.6957
4	lhk	-1.7880	0.9630	**0.0370**	0.0739	4	lhk	-0.5496	0.7087	0.2913	0.5826
5	lhk	-1.8380	0.9669	**0.0331**	0.0662	5	lhk	-0.6819	0.7523	0.2477	0.4954
6	lhk	-1.8658	0.9689	**0.0311**	0.0622	6	lhk	-0.8048	0.7895	0.2105	0.4210
7	lhk	-1.8398	0.9670	**0.0330**	0.0659	7	lhk	-0.9028	0.8166	0.1834	0.3667
8	lhk	-1.8157	0.9652	**0.0348**	0.0696	8	lhk	-0.9847	0.8375	0.1625	0.3249
9	lhk	-1.7815	0.9625	**0.0375**	0.0750	9	lhk	-1.0430	0.8515	0.1485	0.2971
10	lhk	-1.7084	0.9561	**0.0439**	0.0877	10	lhk	-1.0921	0.8625	0.1375	0.2749
11	lhk	-1.6454	0.9500	0.0500	0.1000	11	lhk	-1.1325	0.8712	0.1288	0.2575
12	lhk	-1.5892	0.9439	0.0561	0.1122	12	lhk	-1.1483	0.8745	0.1255	0.2510
0	lemp	-0.8514	0.8027	0.1973	0.3946	0	lemp	-0.3378	0.6322	0.3678	0.7355
1	lemp	-0.6330	0.7366	0.2634	0.5268	1	lemp	1.4616	0.0720	0.9280	0.1440
2	lemp	-0.7694	0.7791	0.2209	0.4418	2	lemp	1.6182	0.0529	0.9471	0.1058
3	lemp	-1.0750	0.8587	0.1413	0.2825	3	lemp	1.5774	0.0574	0.9426	0.1149
4	lemp	-1.4231	0.9226	0.0774	0.1549	4	lemp	1.4331	0.0760	0.9240	0.1520
5	lemp	-1.7658	0.9612	**0.0388**	0.0776	5	lemp	1.1771	0.1197	0.8803	0.2393
6	lemp	-2.1008	0.9821	**0.0179**	**0.0358**	6	lemp	0.8506	0.1975	0.8025	0.3951
7	lemp	-2.3005	0.9892	**0.0108**	**0.0215**	7	lemp	0.4598	0.3228	0.6772	0.6457
8	lemp	-2.4513	0.9928	**0.0072**	**0.0143**	8	lemp	0.0678	0.4730	0.5270	0.9459
9	lemp	-2.4982	0.9937	**0.0063**	**0.0126**	9	lemp	-0.2787	0.6097	0.3903	0.7805
10	lemp	-2.4751	0.9933	**0.0067**	**0.0134**	10	lemp	-0.5420	0.7060	0.2940	0.5879
11	lemp	-2.3801	0.9913	**0.0087**	**0.0174**	11	lemp	-0.7426	0.7711	0.2289	0.4578
12	lemp	-2.3044	0.9893	**0.0107**	**0.0213**	12	lemp	-0.8950	0.8146	0.1854	0.3709
0	lgdp	1.5472	0.0610	0.9390	0.1220	0	lgdp	0.1582	0.4372	0.5628	0.8743
1	lgdp	-0.5099	0.6949	0.3051	0.6102	1	lgdp	-0.0829	0.5330	0.4670	0.9339
2	lgdp	-1.1824	0.8814	0.1186	0.2372	2	lgdp	-0.2752	0.6084	0.3916	0.7832
3	lgdp	-1.4906	0.9319	0.0681	0.1362	3	lgdp	-0.4344	0.6680	0.3320	0.6640
4	lgdp	-1.6220	0.9475	0.0525	0.1050	4	lgdp	-0.5679	0.7149	0.2851	0.5702
5	lgdp	-1.6913	0.9545	**0.0455**	0.0909	5	lgdp	-0.6716	0.7491	0.2509	0.5019
6	lgdp	-1.7124	0.9565	**0.0435**	0.0870	6	lgdp	-0.7605	0.7765	0.2235	0.4471
7	lgdp	-1.7060	0.9559	**0.0441**	0.0882	7	lgdp	-0.8389	0.7992	0.2008	0.4017
8	lgdp	-1.7078	0.9561	**0.0439**	0.0878	8	lgdp	-0.8986	0.8155	0.1845	0.3690
9	lgdp	-1.6779	0.9532	**0.0468**	0.0935	9	lgdp	-0.9509	0.8291	0.1709	0.3418
10	lgdp	-1.6392	0.9493	0.0507	0.1013	10	lgdp	-1.0000	0.8413	0.1587	0.3174
11	lgdp	-1.5949	0.9445	0.0555	0.1109	11	lgdp	-1.0302	0.8485	0.1515	0.3031
12	lgdp	-1.5538	0.9398	0.0602	0.1204	12	lgdp	-1.0535	0.8539	0.1461	0.2922

Notes: diff = mean(formula-based grant intensity) - mean(overall GRW intensity); H0: diff = 0; degrees of freedom = 1198. Only variables with significant differences are presented. *Initial shock in the GRW intensity is rescaled to the amount of the initial shock in the formula-based grant intensity.

4.6 Conclusions

This paper adds to recent literature by analysing the economic effects of regional fiscal equalisation in Germany. While the primary aim of regional fiscal equalisation is to endow regions with a sufficient level of financial resources to provide public goods, potential economic secondary effects are widely disregarded so far. I explicitly consider three features of German regional fiscal equalisation: First, I account for a potential multifaceted impact character by applying a VAR approach and IRF analysis. Second, I examine conditional effects by subdividing the basic sample according to political-economic structures. Third, I compare the effects to the economic outcomes of rather industry-oriented structural funding in Germany.

Using a sample comprising the full set of 258 German labour market regions as basic model, the plotted IRFs suggest statistically significant positive effects on the regional employment rate. This finding may express the influence on migration patterns of rather low-skilled workers and on employees in the public sector. However, the overall economic secondary effects are moderate because further economic variables are not affected statistically significant. Carefully speaking, regional fiscal equalisation cannot be considered as ideal policy instrument to spur regional development in a multifaceted way.

In addition, I find only small heterogeneous treatment responses across the defined subsamples: the results suggest statistically significantly higher responses on the employment rate and GDP per workforce in Western regions, while the effects are higher on the private sector investment rate in Eastern regions. However, the differences appear only for single years and shortly after an increase in the funding intensity. Moreover, the results hint at significantly higher effects on the employment, human capital and investment rate in CDU/CSU preferring regions, while an increase is associated with higher effects on the GDP per workforce in SPD supporting regions (in the short-run perspective). Thus, political-economic structures influence the working of formula-based grants especially in the short run but their influence should not be overrated by policy makers.

Finally, an initial increase amounting to one respective standard deviation leads to significant higher effects of the GRW programme on the GDP per workforce, the employment and human capital rate, while the significant differences diminish when using an initial increase amounting to the same percentage of both policies. However, fiscal equalisation affects only the employment rate statistically significant positive. Structural funding has additional significant positive effects on the human capital rate and regional GDP per workforce. Based on this finding, the last policy implication can be drawn: If the policy objective is to increase the regional GDP and human capital endowment, policymakers should allocate structural funds rather than fiscal equalisation payments.

The analysis conducted in this paper is one contribution towards a comprehensive debate regarding the working of fiscal equalisation in Germany. For future research, I point to the following aspects: First, additional research should gain detailed information about the quality of jobs that are created by an increase of formula-based grants. The quality and wage level of the created jobs as well as the sector may have important implications for regional economies. Second, I analyse fiscal equalisation between German regions. It is also worth to determine the effects of fiscal equalisation on the distribution within the (gaining) regions in future evaluation studies. Third, future research should focus on detailed analyses for particular federal states to identify differences and best practice characteristics.

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A4. Appendix

Table A4.1 Variable description and construction

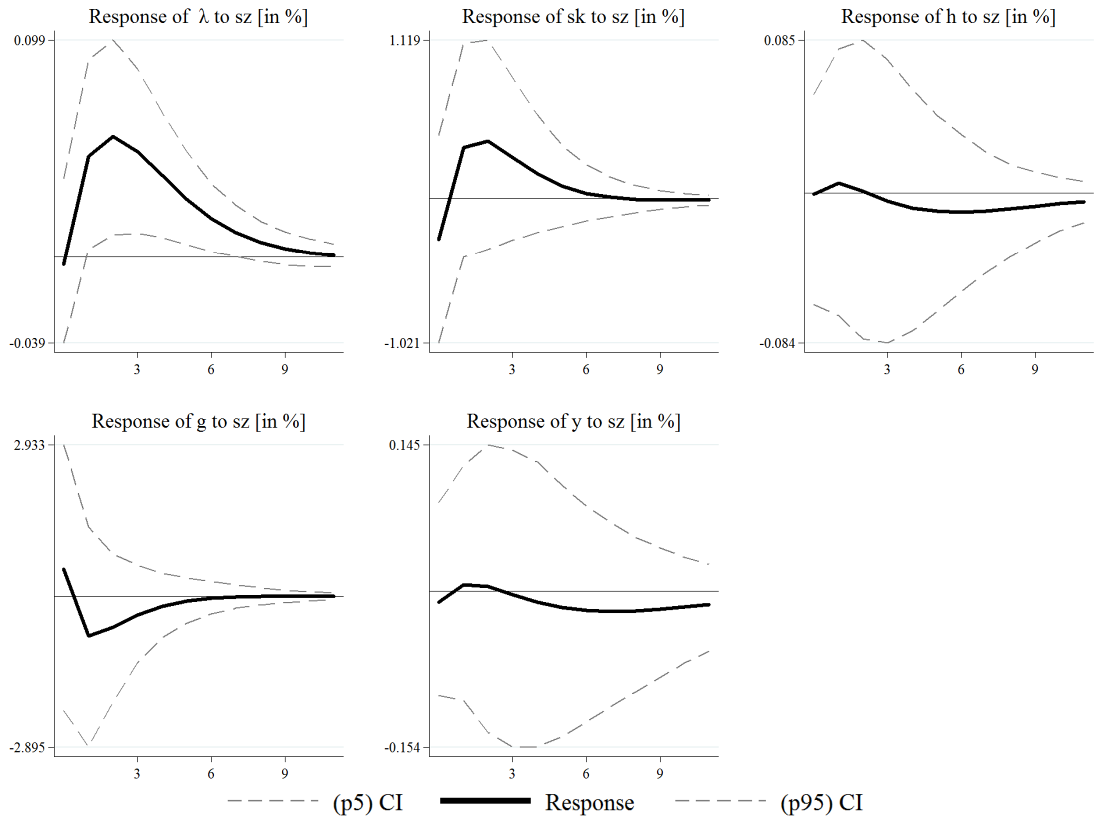
Description	Shortcut	Construction	Data source
Nominal GDP per economically active working population (workforce)	$\boldsymbol{y}$	ln[GDP in Euro / (Population aged 15 to 64 years × Participation rate)] *Note*: Population data is based on the extrapolation of the census 1987. The participation rate is based on the same population data until the year 2011. From 2011, the participation rate is calculated based on the population data of the census 2011.	GDP: Arbeitskreis “Volkswirtschaftliche Gesamtrechnungen der Länder” (Status: August 2015) Population aged 15 to 64 years: Regionaldatenbank Deutschland (Based on the population census 1987) Partizipation rate: Statistik der Bundesagentur für Arbeit / Indikatoren und Karten zur Raum und Stadtentwicklung (INKAR)
Private sector physical capital intensity (manufacturing, mining and quarrying sector)	$\boldsymbol{s_k}$	ln[Industry investments in Euro / GDP in Euro] *Note*: Missing values for the industry investments are interpolated on the basis of an autoregressive process with 3 lags.	Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR), laufende Raumbeobachtungen, various issues
Higher education rate	$\boldsymbol{h}$	ln[Employees with university degree / (Population aged 15 to 64 years × Participation rate)] *Note:* Potential data imperfections related to the registration of the qualification of employees are assumed to be random.	Institute for Employment Research (IAB), Nuremberg
Gross employment rate	$\boldsymbol{\lambda}$	ln[Employees total / (Population aged 15 to 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
Patent intensity (in ln)	$\boldsymbol{g}$	ln[Patents / GDP in Mio. Euro]	Own calculation from the PATSTAT database (Version October 2014, European Patent Office)
Formula-based grant intensity (in ln)	$\boldsymbol{s_z}$	ln[Formula-based grants in Euro / GDP in Euro]	Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR)
Spatial lag variables	$\boldsymbol{Wx}$	Spatial lags for each variable are constructed in absolute values using the STATA command splagvar and a binary first-order neighbourhood matrix. Thereupon, all spatial lag variables are normalised and ln-transformed similar to the non-spatial variables above.	
Further public funding intensity (control variable for formula-based grant intensity)		ln[Sum of further public funding programmes in Euro / GDP in Euro] *Note*: This variable covers regional investment data for the GRW programme, urban development promotion programmes, project funding programmes of the Federal Ministry of Education and Research (BMBF) and further German Ministries as well as programmes of the Reconstruction Credit Institute (KfW) (Start-up, Infrastructure, Innovation, Environment and Living investments)	GRW: Federal Office for Economic Affairs and Export Control (BAFA) Further public funding programmes: Bundesinstitut für Bau-, Stadt-, und Raumforschung (BBSR)
Votes SPD and CDU/CSU Bundestag election 1998		Second votes SPD (CDU/CSU)/total second votes	Allgemeine Bundestagswahlstatistik des Bundes und der Länder/ INKAR
Overall GRW intensity (industry and infrastructure investments)	$\boldsymbol{grw}$	ln[GRW funding volumes in Euro / GDP in Euro].	BAFA

Table A4.2 Panel unit root test

Variable	Number of years	Test-statistic	p-value
y	12	-4.122	0.000
λ	12	-0.345	0.365
λ_detrended	12	-16.080	0.000
h	12	0.130	0.552
h_detrended	12	-17.616	0.000
sk	12	-17.582	0.000
g	12	-17.446	0.000
sz	12	-6.591	0.000
sz_detrended	12	-22.989	0.000
w_y	12	-3.376	0.000
w_λ	12	-1.410	0.079
w_λ_detrended	12	-17.756	0.000
w_h	12	0.011	0.504
w_h_detrended	12	-18.114	0.000
w_sk	12	-15.190	0.000
w_g	12	-13.691	0.000
w_sz	12	-4.567	0.000
Additive public funding intensity	12	-17.276	0.000
w_additive public funding intensity	12	-10.387	0.000

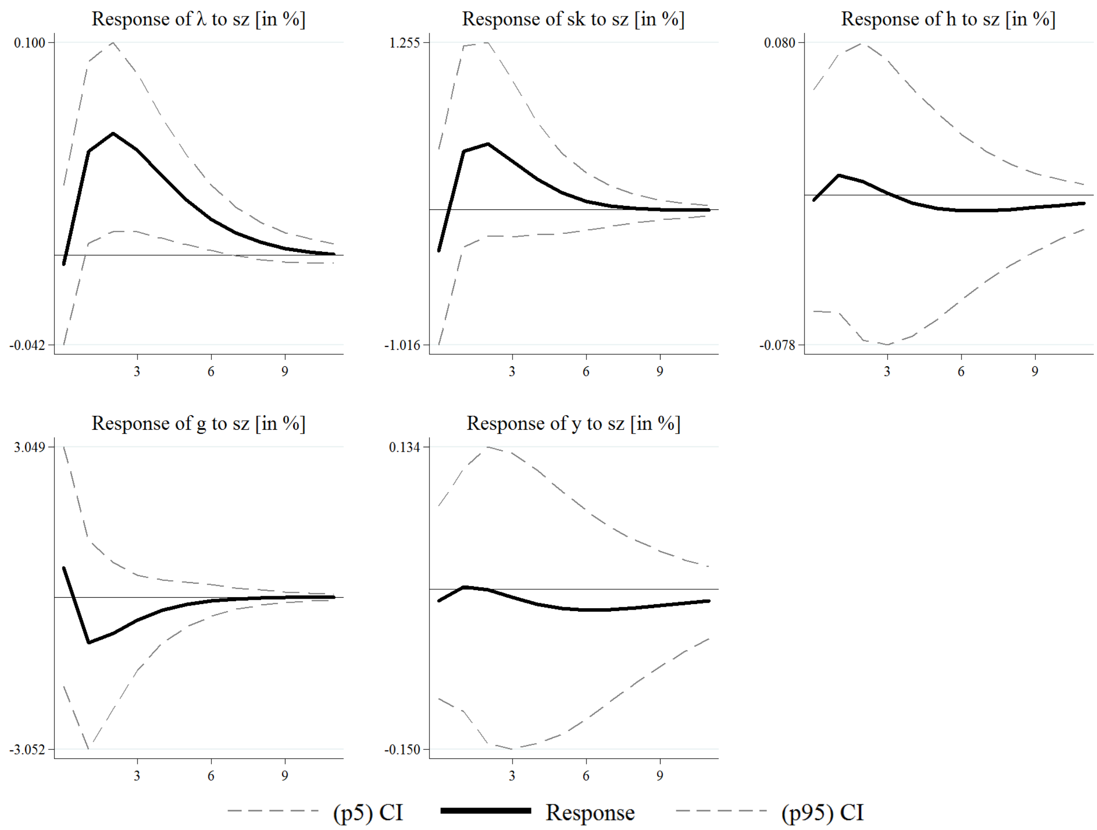
Notes: Panel unit root test based on Im et al. (2003). H0: All panels contain unit roots. HA: Some panels are stationary. The suffix "_detrended" indicates a detrended variable.

Figure A4.1 Impulse response function analysis formula-based grants, spatial lag from the particular dependent variable is excluded



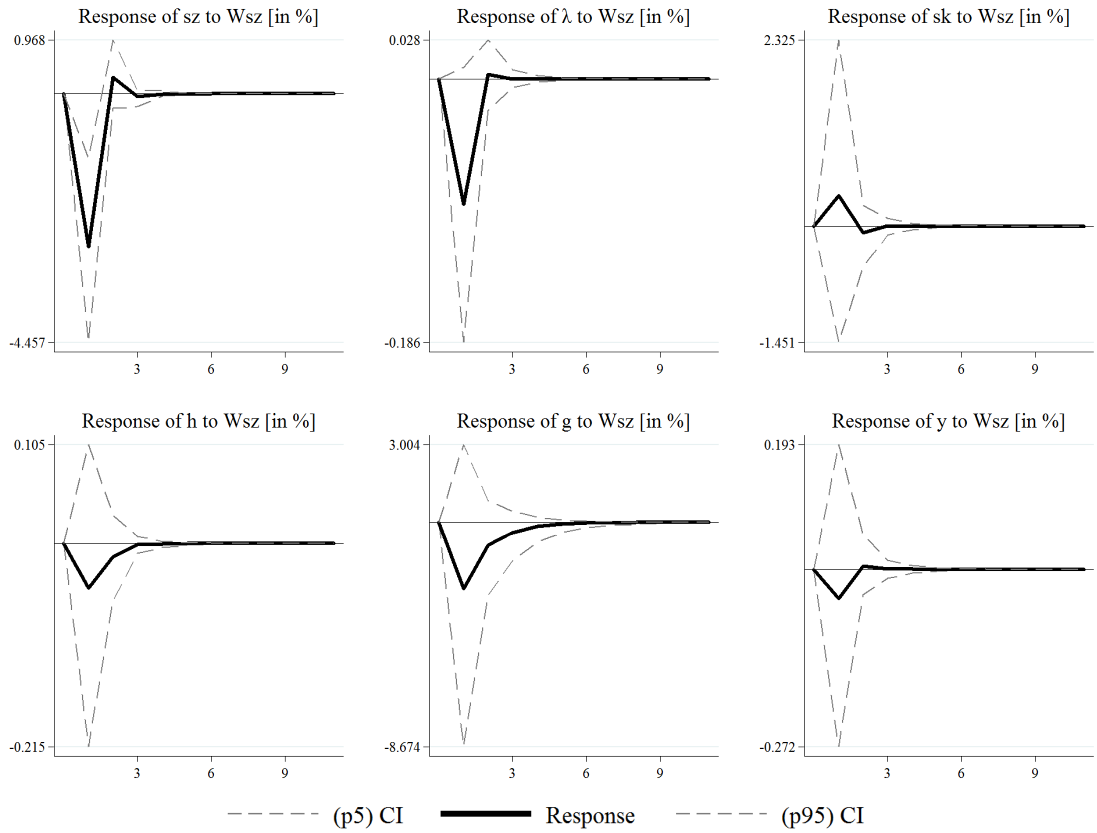
Notes: The solid lines present the responses to an increase in the formula-based grant intensity, the dotted lines show the confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Figure A4.2 Impulse response function analysis formula-based grants, control variables added



Notes: The solid lines present the responses to an increase in the formula-based grant intensity, the dotted lines show the confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Figure A4.3 Impulse response function analysis formula-based grants (spatially indirect effects), basic model



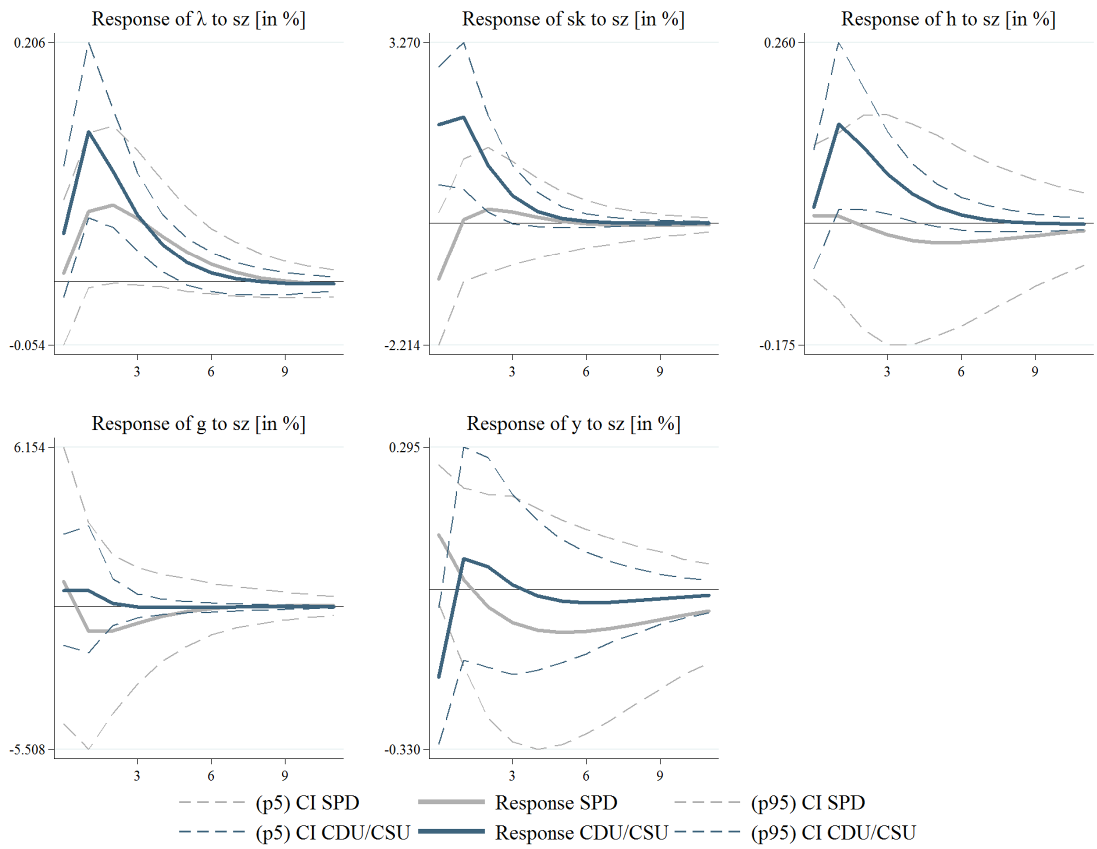
Notes: The solid lines present the responses to an increase in the formula-based grant intensity, the dotted lines show the confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Table A4.3 *t*-test analysis comparing economic responses to an increase in the formula-based grant intensity, East-West classification (based on Figure 4.5)

Funding increases are one *sample-specific* standard deviation in each subsample						Funding increases are equal to the same % in each subsample*					
Time	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**Time**	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	linvq	2.1456	**0.0160**	0.9840	**0.0320**	0	linvq	2.0591	**0.0198**	0.9802	**0.0396**
1	linvq	-0.3938	0.6531	0.3469	0.6938	1	linvq	-0.3283	0.6286	0.3714	0.7427
2	linvq	-0.9320	0.8243	0.1757	0.3514	2	linvq	-0.8176	0.7932	0.2068	0.4137
3	linvq	-1.1860	0.8821	0.1179	0.2358	3	linvq	-1.0674	0.8570	0.1430	0.2859
4	linvq	-1.2781	0.8993	0.1007	0.2014	4	linvq	-1.1759	0.8801	0.1199	0.2398
5	linvq	-1.1969	0.8843	0.1157	0.2315	5	linvq	-1.1073	0.8659	0.1341	0.2683
6	linvq	-1.0456	0.8521	0.1479	0.2959	6	linvq	-0.9651	0.8327	0.1673	0.3346
7	linvq	-0.9056	0.8174	0.1826	0.3653	7	linvq	-0.8415	0.7999	0.2001	0.4001
8	linvq	-0.7713	0.7797	0.2203	0.4406	8	linvq	-0.7259	0.7660	0.2340	0.4680
9	linvq	-0.6839	0.7529	0.2471	0.4941	9	linvq	-0.6542	0.7435	0.2565	0.5130
10	linvq	-0.5935	0.7236	0.2764	0.5529	10	linvq	-0.5762	0.7177	0.2823	0.5646
11	linvq	-0.5170	0.6974	0.3026	0.6052	11	linvq	-0.5078	0.6942	0.3058	0.6117
12	linvq	-0.4588	0.6768	0.3232	0.6464	12	linvq	-0.4547	0.6753	0.3247	0.6494
0	lemp	-1.6957	0.9549	**0.0451**	0.0901	0	lemp	-1.6285	0.9482	0.0518	0.1036
1	lemp	-0.4666	0.6796	0.3204	0.6408	1	lemp	-0.0701	0.5280	0.4720	0.9441
2	lemp	-0.4884	0.6873	0.3127	0.6253	2	lemp	-0.0023	0.5009	0.4991	0.9982
3	lemp	-0.6266	0.7345	0.2655	0.5310	3	lemp	-0.0913	0.5364	0.4636	0.9273
4	lemp	-0.7541	0.7746	0.2254	0.4509	4	lemp	-0.2113	0.5837	0.4163	0.8327
5	lemp	-0.8172	0.7931	0.2069	0.4139	5	lemp	-0.3139	0.6232	0.3768	0.7536
6	lemp	-0.7532	0.7743	0.2257	0.4514	6	lemp	-0.3465	0.6355	0.3645	0.7290
7	lemp	-0.6137	0.7303	0.2697	0.5395	7	lemp	-0.3233	0.6267	0.3733	0.7465
8	lemp	-0.4984	0.6909	0.3091	0.6183	8	lemp	-0.3022	0.6187	0.3813	0.7625
9	lemp	-0.4108	0.6594	0.3406	0.6812	9	lemp	-0.2856	0.6124	0.3876	0.7752
10	lemp	-0.3372	0.6320	0.3680	0.7360	10	lemp	-0.2658	0.6048	0.3952	0.7904
11	lemp	-0.2891	0.6137	0.3863	0.7725	11	lemp	-0.2528	0.5998	0.4002	0.8004
12	lemp	-0.2570	0.6014	0.3986	0.7972	12	lemp	-0.2426	0.5958	0.4042	0.8083
0	lgdp	-3.6109	0.9998	**0.0002**	**0.0003**	0	lgdp	-3.7036	0.9999	**0.0001**	**0.0002**
1	lgdp	-0.0043	0.5017	0.4983	0.9966	1	lgdp	0.0424	0.4831	0.5169	0.9662
2	lgdp	0.5188	0.3020	0.6980	0.6040	2	lgdp	0.5274	0.2990	0.7010	0.5980
3	lgdp	0.5428	0.2937	0.7063	0.5874	3	lgdp	0.5159	0.3030	0.6970	0.6060
4	lgdp	0.4659	0.3207	0.6793	0.6413	4	lgdp	0.4111	0.3405	0.6595	0.6811
5	lgdp	0.3653	0.3575	0.6425	0.7149	5	lgdp	0.2959	0.3837	0.6163	0.7673
6	lgdp	0.2676	0.3945	0.6055	0.7891	6	lgdp	0.1954	0.4226	0.5774	0.8451
7	lgdp	0.1827	0.4275	0.5725	0.8550	7	lgdp	0.1142	0.4546	0.5454	0.9091
8	lgdp	0.1100	0.4562	0.5438	0.9125	8	lgdp	0.0488	0.4806	0.5194	0.9611
9	lgdp	0.0481	0.4808	0.5192	0.9616	9	lgdp	-0.0042	0.5017	0.4983	0.9966
10	lgdp	-0.0033	0.5013	0.4987	0.9974	10	lgdp	-0.0463	0.5185	0.4815	0.9631
11	lgdp	-0.0429	0.5171	0.4829	0.9658	11	lgdp	-0.0762	0.5304	0.4696	0.9393
12	lgdp	-0.0722	0.5288	0.4712	0.9424	12	lgdp	-0.0979	0.5390	0.4610	0.9220

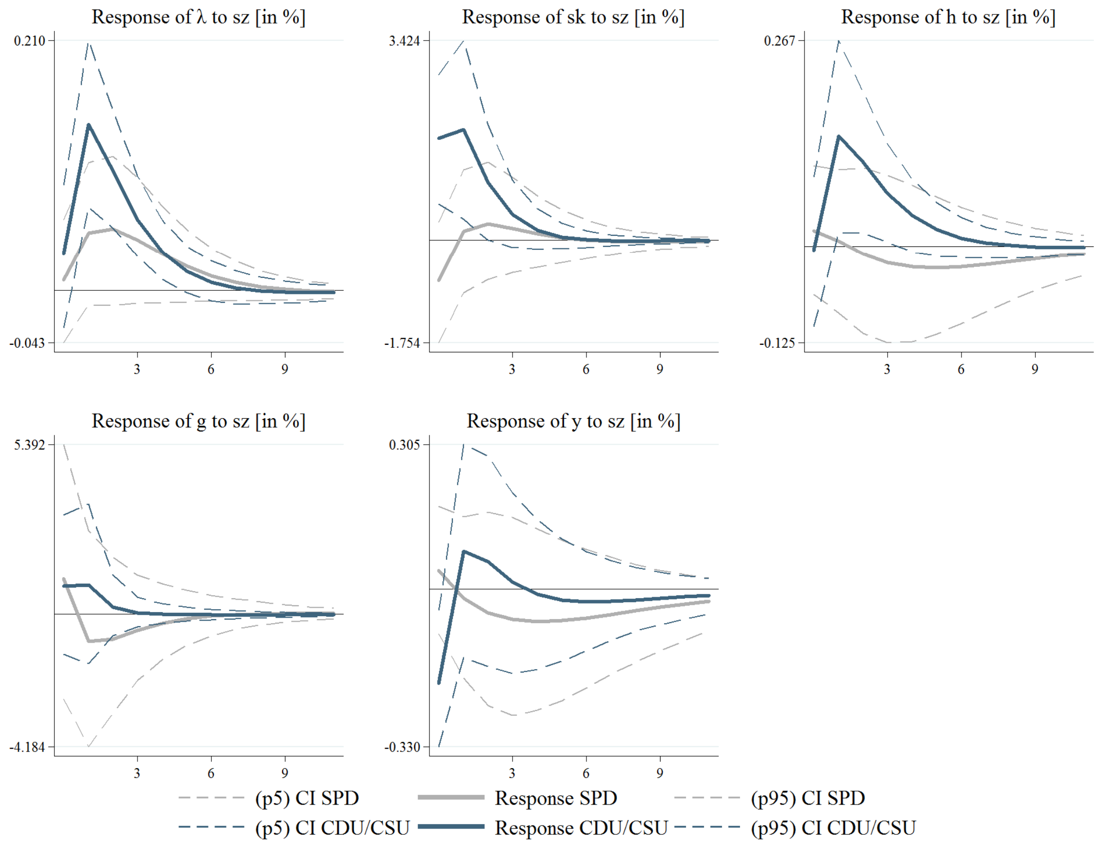
Notes: diff = mean(Eastern_regions) - mean(Western_regions); H0: diff = 0; degrees of freedom = 1198. Only variables with significant differences are presented. *Initial shock in Western regions is rescaled to the amount of the initial shock in Eastern regions.

Figure A4.4 Impulse response function analysis formula-based grants, Share of votes SPD – CDU/CSU considering subsequent Bundestag elections



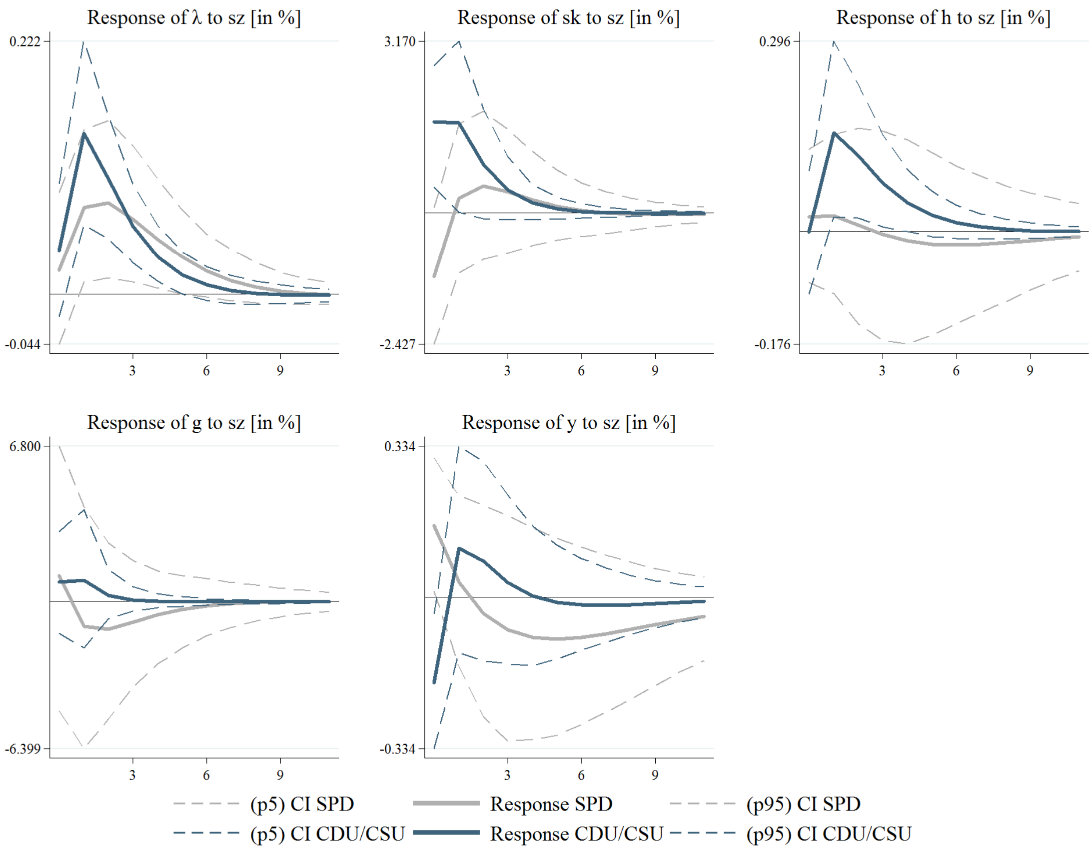
Notes: The solid lines present the responses to an increase in the formula-based grant intensity in regions with a major share of voters for the SPD (grey) and the CDU/CSU (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Figure A4.5 Impulse response function analysis formula-based grants, Share of votes SPD – CDU/CSU considering inherent districts



Notes: The solid lines present the responses to an increase in the formula-based grant intensity in regions with a major share of voters for the SPD (grey) and the CDU/CSU (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Figure A4.6 Impulse response function analysis formula-based grants, Share of votes SPD – CDU/CSU considering inherent districts and subsequent Bundestag elections



Notes: The solid lines present the responses to an increase in the formula-based grant intensity in regions with a major share of voters for the SPD (grey) and the CDU/CSU (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

Table A4.4 *t*-test analysis comparing economic responses to an increase in the formula-based grant intensity, SPD-CDU/CSU classification (based on Figure A4.6)

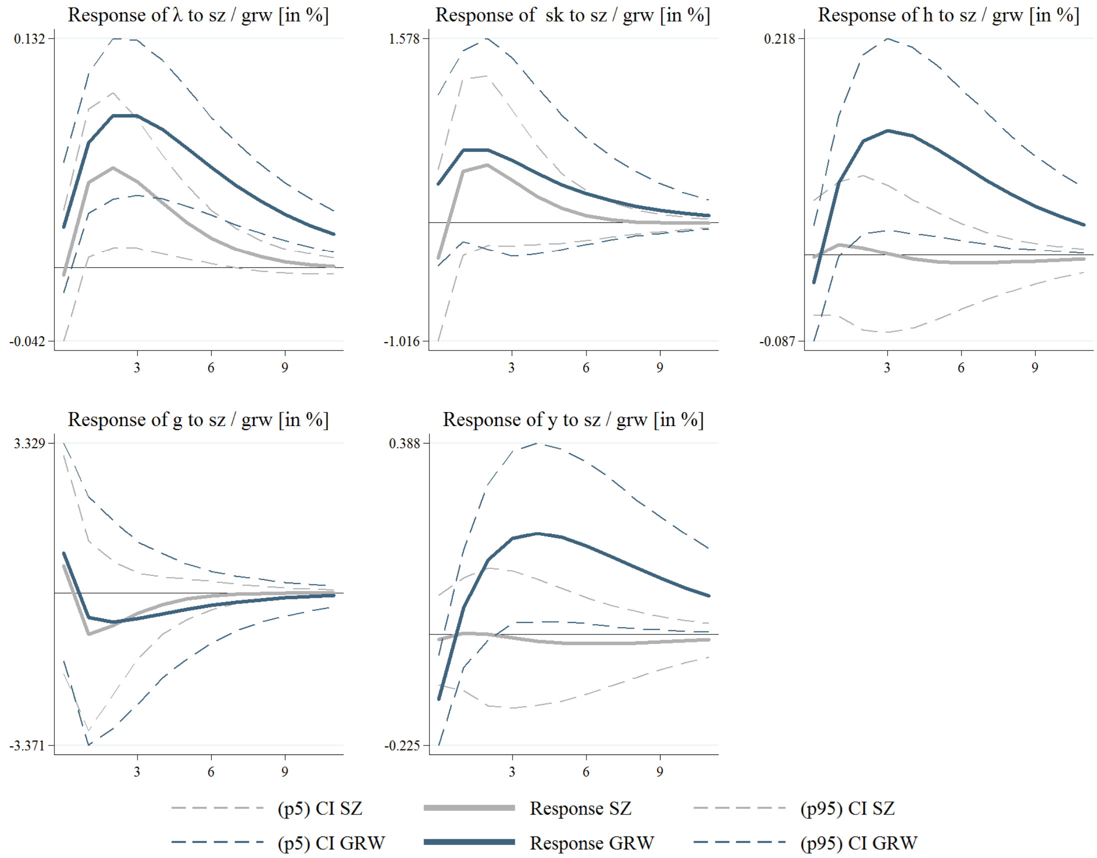
Funding increases are one *sample-specific* standard deviation in each subsample						**Funding increases are equal to the same % in each subsample***					
Time	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**Time**	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lhk	0.2762	0.3912	0.6088	0.7824	0	lhk	0.1431	0.4431	0.5569	0.8862
1	lhk	-1.1505	0.8750	0.1250	0.2501	1	lhk	-1.6682	0.9523	**0.0477**	0.0954
2	lhk	-0.9684	0.8335	0.1665	0.3330	2	lhk	-1.6293	0.9483	0.0517	0.1034
3	lhk	-0.7350	0.7688	0.2312	0.4625	3	lhk	-1.3906	0.9177	0.0823	0.1645
4	lhk	-0.5865	0.7212	0.2788	0.5576	4	lhk	-1.1236	0.8693	0.1307	0.2613
5	lhk	-0.5043	0.6929	0.3071	0.6141	5	lhk	-0.8784	0.8101	0.1899	0.3798
6	lhk	-0.4538	0.6750	0.3250	0.6500	6	lhk	-0.6942	0.7562	0.2438	0.4876
7	lhk	-0.4044	0.6570	0.3430	0.6860	7	lhk	-0.5392	0.7051	0.2949	0.5898
8	lhk	-0.3639	0.6420	0.3580	0.7160	8	lhk	-0.4215	0.6633	0.3367	0.6735
9	lhk	-0.3278	0.6284	0.3716	0.7431	9	lhk	-0.3324	0.6302	0.3698	0.7397
10	lhk	-0.2883	0.6134	0.3866	0.7731	10	lhk	-0.2571	0.6014	0.3986	0.7971
11	lhk	-0.2511	0.5991	0.4009	0.8017	11	lhk	-0.1961	0.5777	0.4223	0.8445
12	lhk	-0.2161	0.5855	0.4145	0.8289	12	lhk	-0.1454	0.5578	0.4422	0.8844
0	linvq	-2.7916	0.9974	**0.0026**	**0.0053**	0	linvq	-2.8523	0.9978	**0.0022**	**0.0044**
1	linvq	-1.0900	0.8621	0.1379	0.2758	1	linvq	-1.5654	0.9412	0.0588	0.1177
2	linvq	-0.3800	0.6480	0.3520	0.7040	2	linvq	-1.0702	0.8577	0.1423	0.2847
3	linvq	-0.0389	0.5155	0.4845	0.9690	3	linvq	-0.6807	0.7519	0.2481	0.4962
4	linvq	0.0927	0.4631	0.5369	0.9262	4	linvq	-0.3848	0.6498	0.3502	0.7004
5	linvq	0.1060	0.4578	0.5422	0.9156	5	linvq	-0.1779	0.5706	0.4294	0.8588
6	linvq	0.0552	0.4780	0.5220	0.9560	6	linvq	-0.0687	0.5274	0.4726	0.9452
7	linvq	-0.0185	0.5074	0.4926	0.9852	7	linvq	-0.0313	0.5125	0.4875	0.9750
8	linvq	-0.0947	0.5377	0.4623	0.9246	8	linvq	-0.0378	0.5151	0.4849	0.9699
9	linvq	-0.1628	0.5647	0.4353	0.8707	9	linvq	-0.0646	0.5258	0.4742	0.9485
10	linvq	-0.2184	0.5864	0.4136	0.8272	10	linvq	-0.0989	0.5394	0.4606	0.9213
11	linvq	-0.2530	0.5999	0.4001	0.8003	11	linvq	-0.1280	0.5509	0.4491	0.8981
12	linvq	-0.2749	0.6083	0.3917	0.7834	12	linvq	-0.1520	0.5604	0.4396	0.8792
0	lemp	-0.3155	0.6238	0.3762	0.7524	0	lemp	-0.8159	0.7927	0.2073	0.4147
1	lemp	-1.0265	0.8476	0.1524	0.3048	1	lemp	-2.2737	0.9885	**0.0115**	**0.0231**
2	lemp	-0.3933	0.6529	0.3471	0.6941	2	lemp	-2.0830	0.9813	**0.0187**	**0.0374**
3	lemp	0.1458	0.4421	0.5579	0.8841	3	lemp	-1.5530	0.9397	0.0603	0.1206
4	lemp	0.4692	0.3195	0.6805	0.6390	4	lemp	-0.9318	0.8242	0.1758	0.3516
5	lemp	0.6187	0.2681	0.7319	0.5362	5	lemp	-0.4369	0.6689	0.3311	0.6622
6	lemp	0.6572	0.2556	0.7444	0.5111	6	lemp	-0.0981	0.5391	0.4609	0.9218
7	lemp	0.5600	0.2878	0.7122	0.5756	7	lemp	0.1018	0.4595	0.5405	0.9189
8	lemp	0.4502	0.3263	0.6737	0.6526	8	lemp	0.2023	0.4199	0.5801	0.8397
9	lemp	0.3211	0.3741	0.6259	0.7482	9	lemp	0.2418	0.4045	0.5955	0.8089
10	lemp	0.1828	0.4275	0.5725	0.8550	10	lemp	0.2398	0.4052	0.5948	0.8105
11	lemp	0.0613	0.4755	0.5245	0.9511	11	lemp	0.2170	0.4141	0.5859	0.8282
12	lemp	-0.0406	0.5162	0.4838	0.9676	12	lemp	0.1815	0.4280	0.5720	0.8560

Table A4.4 continued

Funding increases are one *sample-specific* standard deviation in each subsample						Funding increases are equal to the same % in each subsample*					
Time	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**	**Time**	**Response variable**	**t-value**	**Ha: diff > 0, Pr(T > t)**	**Ha: diff < 0, Pr(T < t)**	**Ha: diff != 0, (|T| > |t|)**
0	lgdp	2.7355	**0.0031**	0.9969	**0.0063**	0	lgdp	2.5569	**0.0053**	0.9947	**0.0106**
1	lgdp	-0.4088	0.6587	0.3413	0.6827	1	lgdp	-0.6643	0.7467	0.2533	0.5066
2	lgdp	-0.5925	0.7232	0.2768	0.5536	2	lgdp	-0.6473	0.7413	0.2587	0.5175
3	lgdp	-0.5539	0.7101	0.2899	0.5797	3	lgdp	-0.4577	0.6764	0.3236	0.6472
4	lgdp	-0.5346	0.7035	0.2965	0.5930	4	lgdp	-0.3084	0.6211	0.3789	0.7578
5	lgdp	-0.5272	0.7010	0.2990	0.5981	5	lgdp	-0.2175	0.5861	0.4139	0.8279
6	lgdp	-0.5334	0.7031	0.2969	0.5938	6	lgdp	-0.1699	0.5674	0.4326	0.8651
7	lgdp	-0.5398	0.7053	0.2947	0.5894	7	lgdp	-0.1484	0.5590	0.4410	0.8820
8	lgdp	-0.5470	0.7078	0.2922	0.5844	8	lgdp	-0.1473	0.5585	0.4415	0.8829
9	lgdp	-0.5562	0.7109	0.2891	0.5781	9	lgdp	-0.1555	0.5618	0.4382	0.8765
10	lgdp	-0.5620	0.7129	0.2871	0.5741	10	lgdp	-0.1679	0.5666	0.4334	0.8667
11	lgdp	-0.5609	0.7125	0.2875	0.5749	11	lgdp	-0.1816	0.5720	0.4280	0.8559
12	lgdp	-0.5619	0.7129	0.2871	0.5743	12	lgdp	-0.1957	0.5776	0.4224	0.8448

Notes: diff = mean(SPD_regions) - mean(CDU/CSU_regions); H0: diff = 0; degrees of freedom = 1198. Only variables with significant differences are presented. *Initial shock in CDU/CSU regions is rescaled to the amount of the initial shock in SPD regions.

Figure A4.7 Impulse response function analysis formula-based grants and overall GRW investments, control variables added (Impulse response function analysis formula-based grants is similar to Figure A4.2)



Notes: The solid lines present the responses to an increase in the formula-based grant intensity (grey) and in the overall GRW intensity (blue), the dotted lines show the corresponding confidence intervals (CI) constructed by using Monte Carlo simulations (1000 repetitions). The estimated responses are based on the VAR approach explained in Section 4.4.2 and the variables described in Table A4.1. Associated regression results are available upon request.

5. Public research, local knowledge transfer and regional development: Insights from a structural VAR model

The paper is accepted for publication:

Eberle, J., Brenner, T., and Mitze, T. (2019): Public research, local knowledge transfer and regional development: Insights from a structural VAR model. Accepted for publication in *International Regional Science Review* (27 May 2019).

During the revision of the doctoral thesis, a related version of this chapter was published as (12 August 2019):

Eberle, J., Brenner, T., and Mitze, T. (2019): Public Research, Local Knowledge Transfer, and Regional Development: Insights from a Structural VAR. *International Regional Science Review, online first*: 1-32 (© 2019 The Author(s) 2019). DOI: https://doi.org/10.1177%2F0160017619863466.

Abstract: This paper estimates the regional economic effects of public research activities. In order to identify the underlying transmission channels from knowledge creation to the regional environment, the empirical identification strategy goes beyond traditional partial effects analyses and studies the complex linkages between public research, innovativeness and regional development on the basis of a structural VAR model. A particular focus is thereby set on assessing if the effects of local public research activity differ by the type of research actors (universities, technical colleges and public research institutes). The empirical results indicate that an increase in the volume of (public) third-party funding to technical colleges is associated with a rise in the regional investment and employment rate as well as the human capital stock. Increasing public third-party funding to both, universities and technical colleges, positively affects the regional patent activity, the employment rate and per workforce output. In comparison, the empirical results provide limited evidence for regional economic effects stemming from an increase in local knowledge creation measured in terms of scientific publications. Here only variations in the publication rate of public research institutes can be linked to positive private sector investment and employment effects.

Keywords: Public research, knowledge transfer, regional economic growth, factor inputs, VAR, impulse response functions

JEL Classification: C33, I23, I25, R11, O38, O47

5.1. Introduction

A central research question in regional economics and economic geography relates to the role of human capital and knowledge creation in driving regional economic growth and development. Building on seminal contributions in the field of new growth theory (e.g. Aghion and Howitt, 1992; Lucas, 1988; Romer, 1990), a common understanding of knowledge-driven growth process is that human capital and research and development (R&D) inputs leads to innovations, which – in turn – trigger economic growth through both private and social returns to these knowledge inputs. Social returns are typically associated with positive knowledge spillovers. The literature on Regional Innovation Systems (RIS) complements growth analyses by studying the main transmission channels of knowledge creation to the regional economy, e.g. related to the contribution of public research activities for regional knowledge transfer and development (e.g. Braczyk et al., 2004). The main conclusion is that public research actors play a crucial role for innovation processes and associated regional development (Fritsch and Schwirten, 1999). Despite the progress made in the contemporaneous literature, however, it is less well understood which types of public research actors and activities contribute the most to regional development and if different actor-activity combinations affect the regional economy through alternative transmission channels.

In this paper, we contribute to this open research agenda by analysing the mutual linkages between research activities carried out by different public research actors and regional economic development in Germany. Germany can be seen as an interesting case study for this endeavour as the German public research landscape comprises different research actors within and outside the university system, which interact with the regional economy to varying extents: Although universities operate in a specific region, seen from a knowledge transfer perspective, the university system has more interregional linkages. This is, for instance, emphasised by a rather spatially unbounded co-operation behaviour of universities (Beise and Stahl, 1999; Fritsch and Schwirten, 1999).[72] Differently, technical colleges are more embedded in the local economic system, for example, due to their co-operation behaviour and a relatively higher share of graduates that remain in the region (Fritsch and Schwirten, 1999). Public research institutes (outside universities) are heterogeneous and do not always have a regional focus when transferring knowledge to firms (Beise and Stahl, 1999; Fritsch and Schwirten, 1999). In the following, we focus here on these three groups of research actors and their relevance for localised knowledge transfer to the regional development.

The amount of public funds that are allocated to research and innovation activities in Germany is considerably large. In 2013, €23.198 billion of public funds were spent (BMBF, 2016b) as a means to compensate for private under-investments in research and innovation activities. Given the significant financial input to public research activities, gaining insight into the explicit regional effects of this type of public investment is of strong interest, both scientifically and politically. In the conduct of our empirical analysis we thus seek to answer the following research questions: Do public research activities foster regional economic development? Which regional economic factors are mainly affected by different types of public research activities? And finally, do knowledge transfer effects differ between universities, technical colleges and public research institutes? Providing answers to these specific research questions shall contribute to a better understanding of the overriding question which type of public research activity gives the largest local return to the public investment.

Based on seminal work on the knowledge production function (Jaffe, 1989), impact analyses of the effects of universities on regional innovativeness has a long tradition – especially the literature

[72] Faggian and McCann (2009) emphasise the interregional flows of university graduates and their impact on regional innovation in Britain.

focusing on the United States (see Drucker and Goldstein, 2007, and Varga and Horváth 2015, for comprehensive reviews of international studies on this topic). However, most quantitative studies are primarily focused on exploring the immediate link between university research activities and regional innovativeness or output, while they ignore to shed light on the broader regional impacts of these public research activities related to employment, physical capital investments or human capital.

For the case of Germany, the economic effects of public research activities have predominantly been analysed using single equation regression models and regional data (e.g. Fritsch and Slavtchev, 2007; Schubert and Kroll, 2013; Spehl et al., 2007). Existing studies examine the effects of public research on regional economic growth in one of two ways: Either they estimate the effect of public research on innovativeness in a knowledge production function approach (Fritsch and Slavtchev, 2007) or they examine the effects of public research on economic growth directly (Schubert and Kroll, 2013). Both approaches thus restrict the study of knowledge transfers to a partial effects analysis. Many other mechanisms, however, can be thought of being relevant for assessing the overall effects of public research activities to the regional economy, such as that they attract high-skilled jobs to the regions or simply increase regional investments.[73]

To deepen our knowledge on the direct and indirect effects of public research on regional economic growth, this paper extends the recent literature in two ways: First, with regard to the plurality of

[73] Florax and Folmer (1992) provide an excellent summary on the research approaches to analyse the impact of regional university knowledge production (including the knowledge production and production function approach). The authors argue that effects on regional output do not taking place directly but rather indirectly via investments and thus demand a longer time period to be observed. Instead, the authors propose to use investments as dependent variable since investments properly measure the economic relevance of university knowledge production and implicitly involve relocation decisions of firms (Florax and Folmer, 1992). The applied econometric approach in this paper explicitly considers such potential indirect effects (e.g. the link between public research on output via investments as well as via human capital, employment or patents) and calculates the particular total effect of an increase in the publicly funded research on each regional economic factor (including investments).

public research activities at the regional level, we take a disaggregated perspective by gathering information on alternative indicators for research activities (scientific publications, acquired third-party funds) of different actors (universities, technical colleges and public research institutes). We then link this research actor-activity information to a set of further economic variables such as the regional investment rate, human capital, employment and innovation indicators as well as economic growth. Second, to the author's knowledge, this is the first study that uses a systems approach which allows for the identification of interdependencies among these variables in all kinds of directions, including the dependencies of growth-relevant aspects, such as investment and human capital, on public research as well as of public research activities on regional economic factors. Hence, we are able to deal with regional dynamics more adequately by treating all variables as endogenous in the regional economic system and by measuring all their mutual interdependencies and feedback effects.[74]

To this end, a structural vector autoregressive (VAR) model is estimated and combined with Impulse Response Functions (IRFs) analyses to identify direct as well as indirect effects of public research activities on regional economic variables as well as resulting feedback effects. The VAR model covers several variables – namely per capita GDP, employment, investment, human capital, innovation output as well as the number of scientific publications and third-party funds as measures

[74] Since the data are restricted to the time period 2000 to 2011, we are mainly able to identify short-run effects but cannot observe long-run knowledge transfer that may emanate especially from basic research activities conducted at universities (positive returns of universities investments may need more time to become measurable). Moreover, we are strongly focused on the research activities of universities. However, beyond that, they contribute to regional economy generally in different ways (e.g. Bleany et al., 1992; Florax, 1992; Garrido-Yserte and Gallo-Rivera, 2010; Goldstein et al., 1995).

for public research activities.[75] With regard to the latter, activities from universities, technical colleges (Fachhochschulen) and public research institutes (especially Fraunhofer and Max Planck institutes) are studied separately with regard to their respective linkages to economic variables.

The remainder of the paper starts by presenting the different types of public research actors in Germany and their particular characteristics (Section 5.2). Moreover, potential spillover effects from public research and their spatial dimension are discussed. Section 5.3 briefly reviews the underlying economic theory and develops research hypotheses. After a brief discussion of the data (Section 5.4), the econometric approach (Section 5.5) and the linkage between theoretical and empirical issues is introduced (Section 5.6). Section 5.7 presents the empirical results of the VAR analysis. Finally, Section 5.8 summarises the findings and concludes this study.

5.2 Conceptual background

5.2.1 The German public research activities in an international context

Auranen and Nieminen (2010) emphasise the decentralised character of Germany's university system, where federal states enjoy a high degree of political autonomy. Compared to the UK, Australia, Finland or Sweden, the German university system is more input-oriented (smaller governmental steering, focus on a sufficient endowment with resources instead of a focus on results and efficiency) and receives less external funding. The higher education R&D expenditures (HERD) per capita and the ratio from HERD to the German gross domestic expenditures on R&D (GERD) are lower compared to countries such as Sweden, Finland, Denmark, Norway, Netherlands, Australia and the UK (Auranen and Nieminen, 2010). Moreover, next to universities, technical colleges

[75] Per capita GDP is measured in terms of GDP per economically active population. A detailed description of the data used for estimation is given in Section 5.4.

and public research institutes (outside universities) are additional actors within the publicly funded research sector in Germany, whose role is explained in more detail below.

5.2.2 Publicly funded research institutes and their regional embeddedness

According to the research and innovation report 2016 of the Federal Ministry of Education and Research (BMBF), the German GERD in 2013 accounted for €79.730 billion with €23.198 billion being publicly financed (29.1 %). Fund recipients are universities, technical colleges, public research institutes and also business organizations in the private sector. Especially universities and technical colleges as well as public research institutes are the major recipients of public support, though. Although the latter actors also receive private R&D funds (see BMBF, 2016b, Table 1, pp. 55-56), for the purpose of this study we define universities, technical colleges and public research institutes as core public research actors (a similar definition can be found, for example, in the study of Beise and Stahl, 1999).[76]

Goldstein et al. (1995) argue that universities contribute to regional development through multiple impact channels. Besides investments in the regional physical capital stock and the creation of human capital via graduates, universities generate outputs that influence the knowledge and technological stock. They create basic knowledge, transfer existing know-how to firms and organizations, provide a basic knowledge infrastructure and may establish an innovative spirit within a region (Goldstein et al., 1995). Regarding their research activities, universities conduct mainly basic research activities with only moderate immediate intentions of commercialization (Beise and Stahl, 1999). The reader should note that this study is solely focussed on research activities and

[76] The *Max-Planck-Gesellschaft*, *Fraunhofer-Gesellschaft*, *Helmholtz-Gesellschaft*, *Leibniz-Gemeinschaft* and the *Akademien der Wissenschaften* are the largest publicly (co-)funded research institutes. The particular research focus differs among these institutes considerably. Moreover, several federal research institutes belong to this group as well (BMBF, 2016a).

knowledge transmission of universities thereby ignoring other supply and demand side linkages with the regional economy.

Compared to universities, technical colleges are more focused on teaching and education. They conduct, on average, less basic research, while their activities are more focused on applied and specialised research in similar technological sectors as regional firms (Beise and Stahl, 1999). This link is further stressed in Fritsch and Schwirten (1999) who show that technical colleges – in contrast to universities – co-operate more frequently with firms than with other research institutes. Finally, technical colleges can be seen as regionally rooted actors, as they predominantly co-operate with regional firms.[77]

Finally, public research institutes have been mainly founded for the purpose of complementing university (basic) research and transferring knowledge to firms. While, for instance, Max-Planck (MP) institutes are especially focused on doing basic research, Fraunhofer institutes conduct mainly applied and contract-based research and foster industrial innovations (Beise and Stahl, 1999). Hence, research activities conducted by technical colleges and public research institutes – especially Fraunhofer institutes – can be seen as more applied and less basic research-orientated compared to universities as well as they are more transfer-orientated to the industry. However, as shown by Beise and Stahl (1999) and Fritsch and Schwirten (1999), public research institutes do not always have an explicit regional focus of co-operating with firms in their geographical vicinity.

5.2.3 Regional knowledge transmission channels

Public research actors produce different forms of new knowledge – basic, applied or industry-related knowledge. Besides providing internal returns to this knowledge creation within the research

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[77] Fritsch and Schwirten (1999) argue that students from technical colleges are more frequently from the hosting region and they also remain more frequently within the region after graduation.

sector, their activities may also create knowledge spillovers to firms via several channels. For instance, Beise and Stahl (1999) emphasise the distribution of new knowledge via scientific publications, joint R&D projects and co-operations, (informal) networks and contacts between public and private researchers as well as via hiring university researchers as important transfer channels. Varga (2000), among others, additionally emphasises the role of spin-offs, graduates and physical facilities (e.g. libraries) as important knowledge diffusion mechanisms.

Regarding the spatial dimension of these knowledge spillovers, neoclassical growth models emphasise the public good characteristics of knowledge (non-excludable and -rivalry), which implies that knowledge spills over frictionless across space (e.g. Mankiw et al., 1992). However, there are several arguments that scrutinise this strong implication of frictionless knowledge spillovers: Firstly, public research institutes function as a regional "aerial" (Fritsch and Schwirten, 1999, p. 81). They absorb foreign knowledge, create new knowledge and make it available within their own region (Fritsch and Schwirten, 1999). Accordingly, it can be expected that knowledge spillovers have, at least to some extent, a local context. Secondly, Audretsch and Lehmann (2005) refer to geographical (localization) theory and argue that new knowledge does not spill across space readily and gratuitously.[78]

In fact, the spatial range of knowledge spillovers running from public research inputs to private sector research outputs has been discussed controversially in recent years: Beise and Stahl (1999) provide an excellent summary of the well-known arguments for the importance of spatial proximity between firms and public knowledge sources: On the one hand, effective knowledge transfer is based on informal networks and contacts, face-to-face-communication or mutual trust to exchange

[78] This may apply even if a certain share of graduates move to other regions (see Faggian and McCann, 2009 for the role of graduate migration in the UK).

tacit knowledge. On the other hand, the authors also provide arguments against the relevance of spatial proximity in this context, for instance, related to modern information and telecommunication techniques as well as specifically for the case of Germany as subject of this analysis, the relative low distances within the country compared to larger economies such as the United States as well as the dense infrastructure network in Germany (Beise and Stahl, 1999). To sum up, the economic effects of public research activities can be expected to partly take place within the region and partly work in a distance-free manner across all locations in Germany or even beyond that. Due to the empirical approach chosen here, we will focus on identifying the strength of localised effects that are specific to the region.

5.2.4 Effects of regional knowledge spillovers on regional economic development

The impact of universities on regional knowledge production (new technologies) and development has been analysed intensely in different spatial contexts so far. The study by Drucker and Goldstein (2007) provides a comprehensive review of international investigations by sub-classifying the studies according to different methodological approaches.[79] The authors argue that case studies provide heterogeneous results as they suffer from two major drawbacks: it is difficult to determine causal effects of universities' activities and the results are hardly generalizable. Moreover, studies on the co-location behaviour of firms and universities provide ambiguous results (Drucker and Goldstein, 2007). Finally, the literature reviews given in Drucker and Goldstein (2007) and Varga and Horváth (2015) show that a large fraction of empirical studies find positive effects of university activities – typically measured by R&D expenditures – on the regional knowledge production.

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[79] The review by Drucker and Goldstein (2007) also comprises firm-level studies, more recent firm-level studies are for example the studies by Barra et al. (2019), Maietta (2015) and Maietta et al. (2017).

Several studies have also analysed the role of public research actors (mainly universities and technical colleges) for regional economic development in Germany. In line with the above mentioned international studies, German studies can also be divided into three research strands (a detailed survey of the methods and results is provided in Table A5.1 in the Appendix). At first, there is a bulk of case studies analysing the demand-side effects of universities on regional income and employment (e.g. Glorius and Schultz, 2002; Glückler and König, 2011; Spehl et al., 2005, among others). The main conclusion from these studies is that universities and technical colleges have positive effects on both regional income and on employment.[80]

Secondly, various firm-level studies focus on the (spatial) co-operation behaviour between public research institutes and firms (e.g. Beise and Stahl, 1999; Fritsch and Schwirten, 1999) and on the location decisions of firms to operate in spatial proximity to universities (e.g. Audretsch and Lehmann, 2005; Audretsch et al., 2005). Analysing survey data, Beise and Stahl (1999), for instance, find that firms see access to public research outputs as a vital element for private research success. However, spatial proximity – with the exception of technical colleges – is not as important as in the Unites States to gain from research spillovers (Beise and Stahl, 1999). This is in line with the results reported in Fritsch and Schwirten (1999), who also conclude that public research institutes are vital for private innovation activities. Spatial proximity is seen as an advantage for establishing co-operations, with the highest share of regional co-operations being found for technical colleges (Fritsch and Schwirten, 1999). Audretsch et al. (2005) highlight that spatial business decisions of firms to locate close to universities depends on scientific disciplines (social or natural science) as well as on the transfer mechanisms (via publications or the number of students). According to a further study by Audretsch and Lehmann (2005), regions with universities that educate a high

[80] Table 25 in the study of Glorius and Schultz (2002, p. 32) as well as Table 1 in the study of Spehl et al. (2005, pp. 6-7) give an overview of further case studies.

amount of students in social and natural sciences and produce a high number of publications (particularly natural sciences) attract more knowledge-based start-ups.

Thirdly, a further strand of literature uses data at the regional level to analyse the effects of public research institutes on various economic variables (see Table 5.1). Fritsch and Slavtchev (2007) analyse the effects of universities (regular and external research funds) on regional patent activity. While the intensity of regular funding volumes (base funding) do not have significant effects, external research funding is found to positively affect regional patent applications (Fritsch and Slavtchev, 2007).[81] In a study for the German federal state of Rhineland-Palatinate, Spehl et al. (2007) emphasise that public knowledge and human capital increase gross value added significantly. Moreover, the authors find significant effects of public research on the regional patent activity (Spehl et al., 2007).[82] Finally, using regional data for all German regions, Schubert and Kroll (2013) find positive effects of various measures for regional university and technical college activities, for example on regional GDP per capita, employment and patent applications.

Summing up, the paper at hand aims at contributing to the analysis of the regional economic effects of public research activities by tackling some unresolved issues in the existing empirical literature using German regional data, which is mainly focused on the analysis of the direct effects of publicly funded research on particular output variables such as regional patents or output (see Table 5.1) while neglecting indirect effects between the variables in regional innovation and production system. The paper sheds light on the total effects of various publicly funded research measures (publications, third-party funds) by different public research actors on several economic variables. In

[81] Table 3 in the study of Fritsch and Slavtchev (2007, pp.214-215) also summarise the results of (international) studies focusing on the elasticities of private sector as well as of university R&D on innovation counts (patents).

[82] Table 2.1 in the study of Spehl et al. (2007. p.6) presents further studies.

order to define the functional relationships between public research and regional economic development, the subsequent chapter discusses the theoretical framework, variable selection and the derived hypotheses used for our empirical modelling approach.

Table 5.1 German empirical studies on regional level – unresolved issues

Authors	Data	Method	Studied public actor(s)	Unresolved Issues
Fritsch and Slavtchev (2007)	Panel data (all studies)	Single equation models (all studies)	Universities	1. Effects of public research institutes (for all German labour market regions) 2. System approach: total effects (direct plus indirect effects) of public research actors on all economic variables in a regional production system
Spehl et al. (2007)			Universities, technical colleges and Institutes within the Ministry of Science of Rhineland-Palatinate	
Schubert and Kroll (2013)			Universities and technical colleges	

5.3 Theoretical considerations and research hypotheses

Theories of economic growth are used to formulate research hypotheses and to impose a causal structure linking variables over time. Our main argument is that public research contributes to regional innovativeness (knowledge production function) and that innovation and new products, respectively, contributes to regional growth and development (e.g. Romer, 1990). We also account for the fact that this causal chain is not necessarily uni-directional. We therefore propose a modification/extension of the standard knowledge production function, which allows incorporating mutual linkages between public research activities and further economic variables in the underlying regional economy. The basic elements of the theoretical argumentation are the regional production function as well as exogenous and endogenous growth theory.

5.3.1 Regional production function

The production function for each region *i* is given by (Mankiw et al., 1992)

$$Y_i = K_i^{\alpha} H_i^{\beta} (A_i L_i)^{1-\alpha-\beta}.[83] \tag{5.1}$$

[83] Y_i is output, K_i physical and H_i human capital, A_i is technology/knowledge and L_i denotes labour.

With regard to the input factors we define labour L_i at time *t* as

$$L_i(t) = \lambda_i(t) \times P_i(0)e^{n_i t}, \tag{5.2}$$

where $\lambda_i(t)$ is the ratio of employed people at time *t* (constant in the long-run perspective), $P_i(t)$ denotes the economically active population from 15 to 64 years and n_i is the growth rate of the economically active population (Eberle et al., 2019).[84] The production function per economically active population is then given by

$$y_i = k_i^{\alpha} h_i^{\beta} (A_i\lambda_i)^{1-\alpha-\beta}. \tag{5.3}$$

As shown in Equation (5.3), per capita output is specified as a function of technology, physical and human capital as well as the employment rate. Details on the specification of these input factors will be given in the following.[85]

5.3.2 Technology

We relax the strict assumption of equal technological growth across regions (e.g. Mankiw et al., 1992) and permit short-run differences in the technological growth rates g_i.[86] To derive explicit research hypotheses, we start with the endogenous growth approach defined by Romer (1990). The model is based on the public good argument of knowledge, but allows for different technological growth rates across regions due to its interdependences with human capital devoted to the R&D-sector (H_A) (Romer, 1990)

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[84] We highly acknowledge a comment from an anonymous reviewer who proposes to use solely unskilled employed persons to measure L_i. We apply this definition as alternative operationalization in the robustness checks reported in Section 5.7 in order to employ a skilled-unskilled dichotomy.

[85] Output, employment and human capital can be measured empirically for German regions, while data on the level of technology and physical capital is complex to collect. Thus, we apply technological growth and capital investments instead (e.g. Eberle et al., 2019). For the remainder of the paper, capital investments are denoted by s_k, while technological growth is denoted by g_i.

[86] In the long-run perspective, we assume that technology is a public good and technological growth may be approximately the same across regions (neoclassical, competitive assumption).

$$\dot{A}_i = \delta H_{A,i} A_i \quad \text{and} \quad \frac{\dot{A}_i}{A_i} = g_i = \delta H_{A,i}, \tag{5.4}$$

where δ indicates a productivity parameter. The research sector in this model is assumed to be private, with firms earning income by licensing their research findings (Romer, 1990). In reality, however, research is typically conducted by firms and public research actors (see Section 5.2). Therefore, we distinguish between these two kinds of research actors. We denote A_i as the economically useable research output (proxied through patents) and R_i as the public research activities (e.g. publications, third-party funds). We thereby assume that public research activities stimulate private research activities and output. In addition, we assume that further input factors in the production sector in Equation (5.1) may – to some extent – also be inadvertently productive in the regional research sector (e.g. Rivera-Batiz and Romer, 1991).

Consequentially, we define the evolution of regional technological development A_i as

$$g_i = \delta H_{A,i} \times \Phi R_i \times w((1-\Phi)\widetilde{R}_j) \times \rho X_i. \tag{5.5}$$

In Equation (5.5), the (exogenously given) R_i is a measure for the regional public research activities within region *i*, $\widetilde{R}_j$ denotes the public knowledge created in other regions *j*, while the spatial weighting matrix w measures the spatial connectivity between the set of regions (see Section 5.4 for further details). Furthermore, X_i controls for other economic variables from the production sector [e.g. K_i, $H_{Y,i}$, $\lambda_i P_i$, Y_i]. We follow Rivera-Batiz and Romer (1991) arguing that these factors may be productive in the research sector as well, but, conversely to these authors, we assume that they have only inadvertent effects on the research sector, which are measured by the parameter ρ.[87]

[87] The argument is, for example, also in the spirit of Arrow (1962), who states that investments and production have – due to learning experiences – also positive (unintended) effects on the stock of knowledge.

Moreover, we add these variables as proxies for potential agglomeration effects and the productivity of region *i* (see Varga, 2000 for the effects of agglomerations on technology transfer). Consequently, public research can be interpreted as a region-specific productivity parameter in the knowledge-production process of private firms, in doing so research institutes make new knowledge available to firms.

To this end, we add the parameter Φ to Equation (5.5), because not all public knowledge created locally is transferred to regional firms. Consequently, Φ is fixed between 0 and 1 and measures the amount of public research activities that are transferred to firms in region *i*, while 1-Φ is the amount that is transferred to firms in other regions. We assume that Φ depends on the co-operation behaviour (the need for spatial proximity for knowledge exchange), the degree of embeddedness in regional (informal) networks (e.g. via graduates) as well as on the form of the newly created knowledge (basic vs. applied knowledge).[88] Due to their focus on basic research and a rather unbounded spatial co-operation behaviour (with primarily larger firms), we expect Φ to be generally lower for universities compared to the other public research actors located in the region as they co-operate with firms farther away (see e.g. Beise and Stahl, 1999; Fritsch and Schwirten, 1999). With regard to public research institutes, we expect Φ to be higher for Fraunhofer institutes compared to Max Planck institutes since Fraunhofer institutes place a stronger focus on applied industry-related research (see Section 5.2). Finally, based on the previous arguments, Φ is expected to be highest for technical colleges.

These considerations can be consolidated to a first hypothesis:

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[88] Applied research may be based on the technological sectors of regional firms and it may require a higher amount of personal interaction for exchange (more tacit). We refer to the seminal study by Boschma (2005) for an extensive discussion of the role of (spatial) proximity on knowledge exchange.

Hypothesis 5.1 (H5.1): *An increase in regional public research activities (R_i) lead to higher innovativeness and technological development (g_i) in the respective region. The size of the effect is expected to vary across the set of research actors (universities, technical colleges and public research institutes) with higher effects for public actors focusing on applied research and local co-operation activities.*

5.3.3 Physical and Human Capital

The interaction between technical growth, physical and human capital is based on Mankiw et al. (1992) and the associated physical and human capital accumulation dynamics. Consequently, a positive change in the technological growth rate g_i affects physical and human capital accumulation positively as it makes physical and human capital more effective, while investment rates are commonly expected to be unaffected (Mankiw et al., 1992).[89] This leads to a second hypothesis:

H5.2: *An increase in regional technological development (g_i) – triggered by higher public research activities (R_i) – leads to a significant positive effect on the stock of human capital (h_i), while the investment rate of physical capital ($s_{k,i}$) remains prima facie unaffected. Due to their research focus and co-operation behaviour, we assume that this link mainly holds for technical colleges and public research institutes (especially Fraunhofer).*

5.3.4 Employment rate

A continuous effect on the employment rate can only occur if a change in the technological growth rate affects aggregate supply on regional labour markets.[90] An increase in the labour-augmenting

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[89] Positive externalities of public research may lead to higher levels of regional output (y_i) and physical capital (k_i), while the ratio of saved and re-invested capital from the generated output (here: investment rate, s_k) is assumed to be constant. An increase in the output implies an increase in total investments and thus a fixed investment ratio.

[90] In exogenous growth models labour supply grows constantly and technological change has no effect on the development of labour (e.g. Mankiw et al., 1992; Solow, 1956). Romer (1990) also assumes that the supply of labour L_i is fixed.

technology (see Equation 5.3) makes labour more effective (higher marginal productivity), increases demand for labour and, thus, wages and employment (if the supply curve of labour is not vertical).

Implied higher wages may attract more labour from outside the region (inducing in-migration). Niebuhr et al. (2012) provide a detailed survey of theoretical approaches showing how mobility may influence labour supply and demand. Neoclassical labour market theory assumes that migration mainly affects labour supply and works towards spatial convergence, because migration to high-wage regions puts the wages in these regions under pressure or – if wages are rigid – generates unemployment (Niebuhr et al., 2012). Moreover, a higher labour supply may lead to over-congestion and, thus, to negative effects on utilities (Varga, 2017). Hence, growth of labour supply would occur only temporarily. However, this does not seem in line with the recent development of employment rate in Germany. For instance, Suedekum (2005) adds unemployment to a new economic geography model to show that migration also affects regional labour demand. This would lead to a spatial polarization of wages and (un)employment rates (Suedekum, 2005).

Merging these arguments, we can formulate the following hypothesis:

> **H5.3:** *As argued in H5.1, an increase in regional public research activities R_i increases the private regional innovation output (g_i). This increases the demand for labour and results in significant positive effects on the regional employment rate (λ_i).*

5.3.5 Output

According to the production function in Equation (5.3), the growth of regional output can be formulated as a function of the input factors as

$$\frac{\dot{y}_i}{y_i} = (1\text{-}\alpha\text{-}\beta)\,\frac{\dot{A}_i}{A_i} + (1\text{-}\alpha\text{-}\beta)\,\frac{\dot{\lambda}_i}{\lambda_i} + \alpha\frac{\dot{k}_i}{k_i} + \beta\frac{\dot{h}_i}{h_i}, \tag{5.6}$$

which immediately translates into our fourth hypothesis:

> **H5.4:** *An increase in regional public research activities (R_i) triggers a positive change in the private innovation output g_i (H5.1), the stock of human capital h_i (H5.2) and the employment rate λ_i (H5.3). These input-related effects are then expected to translate into positive overall effects on regional economic output (y_i). As already stated above, these effects are expected to be particularly significant for certain public research actors such as technical colleges and public research institutes with a focus on applied research and local knowledge transfer.*

5.4 Data

We build a panel data covering 258 labour market regions in Germany in the period 2000 to 2011. We use the classification of labour market regions provided by the *Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR)*, which aims at harmonising the place of residence and place of work of German population by explicitly considering the commuting traffic across small-scale regions (*Landkreise*). Our choice of using local labour markets as the underlying regional scale for the empirical analysis thus aims at reducing measurement errors that stem from the fact that local residents produce output in another regions as they are living. Although the used labour market regions are defined functionally, they are obtained by merging administrative districts (*Landkreise*), which causes them to be not the best choice in some places. However, due to data availability a better definition of functional regions is not available for the purpose of this study.

Table 5.2 Variables and data sources

Shortcut	Definition	Data source
lgdp	Nominal GDP per economically active population (ln): [GDP in € / (Population aged between 15 and 64 × 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.	**GDP:** Arbeitskreis "Volkswirtschaftliche Gesamtrechnungen der Länder" (Status: August 2015) **Population aged between 15 and 64 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 physical capital investments (industry investments in the manufacturing, mining and quarrying sector) as share of the nominal GDP (ln): [Industry Investments in € / GDP in €] **Note:** Missing values of the industry investments 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 (ln): [Employees with university degree / (Population aged between 15 and 64 years × Participation rate)]. **Note:** All alleged data imperfections related to the qualification of employees (human capital) are assumed to be random and do not systematically bias the results.	Institute for Employment Research (IAB), Nuremberg
lemp	Employment rate (ln): [Employees total / (Population aged between 15 and 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lemp_ns	Non-skilled employment rate (ln): [(Employees total - Employees with university degree) / (Population aged between 15 and 64 years × Participation rate)]	Institute for Employment Research (IAB), Nuremberg
lpat	Patent rate* (ln): [Patents region *i* / ∑ Patents Germany]	Own calculation from the PATSTAT database (Version October 2014, European Patent Office)
lpubli_X	Publication Rate* (ln): [Publications X region *i* / ∑ Total Publications X Germany] X = Higher education institutes (hei), universities (uni), technical colleges (fh), public research institutes (ri), Fraunhofer (fraun) and Max-Planck (mp) institutes. **Note:** Public research institutes include MP, Fraunhofer, Helmholtz and Leibniz institutes. Higher education institutes include universities and technical colleges.	Own calculation from the Web Of Science database
ltpf_X	Third-Party Fund Rate* (ln): [Third-Party Funds X region *i* / ∑ Third-Party Funds X Germany] X = Receiving institute (hei, uni, fh) and source of fund: total funds (no suffix), public funds (pub) and industry funds (ind) **Note:** Public third-party funds are the sum of funds from the Bund, Federal States, municipalities, German Federal Labour Market Authority, Deutsche Forschungsgemeinschaft (DFG), EU and other public investors (the dataset contains one negative value of the public third-party funds, which was replaced by 0.25). Total Funds are the sum of private and public funds as well as from funds from foundations.	Statistisches Bundesamt (Germany)
w_variables	Spatial lags for each variable are constructed in absolute values using the STATA command *splagvar*. All spatial lag variables are normalised and ln-transformed similar to the non-spatial variables.	

* In order to take the ln, we added 0.25 to each observation of the variable before normalization because zero values are included.

Table 5.2 shows the construction of variables and corresponding data sources. All variables are specified as intensities and are transformed by the natural logarithm. Public research activities are proxied by the number of publications of universities, technical colleges and public research institutes as well as third-party funds received by universities and technical colleges. Unfortunately, no data on acquired third-party funds are available for public research institutes. As publications are taken from the Web of Science, the data place a relatively strong weight on scientific publications compared to other types of research outlets such as technical reports, etc. Summary statistics for variables are reported in Table 5.3.

Table 5.3 Summary statistics

	Shortcut	Mean	Std. Dev.	Min	Max
Economic variables					
GDP per economically active population	gdp	49341.59	12938.38	22936.38	116626.4
Physical capital investment rate	invq	0.0254	0.0167	0.0027	0.2240
Higher education rate	hk	0.0566	0.0291	0.0155	0.2067
Employment rate	emp	0.6141	0.0901	0.3902	0.9473
Non-skilled employment rate	emp_ns	0.5575	0.0752	0.3581	0.8911
Patent rate	pat	0.0039	0.0085	1.29E-05	0.1007
Publications					
Publication rate higher education institutes	publi_hei	0.0039	0.0101	4.77E-06	0.0911
Publication rate universities	publi_uni	0.0039	0.0101	4.80E-06	0.0918
Publication rate technical colleges	publi_fh	0.0039	0.0067	0.0005	0.0523
Publication rate public research institutes	publi_ri	0.0039	0.0154	3.81E-05	0.1954
Publication rate Fraunhofer institutes	publi_fraun	0.0039	0.0145	0.0003	0.2118
Publication rate Max-Planck institutes	publi_mp	0.0039	0.0169	0.0001	0.2182
Third-Party Funds					
Received by Higher Education Institutes					
Third-party fund rate higher education institutes	tpf_hei	0.0039	0.0099	4.85E-08	0.1122
Industry third-party fund rate higher education institutes	tpf_hei_ind	0.0039	0.0110	2.53E-07	0.1140
Public third-party fund rate higher education institutes	tpf_hei_pub	0.0039	0.0099	6.56E-08	0.1168
Received by Universities					
Third-party fund rate universities	tpf_uni	0.0039	0.0102	5.27E-08	0.1166
Industry third-party fund rate universities	tpf_uni_ind	0.0039	0.0116	2.88E-07	0.1232
Public third-party fund rate universities	tpf_uni_pub	0.0039	0.0101	7.06E-08	0.1199
Received by Technical colleges					
Third-party fund rate technical colleges	tpf_fh	0.0039	0.0092	6.07E-07	0.1215
Industry third-party fund rate technical colleges	tpf_fh_ind	0.0039	0.0092	2.12E-06	0.0925
Public third-party fund rate technical colleges	tpf_fh_pub	0.0039	0.0114	9.29E-07	0.1770

Notes: Number of Regions = 258 and t = 12. Normalised values are presented (before taking the ln). We added 0.25 to each observation of variables containing zero values before normalization (applies for pat, all publi- and tpf-variables). Suffix "_pub" indicates third party funds from public authorities and "_ind" third party funds from the industry. See Table 5.2 for details on variable description.

With regard to the statistical properties of our data, we are concerned with non-stationarity of variables over time as well as cross-sectional dependence, which may both affect the estimation results. In order to test for the degree of non-stationarity within our data, we apply a panel unit root test proposed by Im et al. (2003) (henceforth: IPS). Table A5.2 in the Appendix shows that this is a serious problem, especially for variables measuring public research activities. Thus, we detrend all variables that are non-stationary in their levels. The results of the IPS test highlights that detrended variables reject the null hypothesis of containing unit roots.

Moreover, with the exception of public research activities (see Section 5.3), the role of spatial dependencies has not been discussed so far. Nevertheless, we generate spatial lags for all variables and include them in all regression specification in order to capture underlying spatial spillovers and thus avoid an omitted variable bias. We use a binary first-order neighbourhood matrix to build spatial lags (e.g. Eberle et al., 2019). Matrix elements w_{ij} have the following properties

$$\begin{aligned} &w^*_{ij} = 0 \text{ if } i = j \text{ and } i \text{ and } j \neq \text{common border} \\ &w^*_{ij} = 1 \text{ if } i \neq j \text{ and } i \text{ and } j = \text{common border} \\ &w_{ij} = w^*_{ij} / \textstyle\sum_j w^*_{ij}. \end{aligned} \tag{5.7}$$

In Equation (5.7) w^*_{ij} denotes a particular element of an unstandardised weighting matrix, while w_{ij} denotes a particular element of a normalised weighting matrix (e.g. Eberle et al., 2019). We follow the approach presented in the study by Eberle et al. (2019) and normalise the matrix elements by dividing them with the column sum. The theoretical arguments for spillovers from public research activities also imply potential effects beyond neighbouring regions. However, effects of public research activities that occur independent of spatial distance should partly be captured by the time-fixed effects in our regression specifications.

5.5 Econometric modelling: Spatial panel VAR and impulse response functions

To analyse the economic effects of public research activities on a regional economic system, we estimate a spatial panel VAR (SpPVAR) model (see, for example, Beenstock and Felsenstein, 2007; Di Giacinto, 2010; Eberle et al., 2019; Mitze et al., 2018; Monteiro, 2010; Ramajo et al., 2017).

As argued above, earlier studies of the relationship between public research and regional economic growth usually estimate a one or two regression equation model. In the case of two equations, economic growth is assumed to depend on innovation and innovation is assumed to depend on public research. Such an approach has two limitations. First, there is a strong endogeneity problem since the innovation activity also depends on economic development and, especially on the regional level, public research responds to the economic and innovative activity within the region. Second, public research has not only an effect on the innovation output but may also directly influence human capital, employment and investment in the region. The SpPVAR model captures potential two-way interdependencies between all variables, reducing both limitations. First, endogeneity is explicitly considered in the model. This allows for Granger causal statements, given that all relevant variables are considered and the correct causal structure at time *t* is used (e.g. Hoover, 2012 for a discussion of structural VAR models and causality). Second, effects on other economic variables are explicitly considered in the structural VAR approach. Thus, besides modelling the transmission channels that are discussed in Section 5.3, the SpPVAR approach allows us to detect additional transmission channels and, thus, deepen the insights on the transmission mechanisms of public research activities in the regional economic system.

Our system contains six equations including the subsequent dependent variables: 1) higher education rate (human capital), 2) rate of public research activities, 3) patent rate, 4) physical capital investment rate 5) employment rate and 6) GDP per (economically active) population. The structural SpPVAR – a specification with orthogonalised errors and contemporaneous relations – can be expressed in terms of a spatially augmented model as (e.g. Eberle et al., 2019)

$$\mathbf{B}\mathbf{y}_t = \mu + \tau_t + \mathbf{C}(\mathbf{L})\mathbf{y}_{t-1} + \mathbf{G}(\mathbf{L})\mathbf{W}\mathbf{y}_{t-1} + \mathbf{D}\mathbf{e}_t. \tag{5.8}$$

In Equation (5.8), the vector $\mathbf{y}_t$ comprises the described endogenous variables, μ denotes a vector of regional fixed effects, while τ_t indicates a vector of time-fixed effects (which captures nation-wide economic shocks and technological progress that is not restricted to specific regions), the matrix **B** comprises contemporaneous coefficients, while $\mathbf{C}(\mathbf{L})$ and $\mathbf{G}(\mathbf{L})$ are matrices of polynomials associating contemporaneous to (space-)time lagged variables, **D** relates contemporaneous shocks to the endogenous variables and the vector $\mathbf{e}_t$ describes orthogonal errors (e.g. Eberle et al., 2019, Keating, 1992; Mitze et al., 2018 or Rickman, 2010.[91]

In terms of estimating the system (in a reduced-form specification), the standard fixed effects (FE) estimator is biased due to the inclusion of time lags of the particular dependent variable (e.g. Nickell, 1981).[92] Thus, we use a bootstrap-based corrected FE estimator that has been originally proposed by Everaert and Pozzi (2007). To visualise the estimated mean effects together with 95%

[91] The coefficient matrix $\mathbf{C}(\mathbf{L})$ denotes spatially direct, while $\mathbf{G}(\mathbf{L})$ denotes spatially indirect effects of shocks in $\mathbf{y}_{t-1}$ on $\mathbf{y}_t$ (e.g. Eberle et al., 2019). The analysis here is focused on the IRFs that are based on the spatially direct effects $\mathbf{C}(\mathbf{L})$, while $\mathbf{G}(\mathbf{L})$ is primarily used to control for an omitted variables bias and to get unbiased coefficients in the regression models (see explanation in Section 5.4). We refer to the work of Elhorst (2012) for more information on dynamic spatial panel techniques for single equation models and to Mitze et al. (2018) for VAR approaches.

[92] In fact, the temporal spatial lag $\mathbf{W}\mathbf{y}_{t-1}$ is also biased using a FE estimator. Wooldridge (2012) emphasises that the inclusion of one biased coefficient may also bias all other coefficients. Thus, we run robust checks for every model excluding the temporal spatial lag from the particular regression in order to control for this issue. The results indicate that the bias is negligible as the IRFs are not significantly different from the basic approach.

confidence intervals, we compute IRFs measuring the response of a particular variable to an isolated shock in the rate of public research activities (Lütkepohl, 2005). Confidence intervals for these IRFs are calculated from Monte Carlo (MC) simulations (Love and Zicchino, 2006).

5.6 Linkage between theoretical and empirical considerations

To ensure identification, we need to stipulate the underlying causal structure of contemporaneous effects (**B** matrix) between variables (Rickman, 2010). Based on the theoretical argumentation presented in Section 5.3, we determine the subsequent recursive causal order at time *t*:

$$lhk_t \rightarrow lpubli(ltpf)_t \rightarrow lpat_t \rightarrow linvq_t \rightarrow lemp_t \rightarrow lgdp_t. \tag{5.9}$$

The recursive order in Equation (5.9) can be interpreted in the following way: human capital on the outmost left side has contemporaneous effects on the remaining variables in the regional economic system, while it is not subject to contemporaneous feedback effects from other variables (which only occurs with a time lag). The degree of endogeneity increases the more we move to the right side of Equation (5.9). Thus, in similar veins, public research activities have contemporaneous effects on all regional variables – except on the human capital variable – but are only affected by (potential) feedback effects from these variables with a time lag. Finally, the variable on the ultimate right side of Equation (5.9) – GDP per economically active population (workforce) – is contemporaneously affected by all other variables in period *t* but has only time lagged (feedback) effects on these variables as it is uni-directionally determined by regional input factors at time *t* and, therefore, the most endogenous variable in our production system.

Accordingly, the ordering of the first three variables follows the logic of a knowledge production function as shown in Equation (5.5), where human capital and publicly funded research are the main input factors, while the other factors have only (time-lagged) effects, whose magnitude are ex-ante unclear.[93] Moreover, a policy-induced increase in the TFP may have effects on regional employment, physical capital investments and regional production (e.g. Varga, 2017; see **H5.2** to **H5.4** in this study). Regarding these variables, we follow Eberle et al. (2019) and expect that contemporaneous capital investment decisions are primarily done ex-ante, while, in turn, a change in the employment is rather done on an ex-post basis.

5.7 Empirical results

5.7.1 Regional economic effects of publication activities

Since the SpPVAR approach covers direct and indirect effects within the endogenous regional economic system, the complete effect of changes in one variable on another variable cannot be grasped by simply looking at the estimated regression coefficients. As a consequence, IRFs (impulse response functions) are used for illustrating the reaction of per workforce output and factor inputs to an increase in public research activities in terms of a standard deviation "shock" of the latter variables (in order to interpret the responses as percentage measures, we multiply the estimated responses by 100).[94]

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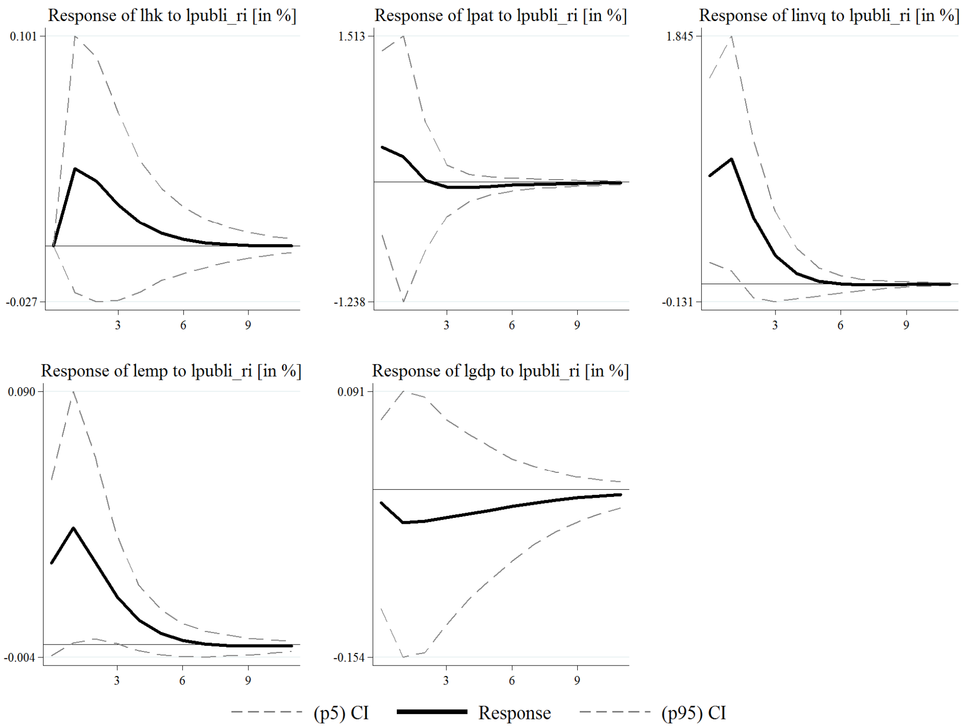
[93] This is in line with the initial model by Romer (1990) or the argumentation by Varga (2017), who states that innovation policies and human capital, respectively, affect technological progress that can be expressed through the total factor productivity (TFP). Moreover, by using human capital, publicly funded research (publications, third-party funds) can be considered as next step in the sharing of knowledge that afterwards moves to a commercialization phase (innovations measured by patents).

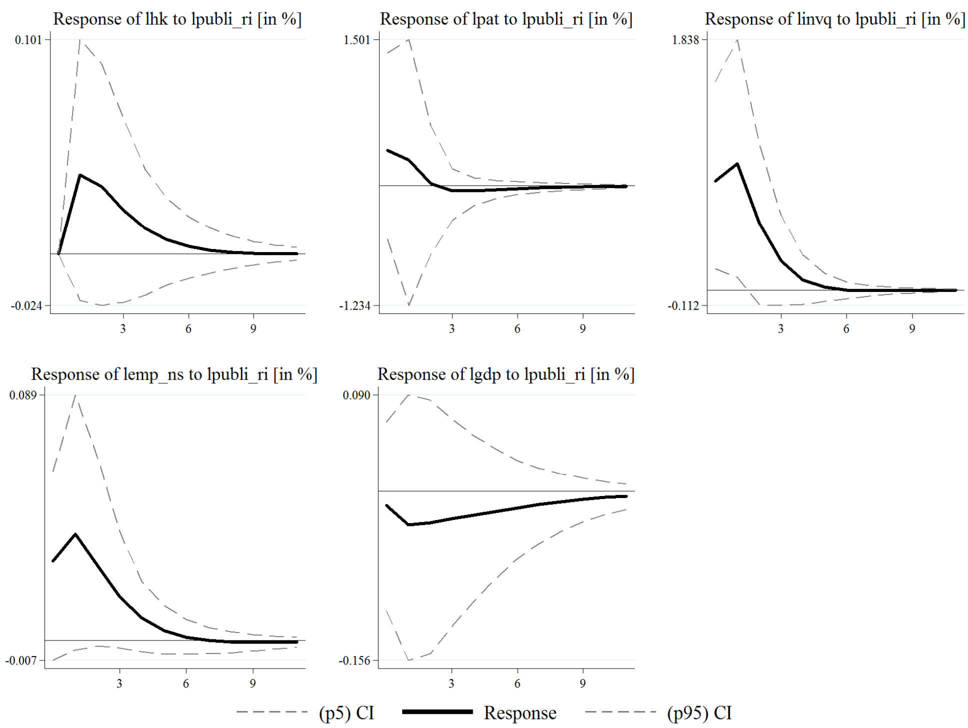
[94] Regression results of each SpPVAR model and non-significant IRFs regarding public research activities are available upon request.

Figure 5.1 IRFs for response of variables to shock in publication activity of public research institutes

a. Employment rate (lemp)



b. Non-skilled employment rate (lemp_ns)



Notes: Impulse response functions are based on the SpPVAR system incorporating the variables shown in Table 5.2 and the estimated coefficients. Solid lines are IRFs and dashed lines are 95% confidence intervals (CI) generated from Monte Carlo simulations with 200 repetitions.

The IRF results indicate that the responses of regional economic variables to a temporary, i.e. one-period, increase in the publication activity of universities in period *t* are statistically insignificant. Carefully speaking, this finding points to the fact that universities conduct mainly basic research and that knowledge disseminates across regional boundaries. Surprisingly, the effects of a positive "shock" in the publication activity of technical colleges are also non-significant. The same result also holds if we aggregate the publication rate of universities and technical colleges (henceforth: higher education institutes, HEIs). The latter aggregation would allow covering scale effects of different HEIs being located in one region.

With regard to the results of a one-period change in the publication activity of public research institutes, the results of the IRFs in Panel a of Figure 5.1 indicate that an increase in the publication activity has significant positive effects on the regional investment and employment rate.[95] Different from Panel a, the robustness-checks in Panel b show, however, that the positive effect on the non-skilled employment rate is non-significant. This finding may point to positive effects of public research institutes on skilled persons, even if the response of the human capital is non-significant.[96]

As stated in Section 5.2, Fraunhofer institutes conduct more applied and innovation-orientated R&D, while MP institutes complement mainly university research. However, we do not find any significant differences between MP and Fraunhofer institutes when we disaggregate their publication activities. There are two ways to interpret these disaggregate findings: First, there are no significant difference in the knowledge transfer of public research actors; second, and potentially more

[95] All of the IRFs in this paper are based on the SpPVAR system in Table 5.2 and the associated estimated coefficients. The time dimension – measured by years – is displayed on the x-axis, while the response to a one standard deviation shock is displayed on the y-axis [multiplied by 100, in %].

[96] Using the non-skilled employment rate instead of the employment rate reveals no differences regarding the significance of the remaining results in this study. Thus, in the remainder of the paper, we solely present the results of the models that uses the employment rate (lemp).

likely, publication data can only be seen as an imperfect indicator to measure public research activities, particularly when the data are disaggregated by public research actors. This disaggregation problem becomes visible when we contrast the disaggregated results with aggregated effects summed over all types of actors, which show significant effects on the regional economy.[97] At the same time, this finding may also indicate that the right mix of public research activities is decisive for observing positive output effects in the regional economy.

5.7.2 Regional economic effects of third-party funded public research activities

Next, we present the results of the SpPVAR models and the associated IRFs using the volume of acquired third-party funds of universities and technical colleges as indicator for the strength of their public research efforts activities (unfortunately no funding data are available for public research institutes). Different from the publication data, we are able to distinguish between overall funding volumes, on the one hand, and public as well as private third-party funding volumes, on the other hand.[98] Hence, we are able to analyse public research activities more precisely by not only detangling public actors (universities and technical colleges) but also the sources of funds.

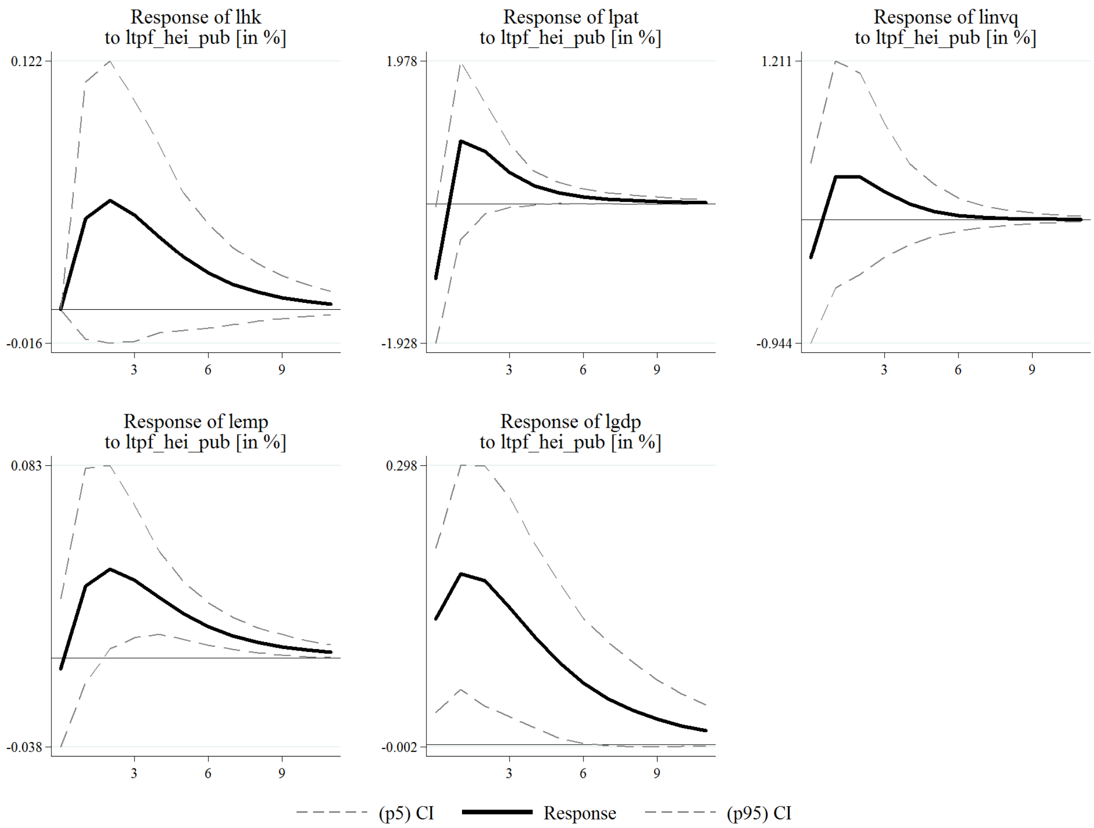
The selected IRFs of the SpPVAR model in Figure 5.2 highlight the growth effects of a positive one standard deviation-"shock" in public third-party funding received by universities and technical colleges combined (higher education institutes). An increase of public third-party funds leads – after a phasing-in process of roughly five years – to a significant positive increase in the regional patent rate. Moreover, the temporary rise in public third-party funds also leads to a significant increase in the employment rate and to a significant increase in the output per workforce. These

[97] In addition to the MP and Fraunhofer institutes, public research institutes also contain the publications of Helmholtz and Leibniz institutes (see Table 5.2).

[98] Please note, total funds are the sum of private as well as of public funds and funds provided by foundations, which are not analysed separately in this paper. In the remainder of the paper, we mainly discuss total and public third-party funds, because the findings for private third-party funds are continuously non-significant.

findings provide support for the hypotheses **H5.1**, **H5.3** and **H5.4**.[99] Conversely, a positive shock to overall and private third-party funds received by HEIs does not go along with any significant changes in regional variables.

Figure 5.2 IRFs for response of variables to shock in public third-party funds of higher education institutes (universities and technical colleges combined)



Notes: Impulse response functions are based on the SpPVAR system incorporating the variables shown in Table 5.2 and the estimated coefficients. Solid lines are IRFs and dashed lines are 95% confidence intervals (CI) generated from Monte Carlo simulations with 200 repetitions.

As stated in **H5.1** to **H5.4**, we expect that the growth effects illustrated in Figure 5.2 are mainly driven by research efforts of technical colleges. The responses to a temporary increase in third-

[99] This findings support the results of Schubert and Kroll (2013), who find also significant net effects on the GDP per capita, the unemployment and the patent rate.

party funding (overall, public, private funds) received by universities do not show significant effects, thereby supporting our previous findings using the publication intensity of universities. This is in line with expectations based on the studies of Beise and Stahl (1999) and Fritsch and Schwirten (1999) regarding the conducted research, graduates and co-operation behaviour of universities.

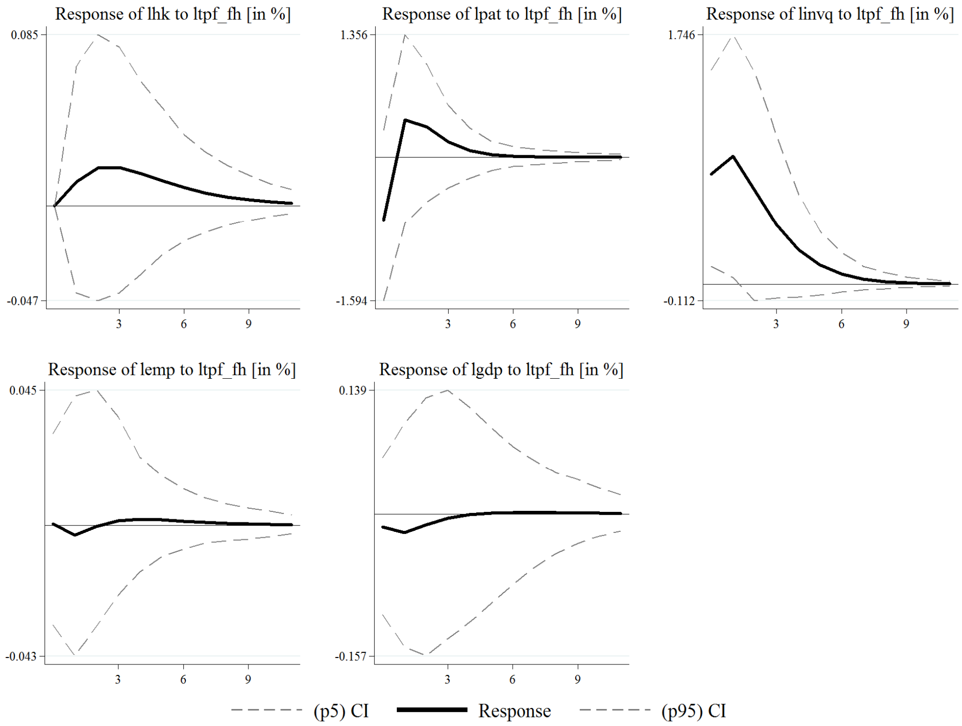
In turn, the IRFs presented in the upper part of Figure 5.3 indicate that a change ("shock") in the overall third-party funds received by technical colleges increases the investment rate significantly in the short run. The effects on the employment rate and output are very small and insignificant, while the effects on the regional patent rate (after a phasing-in of roughly one year) and the human capital are positive (both are statistically insignificant, though, which might be caused by the smaller number for technical colleges).

In line with the overall results for the higher education institutes, private funds allocated to technical colleges do not have any significant regional effects. In contrast, a temporary rise in public third-party funds to technical colleges increases, on average, the stock of human capital and the employment rate significantly (**H5.2** and **H5.3** confirmed). In contrast to the findings for public third-party funds received by higher education institutes (Figure 5.2), we find positive, but insignificant effects on the regional patent rate and the output in this setting (**H5.1** and **H5.4** not confirmed). Carefully speaking, this result may point to the fact that positive effects on a region's patent rate may depend on the right mix of public sector research activities.

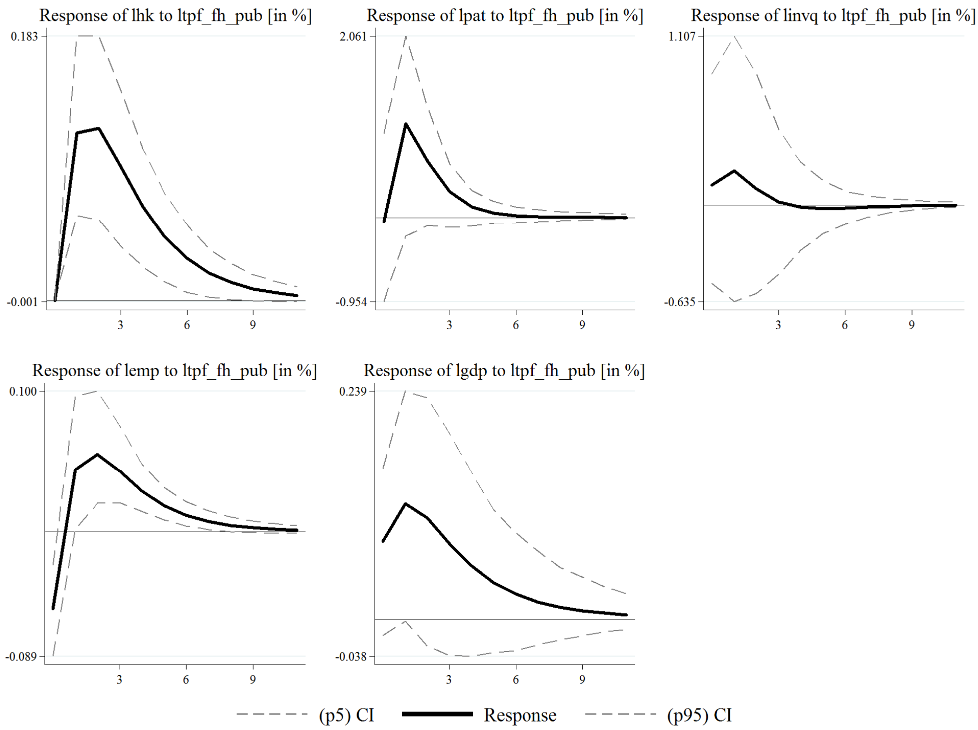
Table 5.4 summarises the results of the analysis conducted in this paper. We find at least some statistical support for regional effects of public research activities on all five economic variables, namely investment, employment rate, stock of human capital, patent activity and economic output studied in the paper. Hence, our hypotheses are, at least, partly confirmed.

Figure 5.3 IRFs for response of variables to shock in third-party funds of technical colleges

a. Overall third-party funds



b. Public third-party funds



Notes: Impulse response functions are based on the SpPVAR system incorporating the variables shown in Table 5.2 and the estimated coefficients. Solid lines are IRFs and dashed lines are 95% confidence intervals (CI) generated from Monte Carlo simulations with 200 repetitions.

Moreover, several details are worth discussing: First, we find little effects of publication activities. Publications seem not to reflect the interaction with the regional economy well. Publications are a more adequate measure for basic research, which is less regional bounded and less connected to the economic activity. In the case of public research institutes, publications have been the only available measure and have shown some significant effects.

Second, the results for third-party funding show that technical colleges have a stronger positive effect on the regional economy than universities. All settings incorporating universities do not indicate any significant regional effects. For technical colleges a number of positive effects are detected, which may be explained by the higher regional embeddedness, the higher share of graduates remaining in the region and the co-operation behaviour. Hence, the higher relevance of technical colleges for the regional economy is clearly confirmed.[100]

Third, distinguishing between public and private third-party funds leads to an interesting result: We do not find any positive effect of private third-party funds. One could have expected that private third-party funds come to a large extent from firms and therefore signal applied research. However, public third-party funds clearly translate into positive effects for the regional economy. Our interpretation is as follows: Many public research funds target joint innovation projects between firms and public research institutes (including universities and technical colleges). It might well be that these joint research projects build a channel for knowledge transfer between public institutes and private actors, often within a region, that finally leads to economic effects. As a consequence, we are able to also find positive effects of such publicly funded research on the regional patent activity

[100] As explained in the introduction, returns on university investments may be expected to take longer to be realised. This exercise remains open for future research.

and economic output. Similarly, we find some evidence that the right mix of public research activities in the region may influence the strength of the observed effects.

Table 5.4 Findings of the conducted SpPVAR models and their associated IRFs

Regional effects of changes in the publication rate					
	lpat	lhk	linvq	lemp	lgdp
Higher education institutes (lpubli_hei)	(-)	(-)	(+)	(-)	(-)
Universities (lpubli_uni)	(-)	(o)	(o)	(+)	(o)
Technical colleges (lpubli_fh)	(-)	(o)	(+)	(o)	(-)
Public Research Institutes (lpubli_ri)	(+)	(+)	+	+ ((+) for lemp_ns)	(-)
Regional effects of changes in third-party fund rate					
	lpat	lhk	linvq	lemp	lgdp
Third-party fund rate higher education institutes (ltpf_hei)	(o)	(+)	(+)	(+)	(+)
Public third-party fund rate higher education institutes (ltpf_hei_pub)	+	(+)	(+)	+	+
Third-party fund rate universities (ltpf_uni)	(o)	(+)	(o)	(+)	(+)
Public third-party fund rate universities (ltpf_uni_pub)	(-)	(+)	(o)	(+)	(+)
Third-party fund rate technical colleges (ltpf_fh)	(+)	(+)	+	(o)	(o)
Public third-party fund rate technical colleges (ltpf_fh_pub)	(+)	+	(+)	+	(+)

Notes: + positive, o neutral, - negative, ( ) non-significant effect, + significant effect.

5.8 Conclusions

This paper has analysed the regional economic effects of public research activities in Germany with a focus on their short-run dynamics. We have extended the recent literature on the transmission channels of knowledge transfer by distinguishing between different actor-activity combinations when analysing the linkages between public research and regional economic variables. By estimating a SpPVAR approach and applying IRF analysis, we have explicitly considered the simultaneous relationship between the regional variables.

We find that especially the volume of public third-party funds received by local public research actors has positive effects on the regional economic activity. This might be caused by the fact that often public funds are given to collaborations between private actors and public institutes. Hence, we conclude that such funds might be especially helpful to make public research activities an effective means of development within their region. We find that regional economic effects are larger for technical colleges compared to universities. This can be interpreted such that technical colleges use the collaboration potential within the region more extensively compared to universities (e.g. due to the focus on applied research and the job market behaviour of graduates that remain more often in the region). We also get some evidence that the strength of regional economic responses to an increase in public research activities depends on the right mix of public research activities, i.e. the joint presence of different research actors in a region.

The empirical results do not provide evidence that research conducted at universities has a significant immediate effect on the local economic activity. This is in line with theoretical expectations and may reflect their focus on basic research and mainly inter-regional co-operations. However, the effects of universities on the regional economy may become significant in the long run. We also find significant positive effects of the research activity of public research institutes. Here, an increase in the publication rate stimulates regional investments as well as the employment rate.

From the results of this study we may carefully draw the following policy implication: If policy makers aim at strengthening the short-run regional economic effects of public research activities, this should be done through an increase in the direct interaction between public research actors and firms. Public funds for collaborations of these actors seem to be a good tool to foster regional development. The regional effects of research conducted by universities seems to be currently low, but this might change if the collaboration behaviour of universities changes. Moreover, one also needs to consider that higher education institutes, particularly universities, obviously have significant supply- and demand-side linkages with the regional economy beyond the level of research activities (see, for instance, Bleany et al., 1992; Florax, 1992; Garrido-Yserte and Gallo-Rivera, 2010). Although these general income and expenditure effects should be considered when assessing the overall regional importance of research and higher education institutions, they were not in the focus of our empirical investigation.

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A5. Appendix

Table A5.1. Recent empirical studies on the regional economic effects of public research

Authors	Data and econometric approach	Regional Unit	Outcome Variable(s), Questionnaire question(s)	(Significant) Effects
Beise and Stahl (1999)	Cross-sectional data (1993-1996), Probit model (Maximum-Likelihood-Estimator (MLE)), multiple linear regression model (Ordinary Least Squares (OLS) Estimator)	Approximately 2300 firms from the Mannheim Innovation Panel (MIP)	*Outcome variables*: public-research-based innovation, Distances between firm and the public research institute *Questionnaire*: Share of companies with innovations which could not have been developed without recent public research (%) between 1993 and 1996; Distribution of sources without which innovations from 1993 to 1996 could not have been developed (%); Size distribution of firms with innovations introduced between 1993 and 1996 which could not have been developed in the absence of public research (%); Average share of sales of new products, which could not have been developed in the absence of public research (%); Estimated sales with new products introduced between 1993 and 1996, which would not have been developed without public research, Distance between firm and cited public research institution	Public research contributes to product and process innovations of firms in Germany. Especially the size of firms and their own research intensity increase the probability of innovations related to public research. Proximity to research institutes is only of minor importance, only technical colleges are more likely to have a regional priority.

Table A5.1 (continued)

Authors	Data and econometric approach	Regional Unit	Outcome Variable(s), Questionnaire question(s)	(Significant) Effects
Fritsch and Schwirten (1999)	1020 Questionnaires filled out by professorships at universities, technical colleges and non-university public research institutes (overall response rate 41 %), Chi-square tests	3 Regions: Baden, Hannover-Braunschweig-Göttingen, Saxony	*Questionnaire*: Forms of co-operation between public research institutions and private firms, Co-operation between public research institutions and private firms by type of innovation and stage of the innovation process, Regional distribution of the co-operation partners, Forms of co-operation between public research institutions, Regional distribution of co-operation partners (other public research institutions)	Publicly financed research institutes do contribute to the innovation process of firms (mostly to early stages by developing new ideas). Co-operations across publicly funded research institutes are important as well, especially for universities. Spatial proximity is more important for co-operations between public and private actors, than across public institutes. This applies especially for technical colleges.
Glorius and Schultz (2002)	Case Study Martin Luther University Halle-Wittenberg	Administrative district Halle	*Outcome variables*: Regional income and employment effects	Regarding direct and indirect effects, the existence of the university contributes to an income of 369.1 Mio. Deutsche Mark per year and creates 7.060 jobs within the region.
Audretsch et al. (2005)	Cross-sectional data (1997-2002), multiple linear regression model (OLS Estimator and Least Absolute Deviation (LAD) Estimator)	281 high-technology firms	*Outcome variable*: Distance (kilometres of a firm to the closest university): natural logarithm, absolute number of kilometres, Median and 92% percentile	Geographical proximity to universities matters for firm location. Firms locate closer to universities the more publications they have in social sciences and the more students they educate in natural sciences. In turn, higher publications in natural sciences and students in social sciences allow firms to locate more far away from universities.

Table A5.1 (continued)

Authors	Data and econometric approach	Regional Unit	Outcome Variable(s), Questionnaire question(s)	(Significant) Effects
Audretsch and Lehmann (2005)	Cross-sectional data (1997-2002), Binominal regression model (MLE)	281 high-technology firms and 54 universities	*Outcome variable*: Number of high-tech start-ups located closest to a university	The results emphasise that start-ups locate often within spatial proximity to universities. The number of firms closely located to a university is influenced by the number of students in natural and social sciences, the publications in natural sciences and the regional absorptive capacity. These results also depend on the particular industry.
Spehl et al. (2005)	Case Study Federal State Rhineland-Palatinate	Federal State Rhineland-Palatinate	*Outcome variables:* Turnover, value added and employment effects	The multiplier analysis (Input-Output-Analysis) shows that the total turnover effect amounts to €1.480 million (€1.280 Mio.), while the effect on the value added (income effect) is approximately €890 million (€440 Mio.). Finally, 20.240 (18.650) full time jobs are created.
Fritsch and Slavtchev (2007)	Panel data (1995-2000), sum of private sector and university R&D for neighbouring regions are included, multiple negative-binomial regression model (Fixed- (FE) and Random Effects (RE) Estimator)	West German NUTS-3 regions (Kreise)	*Outcome variable*: Patent applications	Regular funds to universities (sources for teaching, training or equipment) that are allocated based on the amount of personnel and students, do not have significant effects. External funds to universities received from private firms, government departments or the German Science Foundation have significant positive effects on regional patent activity.

Table A5.1 (continued)

Authors	Data and econometric approach	Regional Unit	Outcome Variable(s), Questionnaire question(s)	(Significant) Effects
Spehl et al. (2007)	Panel data (1995-2003), Technological growth (patents) and academic staff in the neighbouring regions are considered, multiple linear regression model (General-Least-Squares (GLS), FE- and RE-Estimator)	Federal State Rhineland-Palatinate 36 regional units (Kreise)	*Outcome variables*: Real gross value added, Patents	Regional public knowledge capital as well as the regional human capital increases the real value added. However, the results indicate that both input factors do not have significant effects on labour and physical capital. The academic staff in the region itself has no significant effects on patent applications, while constructing a variable including the academic staff from neighbouring regions leads to significant positive effects on regional patent applications. This applies only for technical colleges.
Glückler and König (2011)	Case Study Ruprecht-Karls-University Heidelberg	Heidelberg University Region (Heidelberg, Mannheim and Rhein-Neckar district)	*Outcome variables*: Regional income and employment effects	Regarding direct and indirect effects, the existence of the university contributes to an income of €673 million per year and facilitates 21.600 jobs (conservative estimation).
Schubert and Kroll (2013)	Panel data (2001-2009), FE and RE-Estimator	German NUTS-III Regions	*Outcome variables*: GDP per capita, Unemployment rate, Available income per capita, Patent application per capita	Compared to an average region with local academic activities, a region without such activities has an approximately €4.500 lower GDP per capita, a 3 % higher unemployment rate and 12.5 % less patent volume. Especially the effects on the GDP per capita are regionally bounded (85 %), while the regional effects on the unemployment rate are limited (19%).

Table A5.2 Unit root test

Variable	IPS test-statistic	p-value	Variable	IPS test-statistic	p-value
Regional economic variables			**Third-Party Funds**		
lgdp	-4.12	0.000	Received by Higher Education Institutes		
lemp	-0.34	0.365	ltpf_hei	16.41	1.000
lemp_detrended	-16.08	0.000	ltpf_hei_detrended	-9.09	0.000
lemp_ns	2.03	0.979	ltpf_hei_pub	16.43	1.000
lemp_ns_detrended	-15.89	0.000	ltpf_hei_pub_detrended	-7.73	0.000
lhk	0.13	0.552	ltpf_hei_ind	-0.78	0.216
lhk_detrended	-17.62	0.000	ltpf_hei_ind_detrended	-16.96	0.000
linvq	-17.58	0.000	w_ltpf_hei	-3.41	0.000
lpat	-17.76	0.000	w_ltpf_hei_pub	-5.28	0.000
w_lgdp	-3.38	0.000	w_ltpf_hei_ind	-8.46	0.000
w_lemp	-1.41	0.079	Received by Universities		
w_lemp_detrended	-17.76	0.000	ltpf_uni	13.82	1.000
w_lemp_ns	4.64	1.000	ltpf_uni_detrended	-18.51	0.000
w_lemp_ns_detrended	-17.44	0.000	ltpf_uni_pub	12.81	1.000
w_lhk	0.01	0.504	ltpf_uni_pub_detrended	-30.71	0.000
w_lhk_detrended	-18.11	0.000	ltpf_uni_ind	18.08	1.000
w_linvq	-15.19	0.000	ltpf_uni_ind_detrended	-23.88	0.000
w_lpat	-13.68	0.000	w_ltpf_uni	1.61	0.947
Publications			w_ltpf_uni_detrended	-20.83	0.000
lpubli_hei	4.02	1.000	w_ltpf_uni_pub	-0.52	0.300
lpubli_hei_detrended	-23.78	0.000	w_ltpf_uni_pub_detrended	-21.46	0.000
lpubli_uni	-2.43	0.008	w_ltpf_uni_ind	4.48	1.000
lpubli_fh	5.02	1.000	w_ltpf_uni_ind_detrended	-15.32	0.000
lpubli_fh_detrended	-24.19	0.000	Received by Technical colleges		
lpubli_ri	21.26	1.000	ltpf_fh	18.05	1.000
lpubli_ri_detrended	-16.79	0.000	ltpf_fh_detrended	-17.48	0.000
lpubli_fraun	30.72	1.000	ltpf_fh_pub	13.74	1.000
lpubli_fraun_detrended	-21.70	0.000	ltpf_fh_pub_detrended	-10.17	0.000
lpubli_mp	-11.21	0.000	ltpf_fh_ind	7.66	1.000
w_lpubli_hei	-8.74	0.000	ltpf_fh_ind_detrended	-18.21	0.000
w_lpubli_uni	-11.02	0.000	w_ltpf_fh	-7.59	0.000
w_lpubli_fh	-20.33	0.000	w_ltpf_fh_pub	-10.17	0.000
w_lpubli_ri	-0.54	0.295	w_ltpf_fh_ind	-11.92	0.000
w_lpubli_ri_detrended	-25.51	0.000			
w_lpubli_fraun	-1.51	0.066			
w_lpubli_fraun_detrended	-26.89	0.000			
w_lpubli_mp	-14.50	0.000			

Notes: Number of Regions = 258 and t = 12. 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.

6. Effects of R&D subsidies on regional economic dynamics – Evidence from Chinese provinces

Notes: The paper was submitted to *Research Policy* (8 May 2019). The paper is co-authored by Philipp Boeing. A related version of this paper was published as *Working Papers on Innovation and Space* (Vol. 03.19).

Abstract: We investigate the impact of research and development (R&D) subsidies on R&D inputs of large- and medium-sized firms and on additional innovation and economic activities in Chinese provinces. A panel vector autoregressive (VAR) model and corresponding impulse response function (IRF) analysis allow us to differentiate between direct and indirect effects, which add up to total effects. We find that an increase of R&D subsidies significantly decreases private R&D investments, although there is a significant positive effect on the R&D personnel employed in firms. We interpret these findings as a partial crowding-out effect because public funds substitute some private funds while total R&D inputs still increase. Complementarily, we find a positive secondary effect on the provincial patent activity, our measure of technological progress. Interestingly, we also find potentially unintended effects of R&D subsidies on increases in the investment rate in physical capital and residential buildings. Although R&D subsidies fail to incentivise private R&D expenditures, firms increase total R&D inputs, and provincial economies benefit from secondary effects on technological progress and capital deepening.

Keywords: China, R&D subsidies, regional economic activity, regional economic development, panel VAR, impulse response function analysis

JEL Classification: C33, R11, R58, O38, O47

6.1 Introduction

In recent years, China has been shifting from a capital-led towards a more innovation-led growth model. Although China reached outstanding output growth of more than 8% annually between 1978 and 2007 (Zhu, 2012), more recently the pace of output and productivity growth has been slowing down in the overall economy and manufacturing industries (Bai and Zhang, 2017). This slowdown may be attributed to diminishing returns to higher levels of physical and human capital and a deterioration in the efficiency of resource allocation (Wei et al. 2017). As China moves closer to the global technology frontier, the creation of domestic innovation is seen not only as an important complement to the absorption of technologies developed elsewhere, but also as a main driver of productivity and economic growth. The government comprehensively supports China's transformation towards more innovation-led growth with numerous targets and policies (Cao et al., 2013).

A first-order policy target is to increase research and development (R&D) inputs in firms. To this end, the government quadrupled annual R&D subsidies allocated to large and medium-sized enterprises (LMEs) between 2000 and 2010, the time period underlying this study. Simultaneously, the relative contribution of private R&D investments[101] and employment of R&D personnel in the business sector increased from around 35% to 54% for investments and 36% to 54% for personnel (own calculations). These figures emphasise the importance of the corporate sector within China's innovation system. Against the background of aggregate dynamics at the national level, a striking feature of China's economic development is persistent provincial disparities (Tsui, 2014), which are also observable for innovation inputs and output. To appropriately consider heterogeneity

[101] Following the standard approach in the literature, private R&D investment is calculated by subtracting R&D subsidies from total firm R&D expenditures (Dimos and Pugh, 2016). Private R&D corresponds to "net," "self-financed," or "own" R&D expenditures and does not discriminate between R&D expenditures by state-owned and non-state-owned firms.

among provincial production and innovation systems, our evaluation of China's R&D subsidies is conducted at the provincial level.[102]

Although it is well known that market failure in the private production of knowledge may require an adjustment of private R&D by public subsidies (David et al., 2000), the evaluation literature shows that R&D subsidies could function as both complements and substitutes (Dimos and Pugh, 2016; Zúñiga-Vicente et al., 2014). Most impact evaluations of public R&D subsidies on private R&D expenditures are conducted for developed economies. Until now, only a few studies provide an evaluation for China and the results are somewhat inconclusive (see Boeing 2016; Boeing and Peters 2019; Hu and Deng 2019; Liu et al., 2016). Chen (2018) is the only study at the provincial level and finds a partial crowding-out effect.

The contribution of our study is at least twofold: First, we estimate not only *direct* but also *indirect* effects of R&D subsidies on R&D inputs, which are unobservable in single equation approaches. Second, we estimate the *total* (*direct* plus *indirect*) effects of R&D subsidies on various economic variables in the provincial production system. In this way, we can detect secondary effects on the provincial capital deepening, technological progress, labour, and output, and thus draw conclusions on the role of R&D subsidies for the development of provincial innovation *and* economic activities. To this end, we are the first to use a panel vector autoregressive (VAR) model and corresponding impulse response function (IRF) analysis to analyse the effects of R&D subsidies on the economic performance of Chinese provinces. This econometric approach explicitly allows for the identification of *total* effects on a defined set of economic variables.

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[102] In the Chinese context the Annual Survey of Industrial Enterprises from the National Bureau of Statistics and the Administrative Enterprise Income Tax Records from the Chinese State Administration of Tax are sources of micro data for the quasi-population of LMEs. However, these data are not appropriate for the proposed evaluation because only total subsidies but not R&D subsidies are observed. In contrast, provincial-level data allows us to observe R&D subsidies.

For R&D inputs of LMEs, we find that an increase of R&D subsidies significantly decreases private R&D investments, while there is a significant positive effect on the R&D personnel employed. We interpret these findings as a partial crowding-out effect because firms substitute some private funds with public funds but total R&D inputs still increase. Complementary to this result, we find a positive effect on provincial patents, our measure of technological progress. Interestingly, we also find some evidence for potentially unintended effects because R&D subsidies also increase the investment rate in physical capital and residential buildings. Although investments in physical capital may be complementary to R&D in general, investments in residential buildings more likely suggest some misallocation of R&D subsidies.

The remainder of the paper is set out as follows. In Section 6.2, we review the institutional setting and prior studies on R&D subsidies in China. Section 6.3 provides the theoretical framework. In Section 6.4, we specify our empirical strategy, data and descriptive statistics. In Section 6.5, we present the main results and robustness tests, and discuss our findings and policy implications. We conclude in Section 6.6.

6.2 Institutional setting and prior literature

According to Romer (1990), business R&D plays an essential role in fostering innovation and economic growth. However, market failure in private knowledge production may lead to suboptimal innovation rates and the deceleration of economic growth. Due to externalities in knowledge production that are difficult to internalise, private and social returns to innovation activities differ (Arrow, 1962). In conjunction with moral hazard and risky financing of R&D, this difference in private and social returns may lead to systematic underinvestment in R&D. This market failure may require policy intervention and an upward correction of business R&D activities by the provision of public subsidies (David et al., 2000).

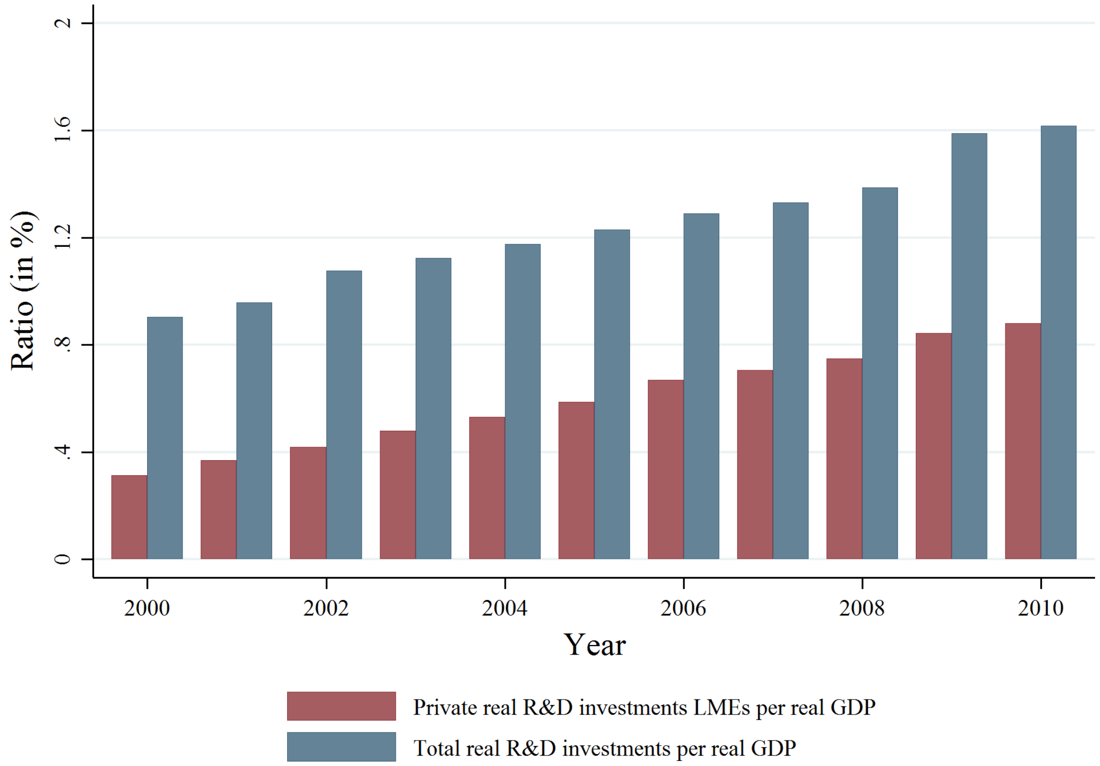
Although governments offer public funding to spur R&D in firms – to incentivise more private R&D investments – R&D subsidies might also crowd out private financing of R&D. A firm invests in R&D if and as long as the marginal rate of return to R&D is larger or equal to the marginal cost of capital. The marginal cost of capital reflects the opportunity costs of investing funds in R&D versus non-R&D projects and thus depends on, among others, the expected returns to other uses of available funds, such as investment in physical assets, available internal finance, and costs of external capital. Based on a theoretical concept developed by Hall (2008), Hottenrott and Peters (2012) show that optimal R&D investment increases only if grantees were initially financially constrained, implying insufficient internal financial means. The empirical evaluation literature indeed shows that R&D subsidies may function as both complements or substitutes, depending and the specific setting, and might have crowding-out, neutral, or additionality effects on the private R&D investment of firms (see Dimos and Pugh, 2016; Zúñiga-Vicente et al., 2014).

6.2.1 The institutional setting

The Chinese State Council aims to develop China into an innovative country by 2020 and a world leader in science and technology by 2050. Against this target, China's ratio of gross expenditures for R&D to GDP has already overtaken the ratio of the European Union; and in gross R&D expenditures, China is projected to overtake the United States around 2020 (OECD, 2014). In order to stimulate additional business R&D expenditures, the Chinese government invests heavily in innovation policy, e.g. through direct grants and tax incentives. Major national R&D programmes include the National High-Tech R&D Programme (the 863 Programme), the National Key Technologies Programme, and the State Basic R&D Programme (the 973 Programme). In addition, firms receive R&D subsidies from programmes administered by sub-national agencies.

During the time period we study, the ratio of total real R&D investments and private real R&D investments by LMEs to real GDP has continuously increased and doubled between 2000 and 2010 (Figure 6.1). Given China's strong growth in GDP over this time period, the increase in R&D intensity is even more striking.

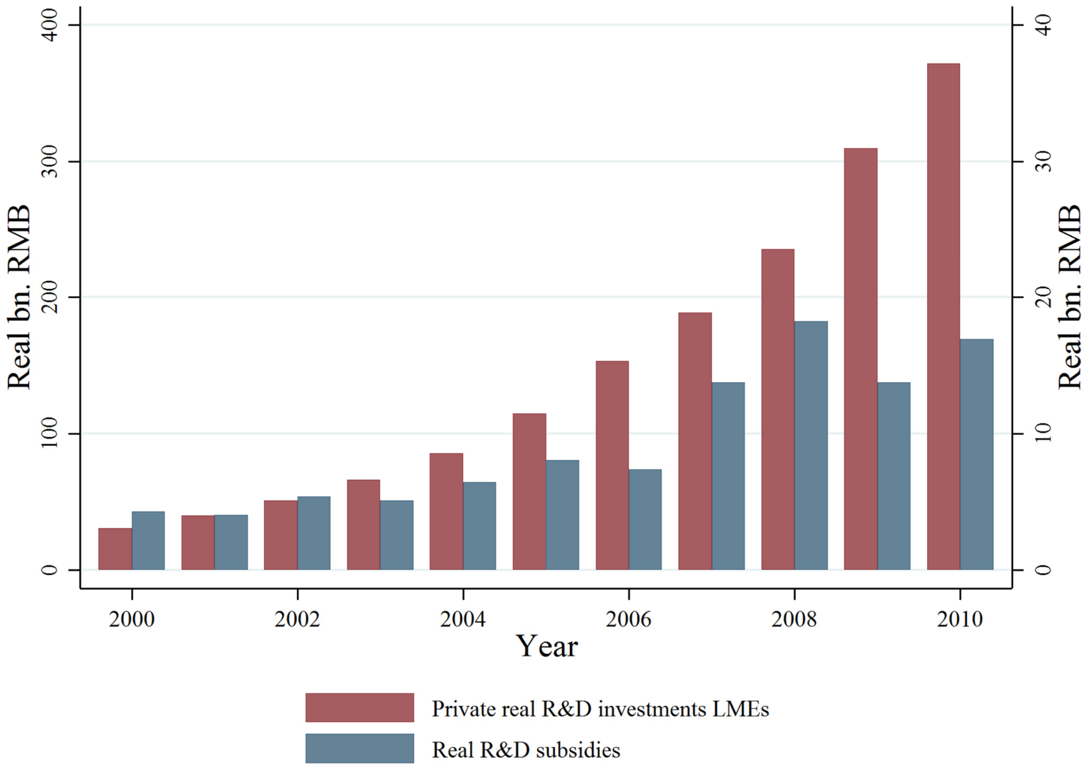
Figure 6.1 Dynamics of private real R&D investments LMEs and total real R&D investments per real GDP in China



Notes: Own calculations based on aggregated provincial data. Data on total provincial R&D investments are based on China's statistical yearbook on science and technology activities of industrial enterprises (various years). For the remaining variables see Table 6.1.

The major innovation policies in this period are formulated in the 10th and 11th Five-Year Science and Technology Development Plans (2001-2005 and 2006-2011) and, more importantly, the Mid- to Long-term Science and Technology Development Plan 2006-2020 (MLP). The MLP aims to foster R&D expenditures of domestic firms, as well as to better coordinate the existing R&D policies to increase the effectiveness of government support (Liu et al., 2011). After 2006, a more mission-oriented policy approach was implemented and amendments of major national R&D programmes took place, paralleled by substantial increases in government funding. Between 2000 and 2010 annual R&D subsidies to LMEs quadrupled from 4.31 to 16.95 real billion RMB, while the private R&D expenditures of LMEs increased twelvefold from 30.84 to 371.86 real billion RMB (Figure 6.2).[103]

Figure 6.2 Dynamics of private real R&D investments LMEs and real R&D subsidies in China

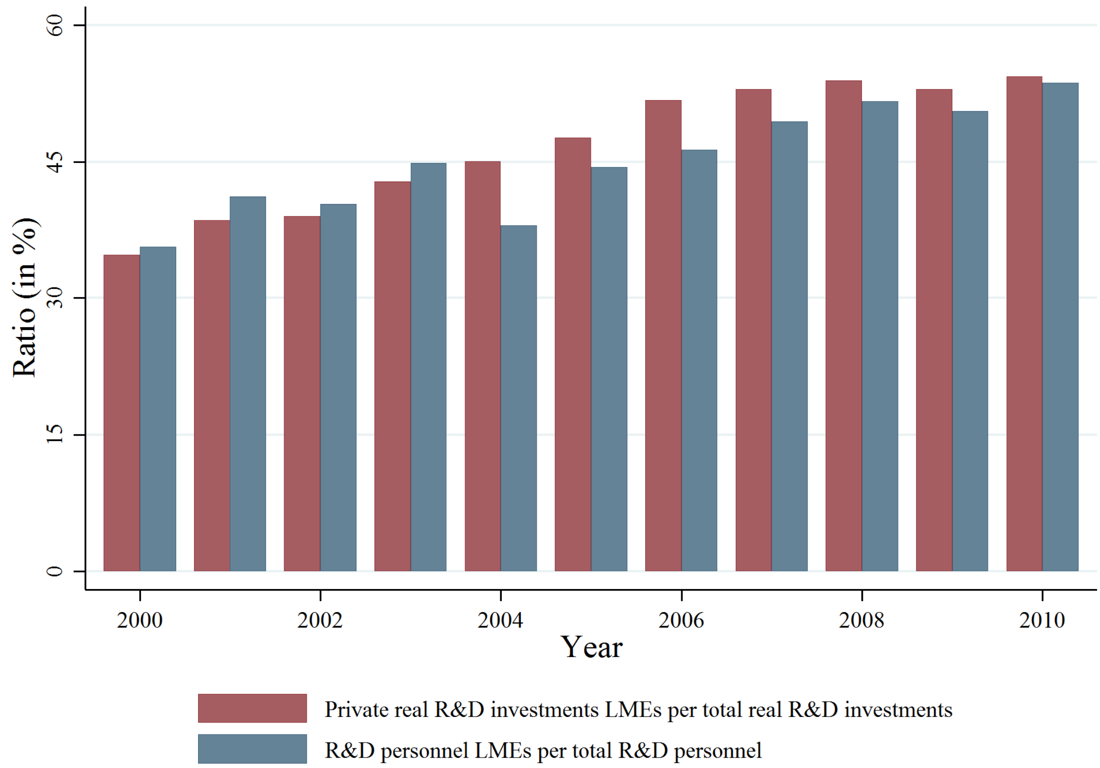


Notes: Own calculations based on aggregated provincial data (see Table 6.1). Absolute values are presented.

These efforts lead to a continuous increase in the ratio of private firm to total R&D investments as well as the ratio of firm to total R&D personnel in China, emphasising the increasing relevance of firms for the China's innovation system (Figure 6.3). However, the key question to ask is whether R&D subsidies have contributed to the rise in private R&D expenditures.

[103] Using the 2005 RMB-EUR year-end exchange rate, this corresponds to an increase from 3.225 billion EUR to 38.888 billion EUR.

Figure 6.3 Dynamics of innovation activities by LMEs in China



Notes: Own calculations based on aggregated provincial data. Data on total provincial R&D investments and total provincial R&D personnel are based on China's statistics yearbook on science and technology activities of industrial enterprises (various years). For the remaining variables see Table 6.1. Ratio per total real R&D investments and ratio per total R&D personnel is presented.

6.2.2 Prior Chinese studies

Most evaluations of the effect of public R&D subsidies on private R&D expenditures are conducted for developed economies. Only a few studies provide an analysis for developing economies. In this section, we focus on the Chinese economy and first discuss prior *firm-level* studies and hereafter *provincial-level* studies. For the early period 2001 to 2006, Boeing (2016) estimates the average treatment effect on the treated (ATT) and finds a partial crowding-out effect. Liu et al. (2016) observe high-tech manufacturing firms in Jiangsu province based on cross-sectional survey data for the year 2012. They estimate the ATT and find that grantees increase private R&D expenditures by 14.3 %. Hu and Deng (2019) use survey data for private-owned manufacturing firms, observed between 2007 and 2011, and find that treated firms almost double private R&D expenditures compared to the pre-treatment year. Most recently, Boeing and Peters (2019) observe misappropriation of R&D subsidies by firms and separately estimate the intention-to-treat (ITT) and complier-average-causal-effect (CACE). Between 2001 and 2011, they show partial crowding-out for the actual effectiveness of R&D policy, whereas the efficacy among compliers (i.e., non-misappropriating firms) confirms additionality. In summary, these studies suggest heterogeneous effects. Boeing (2016) and Boeing and Peters (2019) fail to reject partial crowding-out for the population of firms, but R&D subsidies have a higher effectiveness for high-tech and private firms, which is similar to the results by Liu et al. (2016) and Hu and Deng (2019). Confirming theoretical predictions, these findings emphasise that higher returns to R&D and financial constraints, as expected for high-tech firms and private firms in China, result in higher effectiveness of R&D subsidies compared to the population effect.

To the best of our knowledge, the only *provincial-level* study that evaluates the effect of R&D subsidies on business R&D expenditures is Chen (2018). For the population of firms, he finds insignificant effects on total R&D expenditures, while the effects on private R&D expenditures are significant negative, which one may interpret as evidence for crowding-out. Other related studies mainly investigate the effect of R&D subsidies, tax allowances, and public R&D investment on provincial patent activity. Sun (2000) shows that patent applications are spatially concentrated on provincial level and public R&D (investments and employment) does not significantly increase provincial patent activities. Li (2009) finds significant positive effects of provincial governments' science and technology expenditures on invention patents, but insignificant effects on utility model patents (in contrast to utility patents, invention patents are more closely related to technological inventions). Fan et al. (2012) show that public R&D investments contribute to provincial inequalities in innovation outputs as measured by patents. The findings by Cheng and Zhang (2018) suggest that public R&D subsidies and tax incentives increase the funds that firms devote to R&D collaborations with universities and research institutes. Moreover, both public R&D support measures increase the joint patent output of firms, universities, and research institutes. In a nutshell, these studies confirm, for the most part, positive effect of public support measures on patent output at the provincial level.

Although prior studies at the *provincial level* investigate the *direct* effects of R&D subsidies on firms' R&D input and provincial patent output, we aim to contribute to the literature by analysing the *total* (*direct* plus *indirect*) effects of R&D subsidies on a larger set of theory-based economic variables. For this exercise, we follow recent applications of a VAR approach at the regional level (e.g. Eberle et al., 2019; Mitze et al., 2018; Ramajo et al., 2017). In the Section 6.3, we present a theoretical framework that motivates our subsequent empirical analysis.

6.3 Theoretical framework

Based on Solow (1956), the theoretical growth literature has emphasised the importance of human and physical capital accumulation for economic growth (e.g. Mankiw et al., 1992). Although capital deepening is essential for growth in developing economies, with accelerating economic development the contribution of capital accumulation decreases while the importance of technological progress increases (e.g. Aghion and Howitt, 2009). This is because innovation offsets the diminishing returns to capital by a continual rise in technology. Thus, innovation drives both technological progress and capital deepening, the two main components of economic growth. Once an economy is fully industrialised and has reached the steady state, per capita income and growth is solely driven by innovation and technological progress.[104] However, in the case of China, provincial economies are strongly heterogeneous and display a high level of variation regarding the general economic development (Tsui, 2014) and innovation activities (Li, 2009). Therefore, we apply a provincial-level analysis to evaluate the outcomes of public R&D subsidies in China.

We assume the following production function for each province *i*

$$Y_i = K_i^{\alpha} H_i^{\beta} (A_i \lambda_i P_i)^{1-\alpha-\beta}, \tag{6.1}$$

where Y_i is provincial output, K_i provincial physical and H_i human capital, A_i denotes the level of the provincial technology, λ_i is the provincial employment rate, and P_i denotes provincial resident population. Decreasing returns to scale are imposed by $\alpha > 0$, $\beta > 0$ and $\alpha + \beta < 1$. Following Eberle et al. (2019), we specify provincial labour as $L_i = \lambda_i P_i$, with λ_i as the in long-term fixed provincial employment rate ($\frac{L_i}{P_i}$), while provincial population P_i grows at the exogenous rate n_i. By dividing Equation (6.1) by P_i, the provincial per capita production function can be expressed as

$$y_i = k_i^{\alpha} h_i^{\beta} (A_i \lambda_i)^{1-\alpha-\beta}. \tag{6.2}$$

Equation (6.2) defines the provincial GDP per capita as the output factor, and physical and human capital per capita, and the level of technology and the employment rate as core production factors in the provincial economic system. Note that, due to data limitations, we use the physical capital (fixed assets) investment rate (subsequently labelled as $s_{k,i}$) instead of the physical capital stock (k_i) and the technological growth rate (subsequently labelled as g_i) instead of the provincial technological level (A_i).

[104] Whereas Mankiw et al. (1992) assume that technological process is exogenously given and equally distributed across economies, Romer's (1990) growth model explicitly endogenises the accumulation processes of technology in a R&D sector.

R&D is a human capital intensive activity (Aghion and Howitt, 2009; Romer, 1990) and a substantial share of current business R&D cost are labour cost for internal R&D personnel, hence investments in human capital.[105] We formulate the dynamics of per capita human capital (e.g. Mankiw et al., 1992) as

$$\frac{\dot{h}_i}{h_i} = s_{h,i}(k_i^{\alpha}\, h_i^{\beta-1}\, (A_i\lambda_i)^{1-\alpha-\beta}) - (n_i+\delta). \tag{6.3}$$

In Equation (6.3), $s_{h,i}$ is the investment rate in human capital that depreciates with a constant rate δ (Mankiw et al., 1992). With respect to Equation (6.3), *R&D investments* are accounted for by $s_{h,i}$ and the *R&D personnel* is captured by h_i.

To identify the effects of R&D subsidies (labelled by $s_{h\_public,i}$), we augment our model with private R&D investments by LMEs (labelled by $s_{h\_private,i}$). The parameter will be informative whether or not the crowding-out hypothesis can be rejected. Alternatively, we will also augment the model with firms' R&D personnel (h_i).[106] If crowding-out cannot be rejected for private R&D investments, the parameter for firms' R&D personnel will allow us to differentiate the extent of crowding-out: a neutral effect implies full and a positive effect partial crowding-out of private R&D expenditures. Using firms' R&D personnel instead of total R&D investment has the additional advantage that this measure implicitly controls for potential wage-adjustments of R&D personnel as a result of a policy-induced demand shock for scientists.

[105] In developed economies, this share is usually higher than in developing economies. It was 64.5% for Germany (in 2011) and 52.3% for the United Kingdom, 44.8% for Japan, 44.1% for Korea, and 30.4% for China (all in 2009) (OECD Statistics, 2019). Please note that this is only a theoretical assumption; our flexible empirical approach accounts for alternative transmission channels of R&D investments (Section 6.4.1).

[106] The simultaneous inclusion of both variables ($s_{h,i}$ and h_i) would require our model to consider the same information twice and should be avoided. The correlation coefficients between the variables *R&D personnel LMEs per capita* and *private real R&D investments LMEs per real GDP* support this concern: $\rho_1 = 0.8834$ (all provinces), $\rho_2 = 0.88$ (Tibet excluded), $\rho_3 = 0.8707$ (Tibet and provincial-status municipalities excluded). Correlation coefficients for logarithmised variables are even higher.

An increase in the provincial human capital may also affect other economic variables in the provincial system in Equation (6.2) via economic secondary effects. First, the physical capital investment rate is assumed to be constant and thus unaffected by increases in R&D subsidies (e.g. Mankiw et al., 1992). Second, policy makers allocate R&D subsidies to incentivise corporate R&D investments to promote provincial technological growth.[107] We assume that technological growth (g_i) is determined by input factors that are effective in the provincial corporate research sector (e.g. Rivera-Batiz and Romer, 1991; Romer, 1990).[108] In contrast to Romer (1990) and Rivera-Batiz and Romer (1991), we allow public R&D subsidies (temporarily) to incentivise a varying input of human capital in the research sector (according to the accumulation process of human capital in Equation (6.3)), which is assumed to be given in the original model setups. Third, the provincial employment rate is assumed to be fixed in the long run, temporary effects may depend on substitution and output effects.[109] R&D subsidies to firms may lower the costs for R&D personnel (human capital) and basic labour may become more expensive comparative to R&D personnel, which may lead to a substitution effect. Conversely, if R&D subsidies raise provincial output, they may subsequently also trigger a higher demand for labour (output effect). Lastly, shifts in the provincial

[107] R&D subsidies may predominantly foster human capital (investments) in the research sector (e.g. Romer, 1990) and thus one may argue that technological growth g_i is a main target variable of R&D subsidies. For the reasons mentioned above, human capital is considered a main target variable (transmission channel) of R&D subsidies; but, in line with the applied flexible empirical model, we do not discriminate between human capital that is either productive in a production or research sector (the dynamics of human capital in Equation (6.3) are modelled by Mankiw et al. (1992) for the production sector). A potential effect on the provincial patent rate (proxy for technological growth) is interpreted as secondary effect here.

[108] This assumption is consistent with our flexible empirical panel VAR approach that relates all variables in the economic system among each other. As emphasised by Romer (1990), the role of human capital in the research sector may be of particular importance for the accumulation of technology. Please note the distinction at this point between human capital in a one sector model with diminishing returns (e.g. Mankiw et al., 1992) and in a multiple sector model with a distinct role in the research sector (e.g. Romer, 1990), which has different implications of human capital for *long-term* economic growth.

[109] See Schalk and Untiedt (2000) for a brief discussion of substitution and output effects on regional employment in the context of physical capital subsidies in Germany.

per capita output can be written as a function of changes of provincial input factors presented in Equation (6.2)

$$\frac{\dot{y}_i}{y_i} = \alpha \frac{\dot{k}_i}{k_i} + \beta \frac{\dot{h}_i}{h_i} + (1\text{-}\alpha\text{-}\beta)\ \frac{\dot{A}_i}{A_i} + (1\text{-}\alpha\text{-}\beta)\ \frac{\dot{\lambda}_i}{\lambda_i}. \tag{6.4}$$

According to our theoretical framework, we expect provincial R&D subsidies to lead to a (temporarily) higher human capital investment rate $s_{h,i}$ and level of human capital h_i, given that firms are financially constrained. Moreover, positive secondary effects may arise especially on the provincial technological growth rate g_i, on the provincial per capita output y_i and employment rate λ_i. Due to substitution effects in the very short run, the latter effect is expected to arise after a phasing-in of several years.

6.4 Empirical strategy, data and descriptive statistics

6.4.1 Empirical strategy

The VAR system that we model is composed of six equations with six dependent variables: (1) R&D subsidy intensity **lsub**, (2) human capital **lprdef** and **lhk** (proxied by private R&D investments or R&D personnel of LMEs), (3) technological growth rate **lpat** (provincial patents), (4) physical capital investment rate **linvq** (provincial investments in fixed assets), (5) employment rate **lemp** (provincial employed persons), and (6) real GDP per capita **lgdp** (provincial output). In order to investigate the *total* effects of Chinese R&D subsidies to the provincial corporate research sector, we consider not only *direct* effects (denoted by the estimate in a partial analysis approach) but also mutual *indirect* effects between the defined provincial variables. To this end, we propose a panel VAR and associated IRF analysis that allows us to determine the total effects of an increase in Chinese R&D subsidies on all provincial variables.

The reduced-form VAR system, both flexible and atheoretical, can be specified compactly in matrix notation (e.g. Love and Zicchino, 2006; Rickman, 2010) as

$$\mathbf{y_t} = \mathbf{A}\mathbf{y_{t-1}} + \mathbf{f_i} + \mathbf{t_t} + \mathbf{e_t}. \tag{6.5}$$

In Equation (6.5), $\mathbf{y_t}$ denotes a vector of the six provincial endogenous variables [lsub, lprdef/lhk, lpat, linvq, lemp, lgdp], the matrix **A** is containing reduced-form coefficients, $\mathbf{f_i}$ is a vector of provincial fixed effects to capture time constant heterogeneity, and $\mathbf{t_t}$ is a vector of time dummies to capture general external shocks, respectively, while the vector $\mathbf{e_t}$ comprises (reduced-form) residuals (e.g. Love and Zicchino, 2006; Rickman, 2010). From a methodological perspective, the inclusion of provincial fixed effects has the considerable advantage that all time-invariant confounders are controlled for.[110] To account for the influence of additional time-variant confounders, in Section 6.5.2 we test the robustness of our model after augmenting several time-variant controls.

As a response to criticism of the atheoretical reduced-form VAR approach, the structural VAR approach has been developed (e.g. Rickman, 2010), which can be formulated as

$$\mathbf{B}\mathbf{y_t} = \mathbf{C}\mathbf{y_{t-1}} + \mathbf{f_i} + \mathbf{t_t} + \mathbf{D}\boldsymbol{\varepsilon}_\mathbf{t}. \tag{6.6}$$

In Equation (6.6), the matrix **B** includes contemporaneous (structural) parameters, the matrix of polynomials **C** is connecting contemporaneous to time-lagged variables, and, eventually, diagonal matrix **D** links uncorrelated (exogenous) shocks $\boldsymbol{\varepsilon}_\mathbf{t}$ to the provincial endogenous variables (e.g. Keating, 1992; Rickman, 2010).[111] As Rickman (2010) points out, theory-based restrictions (see Section 6.3) in the structural VAR model are set on the matrix **B**. To this end, in order to identify our structural panel VAR approach, we follow Di Giacinto (2010), who advances an approach by

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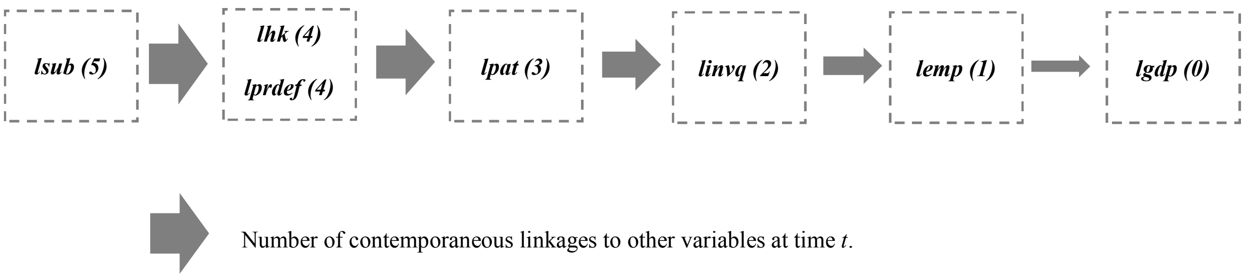
[110] We are estimating six dynamic panel equations (in the reduced-form specification) incorporating provincial fixed effects, which is why the basic fixed-effects estimator suffers from a dynamic panel bias (Nickell, 1981). To account for this issue and to yield unbiased estimates, we use a bias-corrected fixed-effects estimator that is proposed by Everaert and Pozzi (2007).

[111] Please note that $\mathbf{A} = \mathbf{C}^*\mathbf{B}^{-1}$ and $\mathbf{e_t} = \boldsymbol{\varepsilon}_\mathbf{t}^*\mathbf{B}^{-1}$ (Rickman, 2010).

Wold (1954) to presume a recursive causal ordering of the included provincial endogenous variables at period *t* (Choleski decomposition). Based on the developed theoretical framework in Section 6.3, we define the causal ordering at time *t* (see Figure 6.4).

Figure 6.4 Defined causal ordering across the provincial variables at time *t* (contemporaneous linkages)



Notes: Own illustration.

Variables to the left (e.g. R&D subsidy intensity) have contemporaneous and delayed effects on the remaining provincial variables more to the right. Conversely, variables on the right have only time lagged (feedback) effects (e.g. GDP per capita). With respect to Equation (6.2), GDP per capita is the key outcome variable in the provincial system and thus the most endogenous variable with solely time lagged effects on the remaining provincial variables, while the investment rate and the employment rate are ordered on the basis of their flexibility in the short run and thus appear more to the left in Figure 6.4 (e.g. Eberle et al., 2019). We define the R&D subsidy intensity as the most exogenous variable in the provincial economic system. R&D subsidies are assumed to directly (contemporaneously) affect R&D investments and personnel of LMEs, which are seen as important input factor in knowledge production (Romer, 1990) and thus directly affect provincial technological growth g_i (patents), while labour and capital goods are assumed to trigger (delayed) secondary effects on g_i.

An important concern is reverse causality. If human capital determines R&D subsidies and not vice versa, a picking-the-winner strategy would imply a non-random allocation of public funds to firms with more human capital and R&D investments and an upward bias of the estimated effect. Because this corresponds to a different causal ordering, in Section 6.5.2 we perform a robustness test to control for different effects of R&D subsidies on other variables in the economic system (this corresponds to a change of R&D subsidies and R&D investments and personnel of LMEs in Figure 6.4).

By applying the moving-average (MA) presentation of the VAR, we illustrate the responses (total effects) of the provincial variables to an orthogonal increase in the R&D subsidy intensity (Lütkepohl, 2005), while the calculated confidence intervals are based on Monte Carlo simulations (Love and Zicchino, 2006).

6.4.2 Data

The data is mainly obtained from China's National Bureau of Statistics (NBS) and contains information at the province-year level observed between 2000 and 2010.[112] Table 6.1 present's details for the variable definitions and data sources, and in Appendix A6.1 we discuss some features of China's officially reported data. In the remainder of this paper, we use the variable abbreviations presented in Table 6.1. Table A6.1 in the Appendix provides summary statistics of the six economic core variables. We construct real values for monetary output and investment measures by using the provincial consumer price index (CPI). Technological growth is measured by granted invention patents obtained from China's patent office (CNIPA).[113]

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[112] In 2011, the NBS survey was amended and the availability of consistent information on R&D investments and R&D personnel of LMEs restricts our analysis until 2010. LMEs are defined as firms with at least 300 employees, 30 million RMB sales revenue, and 40 million RMB assets (National Bureau of Statistics of China, 2003)

[113] In this context, we regard granted patents as a superior measure compared to patent applications, as granted patents have passed two selections. First, the expected economic value exceeds the cost of patenting (application), and second, the invention has passed examination at the patent office (grant). This two-step selection also helps to mitigate the distortion of application-based patent subsidies on patents as an indicator of technological growth in China.

Table 6.1 Variable descriptions and data sources

Variable abbreviation	Description	Data sources
	Core variables VAR model	
lgdp (y)	Real GDP per capita (per resident population). CPIs are used to calculate real values.	National Bureau of Statistics of China
lemp (λ)	Employment rate (Number of employed persons at year-end by region per capita (per resident population)). Missing data for 2003 and 2006 are calculated on the basis of the formula: (Employed Persons_{t-1} + Employed Personsi_{t+1})/2	National Bureau of Statistics of China, China statistical yearbook (various years)
linvq (s_k)	Real investments in fixed assets per real GDP.	National Bureau of Statistics of China
lhk (h)	R&D personnel LMEs per capita (per resident population).	Statistics yearbook on science and technology activities of industrial enterprises (various years)
lprdef ($s_{h\_private}$)	Private real R&D investments LMEs per real GDP (R&D subsidies subtracted from R&D investments LMEs).	Statistics yearbook on science and technology activities of industrial enterprises (various years)
lpat (g)	Patents per 100 Mio. real GDP (Granted Patents, Invention).	CNIPA (various years)
lsub (s_{h_public})	Real R&D subsidies to LMEs per real GDP.	Statistics yearbook on science and technology activities of industrial enterprises (various years)
	Control variables VAR model	
lcontrol1	Real non-firm R&D investments per real GDP.	Statistics yearbook on science and technology activities of industrial enterprises (various years)
lcontrol2	Ratio private firms to state-owned firm.	National Bureau of Statistics of China
lcontrol3	Ratio loss making state-owned firms to total state owned firms.	National Bureau of Statistics of China
lcontrol4	Ratio innovative LMEs to total LMEs.	Statistics yearbook on science and technology activities of industrial enterprises (various years)
lcontrol5 and lcontrol6	Ratio valued-added sector 1 and sector 2, respectively, to total value-added.	National Bureau of Statistics of China
lcontrol7	Ratio coal deposit to total coal deposit China. Figures of 2003 used for missing earlier years.	National Bureau of Statistics of China
control8 (not in ln)	Exports minus imports as share of the sum of ex- and imports: (Exports_i – Imports_i) / (Exports_i + Imports_i).	National Bureau of Statistics of China
linvq_rb	Real investments in residential buildings in the whole Country per real GDP.	National Bureau of Statistics of China

Notes: All variables are in logarithm (ln).

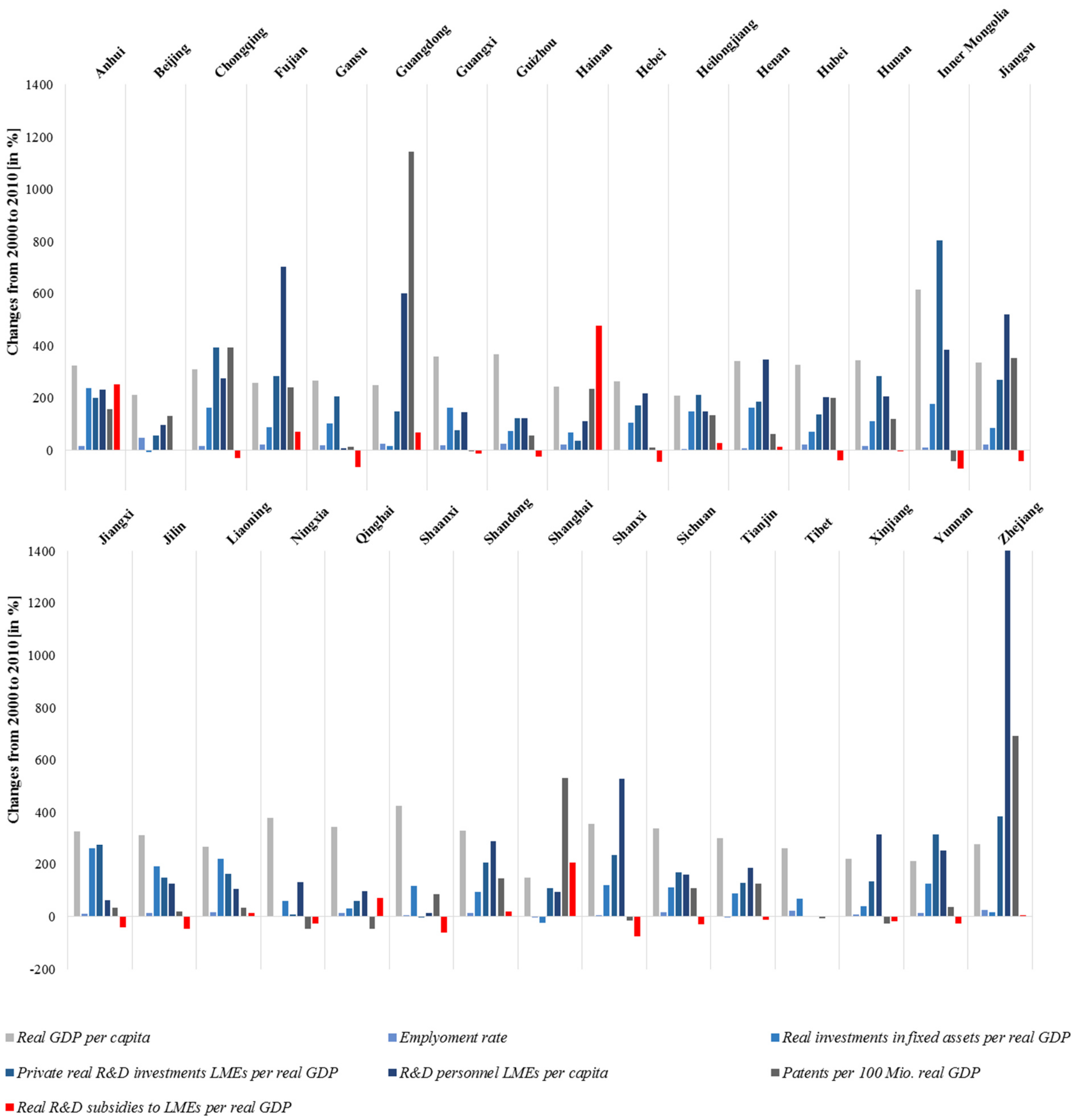
As a robustness test, we augment several time-variant provincial characteristics that may influence the coefficients of the core VAR variables. First, we control for non-LMEs R&D investments, mainly from universities and research institutes, in order to account for further determinants of technological growth at the province level. R&D personnel and private R&D investments of LMEs are likely to be correlated with non-LMEs R&D investments, and this may lead to omitted variable bias. Second, we include the ratio of private to state-owned firms and the ratio of loss-making state-owned firms. We hereby we aim to control for heterogeneity in financial constraints. In comparison to state-owned firms, China's private firms are constrained in access to external finance, and among state-owned firms loss-making ones are more likely to encounter internal financial constraints. Third, we include the ratio of innovative LMEs to total LMEs as a measure for potential knowledge spillovers at the province level, because the expected value of firms' R&D, and hence the decision to perform R&D, is also dependent on the degree of spillovers. Fourth, the ratios of the valued-added of the primary and the secondary sectors to total valued-added are added as indicators for the provincial economic composition. Fifth, provincial coal resources are added because these may absorb short-term oriented investments to the detriment of long-term economic development, also known as *resource curse*, which would increase the opportunity cost of R&D. Finally, we use the trade specialization index proposed by Li (2009) that measures export activities and the absorption of foreign technological knowledge, which is embodied in foreign goods.

6.4.3 Descriptive statistics

For each core variable in each province, we report the long-term growth rate from 2000 to 2010 in Figure 6.5 and the summarised economic activities for the entire period 2000 to 2010 in Table A6.2. Beijing, Shanghai, and Tianjin, which are relatively developed provincial-status municipal-ities, have the highest GDP per capita, as well as the highest patents-to-GDP ratio (Table A6.2). However, municipalities may benefit from agglomeration effects, and a comparison restricted to the remaining provinces provides a more conservative analysis. Developing provinces with lower initial- and average GDP per capita show the highest growth in physical capital investments (e.g. Jiangxi, Anhui, or Liaoning; see Figure 6.5). More developed provinces, such as Zhejiang and

Guangdong, have high growth rates in private R&D investments, R&D personnel, and patenting. As a stylised fact, and confirming theoretical predictions, this suggests that less developed provinces have relatively higher marginal returns to physical capital, whereas more developed provinces pursue innovation to substitute capital- with technology-driven growth.

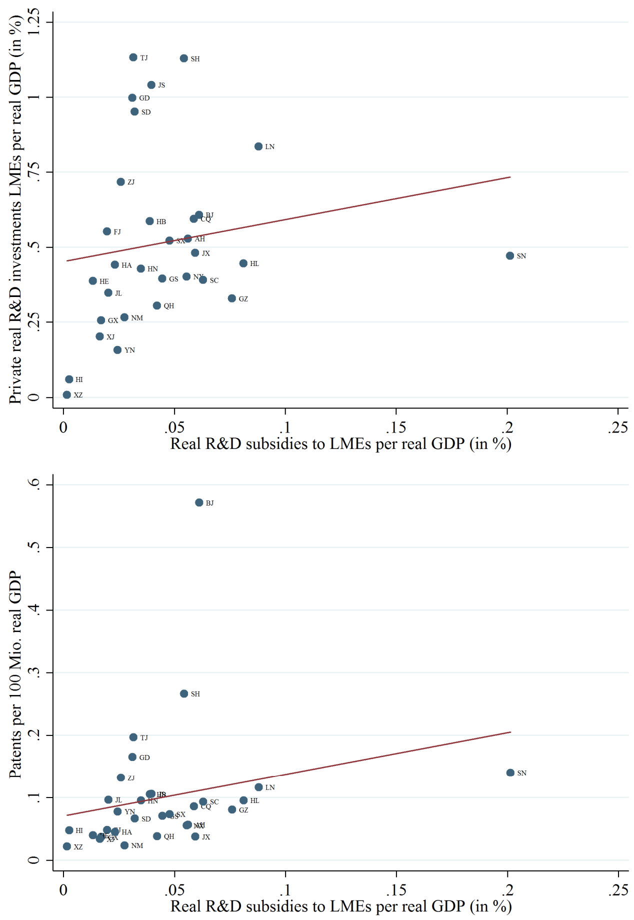
Figure 6.5 Provincial changes from 2000 to 2010 for various economic indicators (in %)



Notes: Own calculations based on provincial data (see Table 6.1).

R&D subsidies may be an important policy instrument to support the transition towards innovation and technology-led growth. Figure 6.6 shows that provinces that allocate higher levels of R&D subsidies also have higher levels of private R&D investments and receive more granted patents between 2000 and 2010 (scaled by real GDP). The pattern suggests that an increase in the intensity of R&D subsidies to GDP is accompanied by an increase in the private intensity of R&D and patents to GDP. While acknowledging that these figures do not allow for a causal interpretation, in the subsequent section we perform an analysis that addresses identification issues.

Figure 6.6 Scatterplot average private real R&D investments LMEs per real GDP (first panel) and average patents per 100 Mio. real GDP (second panel) in relation to average real R&D subsidies to LMEs per real GDP (values for the entire period 2000 to 2010)



Notes: Own calculations based on provincial data (see Table 6.1). The shortcuts for the provinces are: AH: Anhui, BJ: Beijing, CQ: Chongqing, FJ: Fujian, GS: Gansu, GD: Guangdong, GX: Guangxi, GZ: Guizhou, HI: Hainan, HE: Hebei, HL: Heilongjiang, HA: Henan, HB: Hubei, HN: Hunan, NM: Inner Mongolia, JS: Jiangsu, JX: Jiangxi, JL: Jilin, LN: Liaoning, NX: Ningxia, QH: Qinghai, SN: Shaanxi, SD: Shandong, SH: Shanghai, SX: Shanxi, SC: Sichuan, TJ: Tianjin, XZ: Tibet, XJ: Xinjiang, YN: Yunnan, ZJ: Zhejiang.

6.5 Empirical results

In this section we present the results of our panel VAR approach and the IRF analysis. To avoid having our results influenced by outliers, in the basic model we exclude Tibet and the municipalities Beijing, Chongqing, Shanghai, and Tianjin but include the municipalities in a robustness test. Due to substantial economic dynamics in Chinese provinces, we apply a panel unit root test (Im et al., 2003) as a pre-estimation check to control for stationarity of the variables. As shown in Table 6.2, for some variables the test indicates non-stationarity, and thus we detrend these variables.

Table 6.2 Panel unit root tests

	Years	**IPS test-statistic**	**p-value**
lgdp	11	2.91	0.998
lgdp_det	11	-2.31	0.011
lemp	11	0.88	0.810
lemp_det	11	-4.02	0.000
linvq	11	-1.25	0.105
linvq_det	11	-4.76	0.000
lhk	11	-2.10	0.018
lnrdef	11	-3.32	0.000
lpat	11	1.36	0.913
lpat_det	11	-7.04	0.000
lsub	11	-6.23	0.000

Notes: Panel unit root tests are based on Im et al. (2003) for the core variables over the time period 2000-2010. The outliers Beijing, Shanghai, Tianjin, Chongqing and Tibet are excluded. The null hypothesis (H0) states that panels comprise unit roots, the alternative hypothesis (HA) states that panels are stationary. We add to the detrended variables the suffix "_det". Control variables are also detrended if the unit root test reports non-stationarity.

As noted in Section 6.4.1, the econometric approach allows us to calculate the total (*direct* plus *indirect*) effects of an increase in public R&D subsidies on all economic variables in Equation (6.2). The total effects on private R&D investments and personnel of LMEs (captured by human capital in Equation (6.2)) are considered as primary effect because the human capital variable is seen as primary transmission channel of Chinese R&D subsidies. Moreover, R&D subsidies may have additional (unintended) effects on the remaining variables that are interpreted as economic secondary effects.

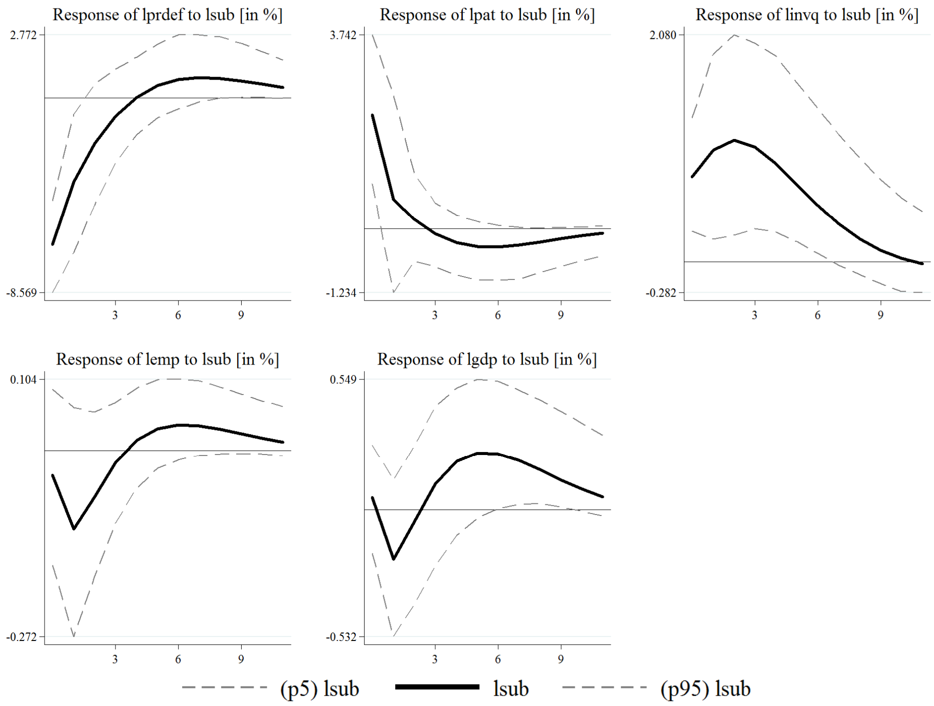
6.5.1 Basic model

In Figure 6.7, we investigate the total effect of R&D subsidies on the R&D personnel and private R&D investments of LMEs and total effects on our secondary variables. We report the reaction of our core variables to an orthogonal increase in the R&D subsidy intensity in the amount of one standard deviation (multiplied by 100 [in %], y-axis). The figures illustrate the estimated responses by the solid lines and the dashed lines show the calculated confidence intervals for the various IRFs (x-axis denotes years).

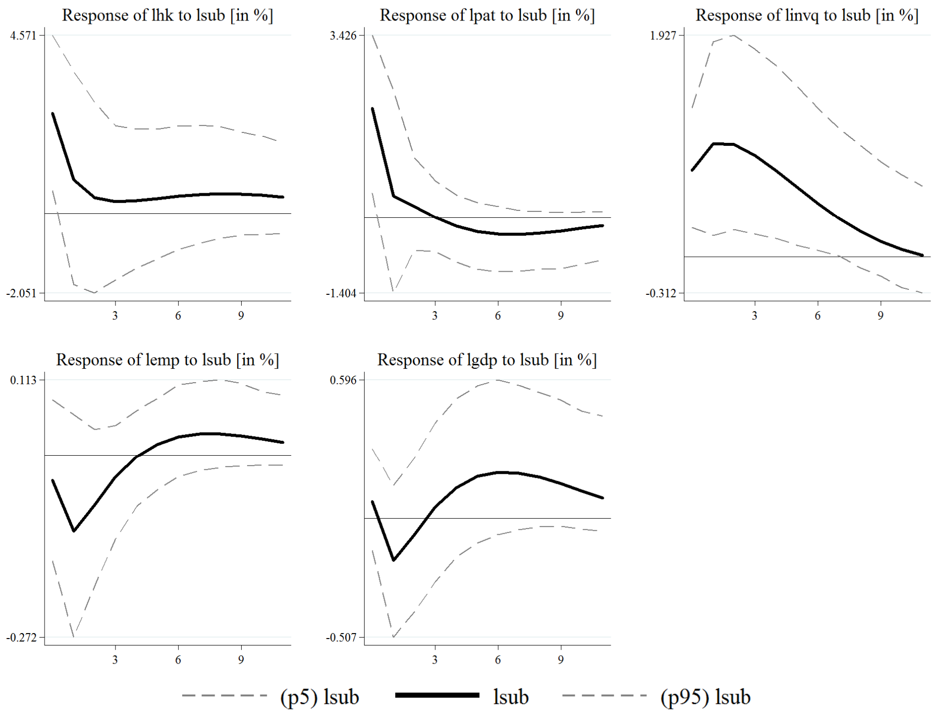
We start with the effect of R&D subsidies on R&D inputs of LMEs. Panel 1 shows that an increase in the R&D subsidy intensity leads to a contemporaneous significant negative effect on the private R&D investment rate. Panel 2 shows that an increase in the R&D subsidy intensity leads to a continuous positive effect on R&D personnel, while the confidence intervals suggest that this effect is only significant in the first year. We interpret these findings as a contemporaneous partial crowding-out effect because firms substitute some private funds with public funds, but total R&D inputs still increase.

Figure 6.7 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2000-2010

1. Private real R&D investments LMEs per real GDP (lprdef)



2. R&D personnel LMEs per capita (lhk)



Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

In addition to the effect on R&D, Panels 1 and 2 show that an increase in the R&D subsidy intensity has a significant positive effect on the provincial physical capital investment rate and patent activity. The effect on physical capital suggests that R&D subsidies have an effect on investments into assets, which may be research or non-research related, and we will explore this point further in Section 6.5.2. Increases in patents may be explained by a simultaneous increase in R&D inputs, emphasised by a closely related shape of the two response functions (see Panel 2 of Figure 6.7).[114] Moreover, the positive effects on the physical capital investment rate may also emanate positive secondary effects on patents.

For the regional employment rate, we find a negative effect in the short run, potentially through substitution and adjustment effects, but a rather (insignificant) positive effect in the medium run. As for the real provincial GDP per capita, our results also suggests a short-run negative effect; however, the responses in Panels 1 and 2 show a delayed significant positive effect. In conclusion, there is some evidence that R&D subsidies have a positive effect on the provincial economy in the medium run.

6.5.2 Robustness tests

In this section we report five robustness tests. First, we augment our basic model with several control variables to address a potential omitted variable bias (see Table 6.1 for an overview of variables). The results in Figure A6.1 confirm the significant negative contemporaneous effect on the private R&D investments of LMEs (Panel 1) and a significant positive contemporaneous effect on R&D personnel (Panel 2). Furthermore, in Panel 2 the effect on the patent activity turns insignificant, while the positive effect on the physical capital investment rate remains robust in both

[114] Griliches (1990) mentions that the relationship between patents and R&D inputs "is close to contemporaneous with some lag effects which are small and not well estimated" (p. 1674).

panels. The significant negative effects on the employment rate and GDP per capita are restricted to the short-term perspective, while the significant positive effect on the GDP per capita diminishes in this setting.

Second, we account for changes in China's innovation policy introduced after the *National Conference on Technological Innovation* in 1999 (Liu et al., 2011). Because the enforcement of national policies at the provincial level takes time, we extend the implementation period by three years and restrict our analysis to the years 2003 to 2010 (Figure A6.2).[115] The effect on the private R&D investment rate of firms is still contemporaneously negative but turns insignificant afterwards (Panel 1). The results also show that an increase in the R&D subsidy intensity has a long-lasting significant positive effect on the R&D personnel of LMEs (Panel 2). The estimated response of the physical capital investment rate and the provincial patent activity remains significant positive. We do not find a significant effect on the employment rate, nor on the per capita income. These findings largely support our main results and indicate no substantial increase in the effectiveness of R&D subsidies in more recent years.

Third, we return to the question whether the effect of R&D subsidies on the physical capital investment rate suggests the use of R&D subsidies for non-research investments. We use investments in residential buildings as an indicator for short-term profit maximising investments, which, however, are unlikely to be complementary to R&D. Due to data limitations, this analysis is restricted to the years 2003 to 2010. The corresponding IRFs in Figure A6.3 show that a shock in the R&D subsidy intensity has a significant positive short-run effect on the investment rate in residential

[115] We also apply unit root tests for this time period before estimation. Please note that we also detrend the variable *linvq*, although the unit root test reports stationarity for the time period 2003-2010; however, IRF analysis does not work otherwise.

buildings. Thus, the results support that R&D subsidies are partially misallocated to non-research investments.

Fourth, we include provincial-status municipalities. We fail to note changes on the responses of our core variables, except for the employment rate and GDP per capita, which are a significant negative in the short term but convert into positive effects in the medium run (Figure A6.4). As a further sensitive analysis, we test the inclusion of the four municipalities in the time period 2003 to 2010. The significant positive effect on the R&D personnel employed in firms and the negative effect on the private R&D investments of LMEs remains robust (Figure A6.5). However, the positive response of the physical capital investment rate is non-significant in the setting where R&D inputs are measured by private R&D investments of firms (Panel 1).

Fifth, different to our prior assumption that public funding has a rather exogenous effect on firms' R&D personnel and private R&D investments, we now assume that R&D personnel and private R&D investments at time *t* endogenously determine the allocation of public funds. To this end, the causal ordering between human capital and R&D subsidies at time *t* in Figure 6.4 is reversed. In the model, this restricts any potential effect of R&D subsidies on private R&D investments at time *t* to zero. The findings suggest that the effects of R&D subsidies on R&D personnel and private R&D investments are only of contemporaneous significance, as they disappear in this setting (Figure A6.6). Firms instantaneously substitute own funds with public funds, while there is no effect in subsequent periods. Accordingly, there are no significant effects on the R&D personnel at all. The results confirm a contemporaneous effect of R&D subsidies on R&D inputs of firms, while there is no crowding-out effect in subsequent time periods where the R&D activities remain constant. The significant positive effect on the patent activity, investment rate as well as partially on the real GDP per capita remains unchanged.

6.5.3 Discussion

Our main empirical insight is that an increase of R&D subsidies significantly decreases private R&D investments, while there is a significant positive effect on the R&D personnel employed in firms. We interpret these findings as a partial crowding-out effect because public funds substitute some private funds while total R&D inputs still increase. Hence, R&D subsidies have not contributed to a rise in private R&D expenditures but still led to an increase in total R&D inputs. This finding corroborates prior investigations of China's R&D subsidies at the firm (Boeing, 2016) and provincial level (Chen, 2018).

In addition, we find positive secondary effects on the provincial patent activity and the investment rate in physical capital. Through increases in total R&D inputs, provincial economies benefit from technological progress and capital deepening. The former empirical finding especially confirms the prediction of our theoretical framework. What is more, we find some evidence for potentially unintended effects as R&D subsidies also increase the investment rate in residential buildings. Although investments in physical capital may be complementary to R&D in general, investments in residential buildings more likely suggests partial misallocation of R&D subsidies. This finding is in line with the firm-level evidence presented in Boeing and Peters (2019), which show that misappropriated R&D subsidies are partially used for investments in physical capital. In particular, real-estate investments seem to increase the opportunity cost of R&D investment in China. Based on data for manufacturing firms in 35 Chinese cities, Rong et al. (2016) find that housing price appreciation creates opportunities for high earnings of real estate investments. For this reason, manufacturing firms enhance diversification in the real estate sector and thereby decrease investments in innovation, which may provide a possible explanation for the effect of R&D subsidies on the investment rate in residential buildings.

In general, our findings imply that China's R&D subsidies have effectively stimulated R&D activities of firms, as well as further economic activities of provinces, but failed to increase private R&D funding. Although a first-order goal of China's innovation policy is to increase R&D activities in firms, this goal could be reached more efficiently under an additionality rather than partial crowding-out regime. Thus, a crucial question is how to improve China's R&D policy towards a higher effectiveness in stimulating private R&D expenditures. Below we discuss three potential avenues.

First, rigorous monitoring may increase the odds of R&D subsidies being invested in research, instead of non-research, and this is a necessary condition for any effect on R&D activities. Second, selection of financially constrained recipients and strict monitoring of funding contract rules, especially in the case of matching grants, reduces the risk that public funds become a substitute for private funds. Even if grantees fulfilled matching criteria of supported R&D projects by using private funds from non-supported R&D projects, this reallocation does not lead to crowding out of private funds. Third, China's increasing emphasis on mission-oriented R&D programmes bears the risk of disproportionally lower marginal returns to supported projects relative to non-supported projects. A strict mission-oriented policy may enhance government failure in the identification of R&D projects with the highest social returns and results in resource misallocation to the detriment of welfare and growth. Rigorous ex-post evaluation will help to identify and adjust ineffective policies in time.

6.6 Conclusions

In this study, we investigate the impact of R&D subsidies on R&D inputs of large- and medium-sized firms in Chinese provinces. A panel VAR model and corresponding IRF analysis allow us to differentiate between direct and indirect effects, which add up to total effects. Based on this approach we can identify the impact of R&D subsidies on additional measures of provincial innovation and economic performance. A main result is that R&D subsidies fail to incentivise private R&D expenditures while firms increase the total employment of R&D personnel. We interpret these findings as a partial crowding-out effect because public funds substitute some private funds while total R&D inputs still increase. Beyond that, we gain novel insights into additional transmission channels of R&D subsidies. Notably, we find positive effects on measures of technological progress, capital deepening, and growth, while there is a negative effect on employment in the short run. Politically unintended effects of R&D subsidies on investments in residential buildings suggests partial misallocation of public funds.

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A6. Appendix

Appendix A6.1 Data properties.

The use of China's provincial data is not without challenges, and in this section we briefly discuss some main issues.

1. Due to a decentralised accounting approach, the sum of *provincial GDP* is not equal to China's national GDP. For example, data on the national GDP is approximately 5.9 % smaller compared to the summed provincial GDP for the year 2010. Differences also applies to employed persons, population, investments in fixed assets and patents in our data.

2. NBS calculates *resident population data* for the years 2000, 2001 and 2010 based on the National Population Census 2000 and 2010, while data for the remaining years is based on annual national sample surveys on population changes. According to the National Population Census in 2010, population data for Beijing (2006 to 2009) as well as for Tibet (2001 to 2009) was corrected in retrospect and we use the corrected data.

3. Data on the *employed persons* by regions is obtained from various issues of China's Statistical Yearbooks. As mentioned in Table 6.1, there is no data available for the years 2003 and 2006. Until the year 2010, the annual provincial data is based on the National Population Census in 2000, as well as on the annual Sample Survey on Labour Force. Data for the year 2010 is based on the National Population Census 2010 and the annual Sample Survey on Labour Force (similar to the data on resident population). According to the novel Census in 2010, data on the national wide employed persons is also corrected in retrospect for the period 2001 to 2009. However, corrected data on provincial level is, to our knowledge, not available. The modifications on national level show only moderate differences (e.g. modified data on the employed persons on national level is 1.55 % smaller for the year 2005), implying that modified data on provincial level would be slightly smaller than the applied extrapolated provincial data in this study.

4. The data on the *R&D personnel* and *investments of LMEs* was collected from the Statistics yearbook on science and technology activities of industrial enterprises (various years). In order to ensure the consistency of the time series, we calculate the annual sum by aggregating the provincial values. The calculated national value for both variables corresponds in each year to the variables "Full time Equivalent of R&D Personnel" and "Expenditure on R&D" in the category "Basic Statistics on Science and Technology Activities of Large and Medium-sized Industrial Enterprises" in various Chinese Statistical Yearbooks. This confirms the consistency of our main R&D variables.

5. The *patent data* from China's patent office CNIPA (formally State Intellectual Property Office of China (SIPO)) is equal to the published provincial data by the NBS, only for the provinces Zhejiang and Guangzhou the patent count differs by one patent.

Table A6.1 Summary statistics, 2000-2010

	Observations	Mean	Median	Std. Dev.	Min.	Max.
			(1) All Provinces			
	Observations	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**
gdp	341	17525.02	13130.93	13448.59	2755.85	72296.29
emp	341	0.5128	0.5114	0.0741	0.3637	0.7324
invq	341	0.4909	0.4636	0.1577	0.2576	0.9339
hk	341	0.0005	0.0004	0.0005	0	0.0026
prdef	341	0.0045	0.0039	0.0031	0	0.0147
pat	341	0.0884	0.0614	0.0996	0	0.8133
sub	341	0.0005	0.0004	0.0005	0	0.0039
			(2) Without Tibet			
	Observations	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**
gdp	330	17792.19	13483.73	13572.57	2755.85	72296.29
emp	330	0.5127	0.5115	0.0751	0.3637	0.7324
invq	330	0.4826	0.4495	0.1523	0.2576	0.9339
hk	330	0.0005	0.0004	0.0005	0.00001	0.0026
prdef	330	0.0047	0.0039	0.0030	0.0001	0.0147
pat	330	0.0906	0.0636	0.1004	0.0093	0.8133
sub	330	0.0005	0.0004	0.0005	0.0000009	0.0039
			(3) Without municipalities			
	Observations	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**
gdp	297	14695.55	12246.18	9398.49	2755.85	50716.66
emp	297	0.5129	0.5116	0.0687	0.3637	0.7324
invq	297	0.4977	0.4752	0.1607	0.2576	0.9339
hk	297	0.0004	0.0003	0.0004	0	0.0026
prdef	297	0.0041	0.0036	0.0028	0	0.0132
pat	297	0.0664	0.0561	0.0429	0	0.3068
sub	297	0.0005	0.0003	0.0005	0	0.0039
			(4) Without municipalities and Tibet			
	Observations	**Mean**	**Median**	**Std. Dev.**	**Min.**	**Max.**
gdp	286	14895	12338.08	9492.73	2755.85	50716.66
emp	286	0.5129	0.5116	0.0696	0.3637	0.7324
invq	286	0.4885	0.4704	0.1552	0.2576	0.9339
hk	286	0.0004	0.0003	0.0004	0.00001	0.0026
prdef	286	0.0042	0.0036	0.0027	0.0001	0.0132
pat	286	0.0681	0.0581	0.0426	0.0093	0.3068
sub	286	0.0005	0.0004	0.0005	0.0000009	0.0039

Notes: Own calculations based on provincial data (see Table 6.1). Summary statistics are shown for the variables before ln-transformation and before detrending.

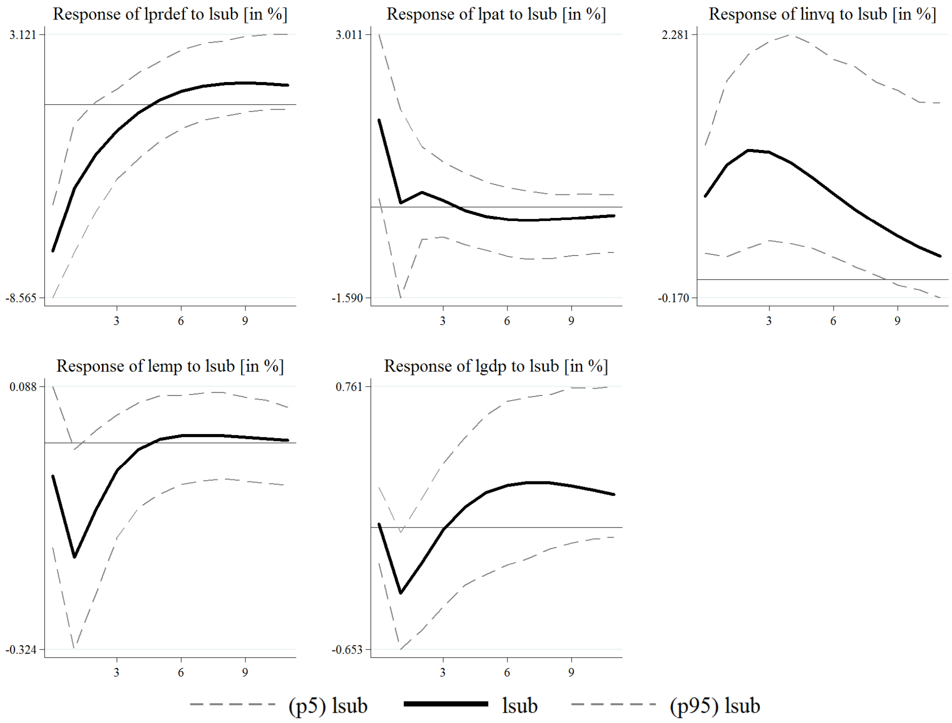
Table A6.2 Summarised economic activities of Chinese provinces, 2000-2010

Province	**Province code**	**Real GDP per capita (in RMD)**	**Employment rate (in %)**	**Real invest-ments in fixed assets per real GDP (in %)**	**Private real R&D invest-ments LMEs per real GDP (in %)**	**R&D personnel LMEs per cap-ita (%)**	**Patents per 100 Mio. real GDP**	**Real R&D sub-sidies to LMEs per real GDP (%)**
Anhui	AH	9931.11	57.63	64.99	0.53	0.03	0.06	0.06
Beijing	BJ	47487.28	60.40	39.24	0.61	0.12	0.57	0.06
Chongqing	CQ	13838.82	61.58	64.19	0.59	0.05	0.09	0.06
Fujian	FJ	21119.31	53.34	42.87	0.55	0.06	0.05	0.02
Gansu	GS	8355.77	52.03	54.59	0.40	0.03	0.07	0.04
Guangdong	GD	26118.49	50.59	30.95	1.00	0.11	0.17	0.03
Guangxi	GX	9664.27	56.56	51.88	0.26	0.01	0.04	0.02
Guizhou	GZ	6164.53	59.47	55.21	0.33	0.01	0.08	0.08
Hainan	HI	12557.51	46.24	47.12	0.06	0.00	0.05	0.00
Hebei	HE	15589.74	51.48	53.15	0.39	0.03	0.04	0.01
Heilongjiang	HL	15125.84	43.25	42.54	0.45	0.06	0.10	0.08
Henan	HA	12159.59	60.03	52.80	0.44	0.04	0.05	0.02
Hubei	HB	13366.52	47.46	49.68	0.59	0.05	0.11	0.04
Hunan	HN	11743.63	56.40	46.46	0.43	0.03	0.10	0.03
Inner Mongolia	NM	20497.95	44.04	65.77	0.27	0.03	0.02	0.03
Jiangsu	JS	26810.00	52.37	47.31	1.04	0.12	0.11	0.04
Jiangxi	JX	10653.52	48.70	64.57	0.48	0.03	0.04	0.06
Jilin	JL	15600.97	41.25	65.99	0.35	0.03	0.10	0.02
Liaoning	LN	21680.34	46.85	62.56	0.84	0.08	0.12	0.09
Ningxia	NX	12574.28	50.34	72.49	0.40	0.03	0.06	0.06
Qinghai	QH	11595.21	48.95	65.93	0.31	0.02	0.04	0.04
Shaanxi	SN	12436.36	51.15	60.92	0.47	0.06	0.14	0.20
Shandong	SD	21597.89	54.89	49.67	0.95	0.07	0.07	0.03
Shanghai	SH	50526.30	42.75	35.26	1.13	0.15	0.27	0.05
Shanxi	SX	13576.99	44.75	50.49	0.52	0.05	0.07	0.05
Sichuan	SC	10321.21	56.96	58.13	0.39	0.03	0.09	0.06
Tianjin	TJ	39663.56	40.69	50.41	1.13	0.13	0.20	0.03
Tibet	XZ	9682.03	51.59	78.14	0.01	0.00	0.02	0.00
Xinjiang	XJ	13864.87	37.78	54.99	0.20	0.02	0.03	0.02
Yunnan	YN	8664.30	56.43	56.94	0.16	0.01	0.08	0.02
Zhejiang	ZJ	28861.31	65.49	45.65	0.72	0.10	0.13	0.03

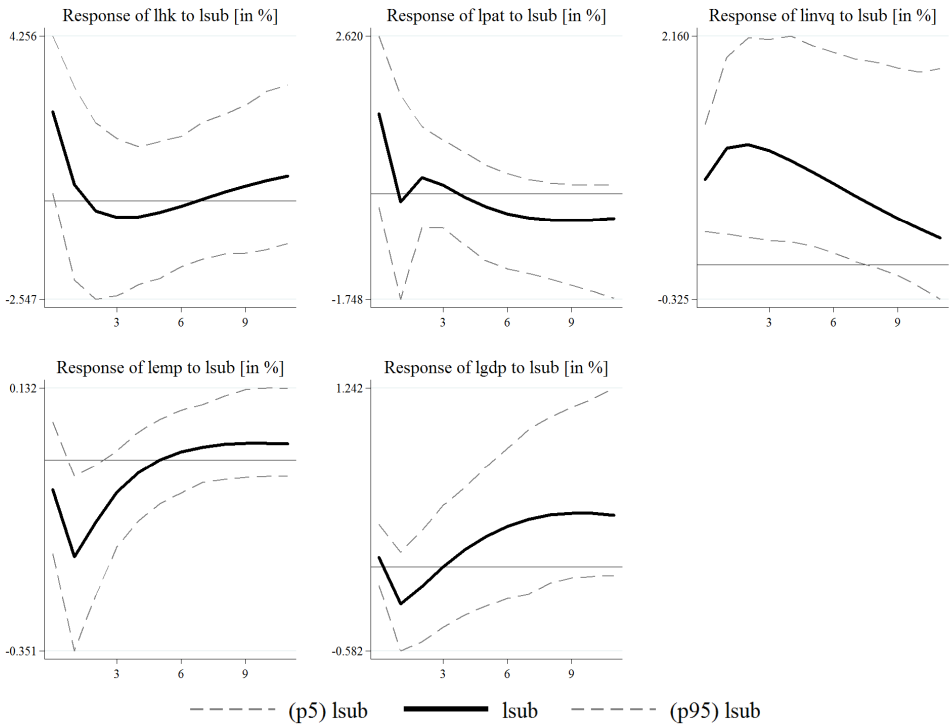
Notes: Own calculations based on provincial data (see Table 6.1).

Figure A6.1 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2000-2010 (control variables included)

1. Private real R&D investments LMEs per real GDP (lprdef)



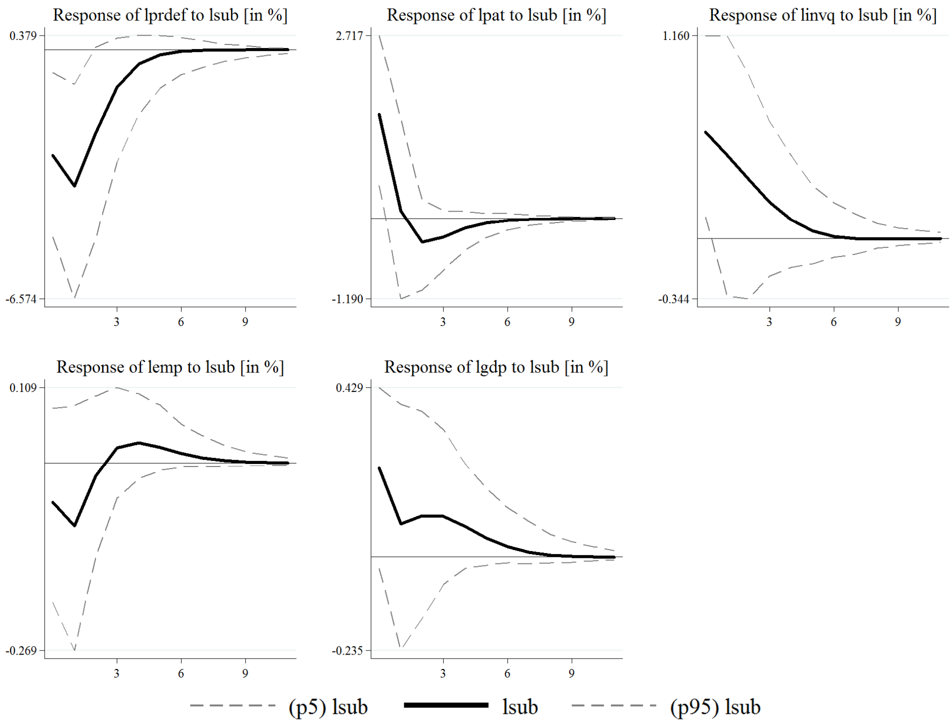
2. R&D personnel LMEs per capita (lhk)



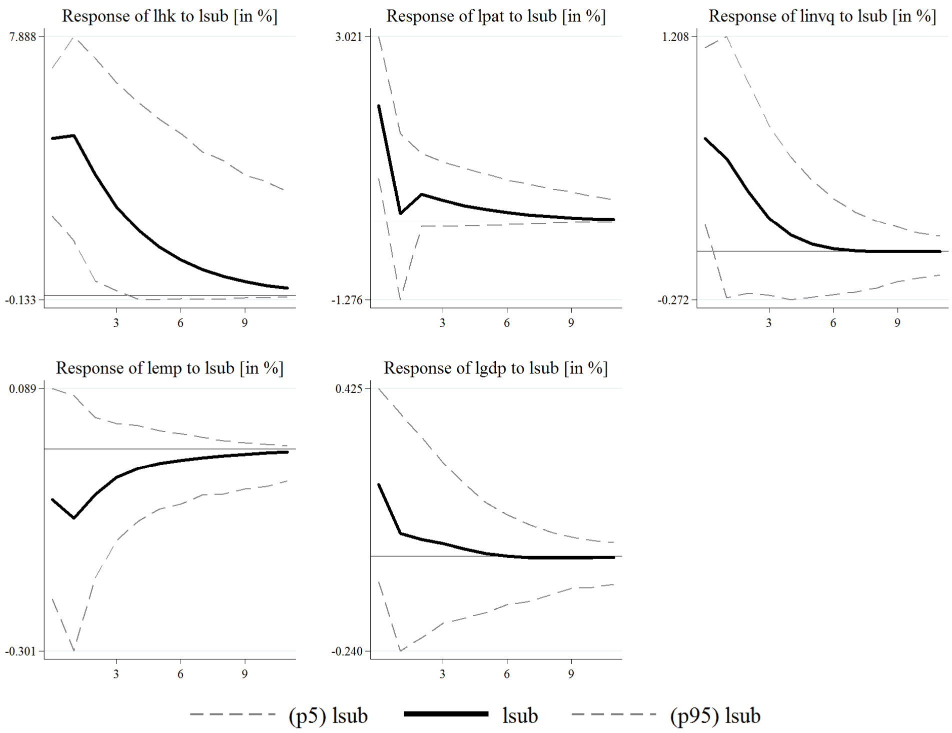
Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

Figure A6.2 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2003-2010

1. Private real R&D investments LMEs per real GDP (lprdef)



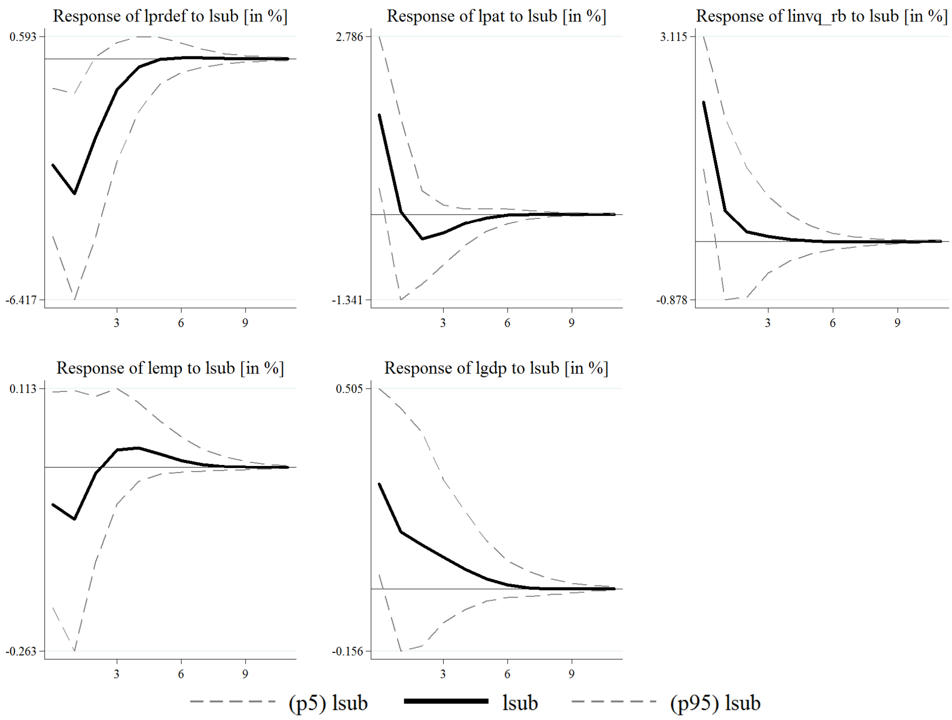
2. R&D personnel LMEs per capita (lhk)



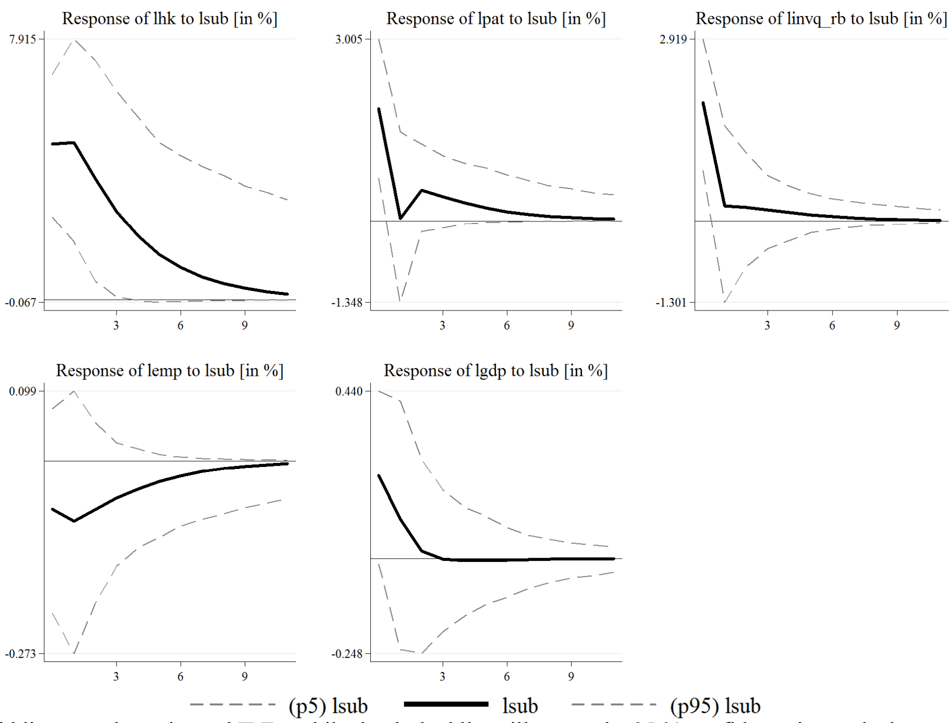
Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

Figure A6.3 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2003-2010 (*linvq_rb* denotes investment rate in residential buildings).

1. Private real R&D investments LMEs per real GDP (lprdef)



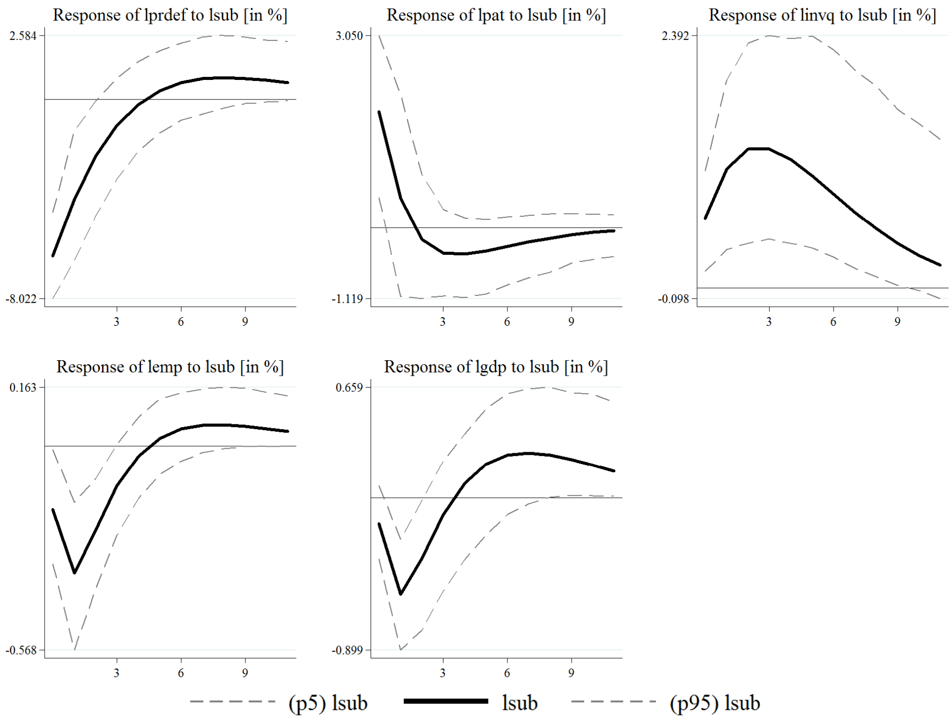
2. R&D personnel LMEs per capita (lhk)



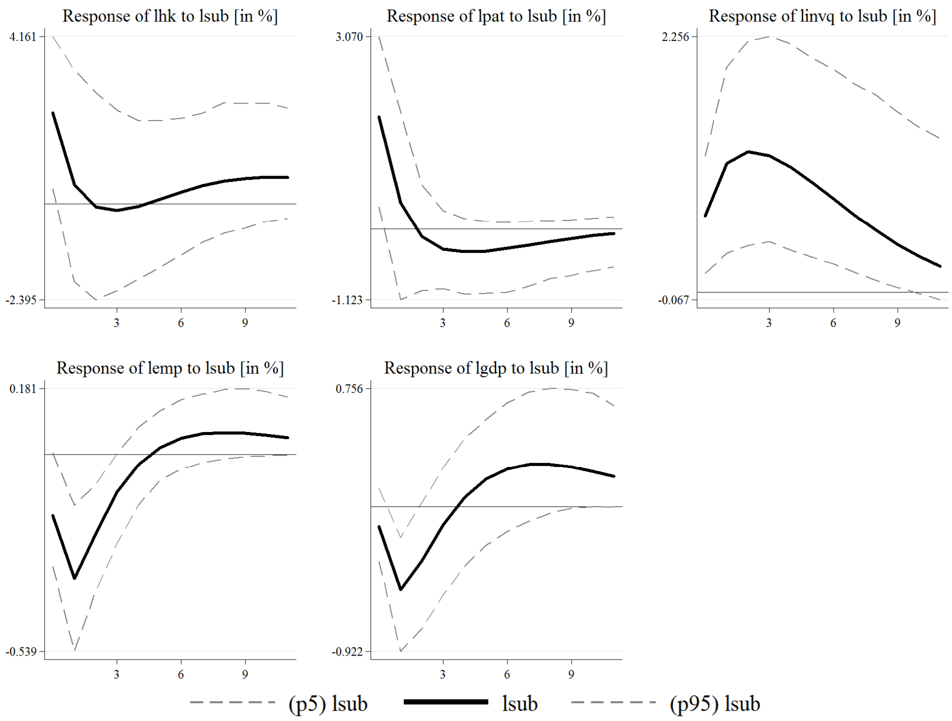
Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

Figure A6.4 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2000-2010 (Beijing, Shanghai, Tianjin and Chongqing included)

1. Private real R&D investments LMEs per real GDP (lprdef)



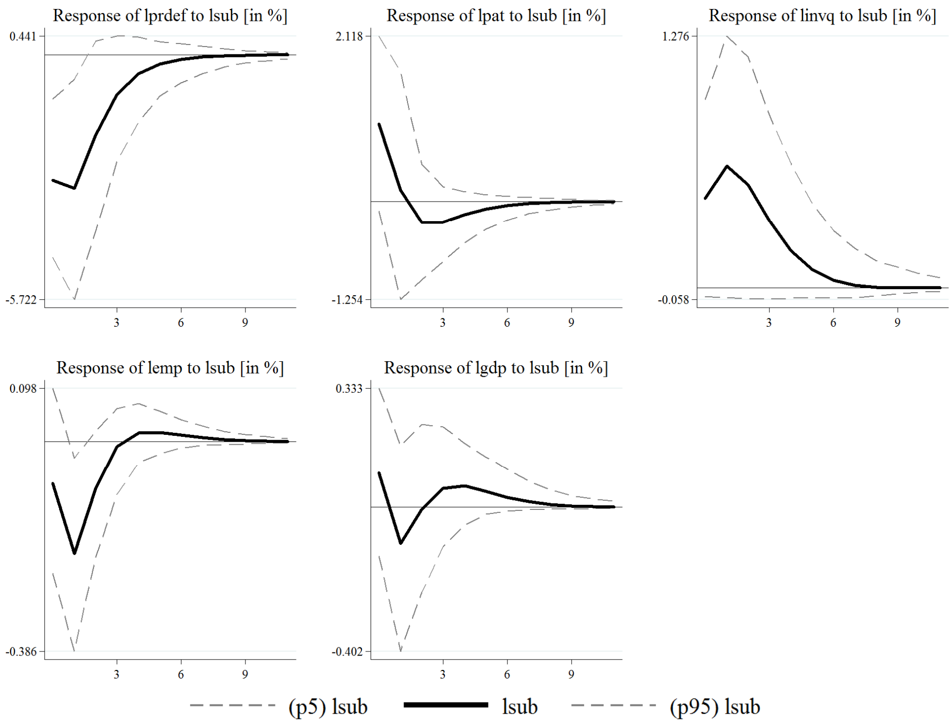
2. R&D personnel LMEs per capita (lhk)



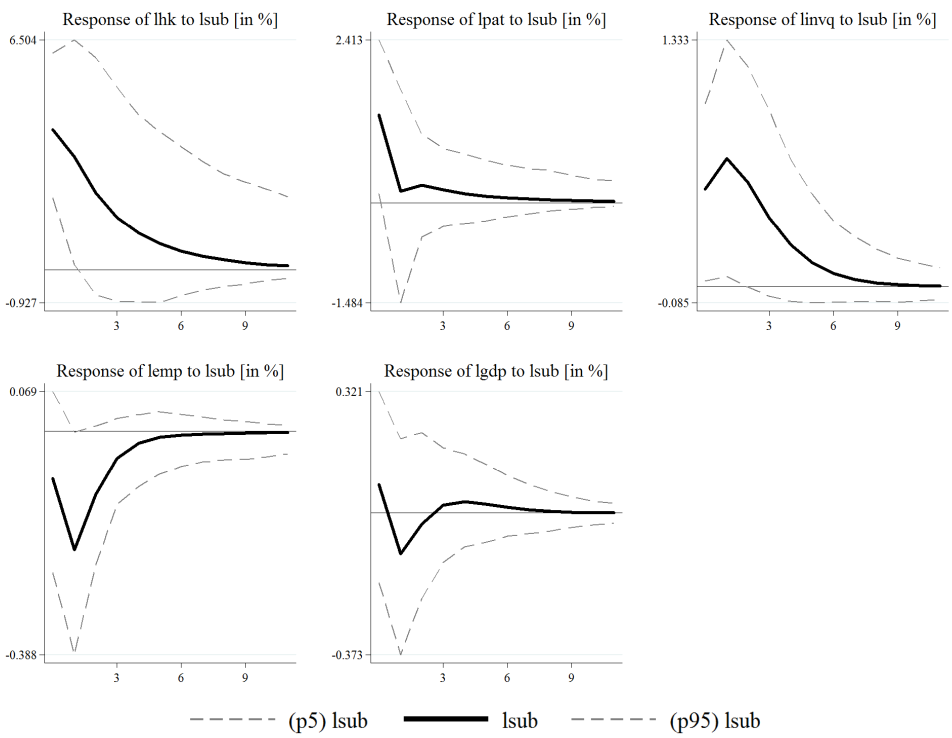
Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

Figure A6.5 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2003-2010 (Beijing, Shanghai, Tianjin and Chongqing included)

1. Private real R&D investments LMEs per real GDP (lprdef)



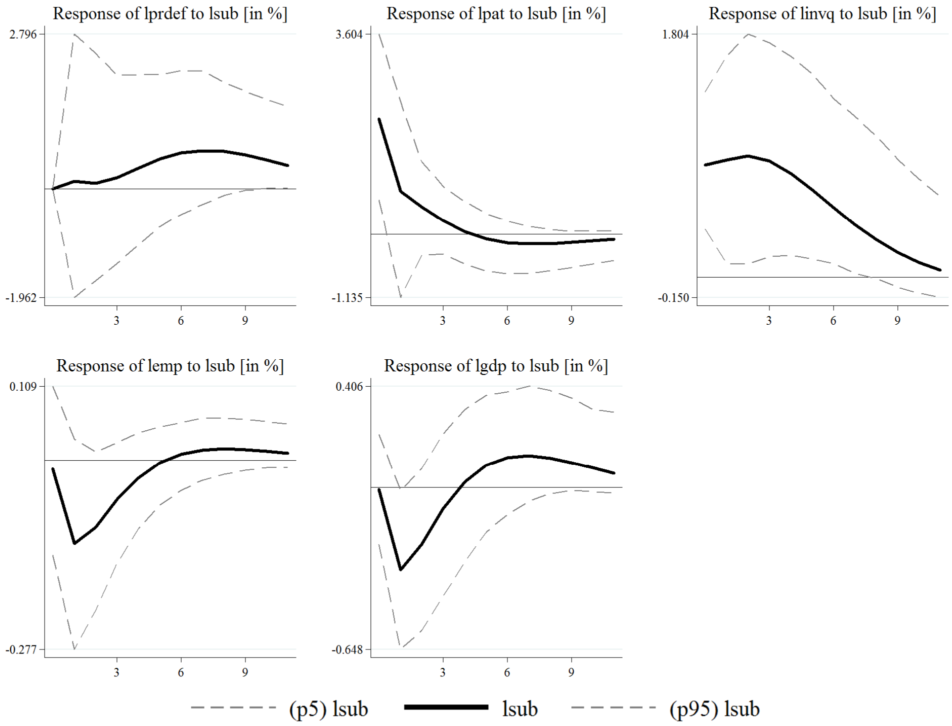
2. R&D personnel LMEs per capita (lhk)



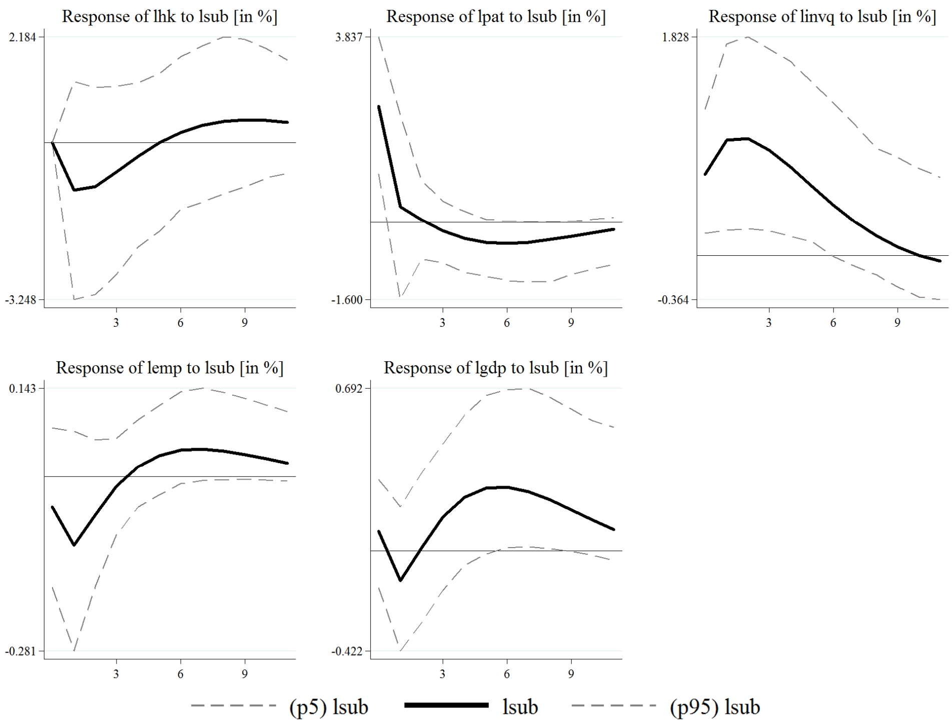
Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

Figure A6.6 IRF analysis for an increase in R&D subsidy intensity (*lsub*), 2000-2010 (Changed causal ordering).

1. *Private real R&D investments LMEs per real GDP (lprdef)*



2. *R&D personnel LMEs per capita (lhk)*



Notes: The solid lines are the estimated IRFs, while the dashed lines illustrate the 95 % confidence intervals that are calculated by conducting Monte Carlo simulations (500 repetitions).

7. General conclusions

The thesis at hand contributes five research papers, whereas the overarching objective is to investigate and compare the effects of different policy measures on regional economic growth and development in Germany and China. In doing so, each individual research paper analyses a specific policy and raises specific research questions that are presented in Sections 2 to 6.

In Section 2, the complex effects of the "Joint Task for the Improvement of Regional Economic Structures" (GRW), the most important German policy framework to stimulate regional economic development in less developed regions, are analysed. The main pillars are to spur the investment activity of regional firms and to improve the regional infrastructure (Alecke et al. 2012, 2013; Deutscher Bundestag, 2014). Implied target variables are the private as well as the public physical capital.

Subsequently, the analysis on the economic effects of GRW funding is extended by considering potential regional conditions that facilitate an effective use of the provided funds. That said, the basic contribution of the second research paper is to analyse the conditional overall effects of GRW investments by estimating and comparing the responses in regions with low and high levels of absorptive capacity and economic freedom (see Section 3).

In Section 4, the unconditional and conditional effects of regional fiscal equalisation are investigated. In addition, the estimated unconditional economic responses are compared to these of GRW funding. This policy measure particularly aims to provide additional financial means to regions with higher needs to assure an adequate local supply of public goods. Thus, the policy has also a distinct redistributive dimension (Lenk et al., 2013). The implied target variable of regional fiscal equalisation is essentially the public physical capital.

The research paper presented in Section 5 is focused on public research activities (measured by publications and received third-party funds) of various public actors in Germany and can be linked to the concept of regional innovation processes and innovation-led growth strategies. Contrary to the first two policy measures, public research activities are not restricted to particular regions. However, they are an important component for regional innovation processes and economic development (Fritsch and Schwirten, 1999; Schubert and Kroll, 2013). In this setting, the regional technology and research sector is seen as the primary transmission channel.

Finally, the last research paper analyses the economic effects of Chinese research and development (R&D) subsidies to firms (see Section 6). The Chinese government currently transforms the economic system by implementing a more innovation-based development agenda (Cao et al., 2013; Liu et al., 2011). To implement this agenda, firms play an increasingly important role for Chinese innovation systems and economic development (Boeing, 2016). The implied target variables are the private R&D investment rate and R&D personnel of Chinese firms (human capital).

The empirical findings in each research paper emphasise that German and Chinese policies matter considerably for regional development paths. In the remainder of Section 7, the key unconditional and conditional findings are summarised and (policy) implications are derived. Moreover, possible limitations (Section 7.2) and lines to future research are briefly discussed (Section 7.3).

7.1 Main findings and policy implications

Research Question 1: What are the overall economic effects of the analysed policy measures in Germany and China on different regional input and output factors of a regional production function? (Unconditional effects)

Overall GRW investments trigger significant positive effects on the regional gross domestic product (GDP) per workforce, the employment and human capital rate.[116] Differences between industry

[116] As explained in Sections 1.1.3 and 1.2, the first two research questions deal with *unconditional funding effects* (see Figure 1.2).

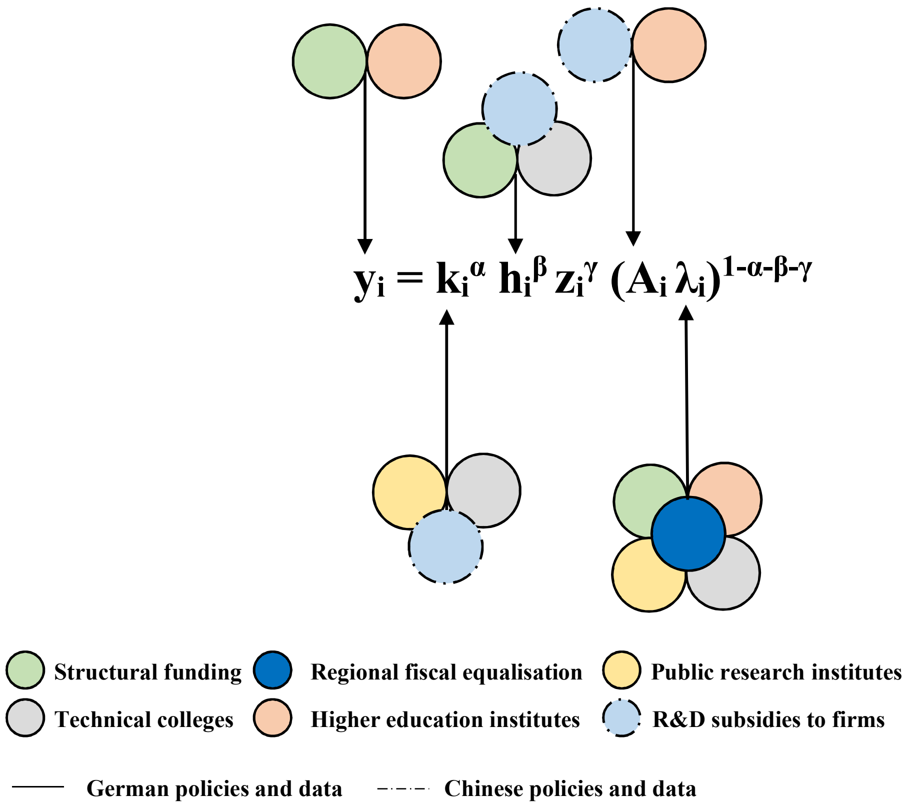
and infrastructure investments are moderate but become particularly visible for regional GDP: GRW industry investments do not have significant positive effects at all, while statistically significant increases of a shock in GRW infrastructure investments are restricted to single years.

Regional fiscal equalisation payments in Germany are associated with a significant positive effect on the regional employment rate, whereas the effects on other economic variables are statistically insignificant. This finding may be explained by a missing industry-related policy dimension and associated minor economic secondary effects. However, no statistically significant differences in the magnitudes of the effects between German structural funding and regional fiscal equalisation are identified.

The unconditional effects of public research activities on regional economies are heterogeneous: An increase in the publication rate of public research institutes triggers significant positive effects on the physical capital investment and (total) employment rate of regional economies. Conversely, the findings reveal that research activities of universities are not associated with statistically significant impacts on regional development, at least in the analysed short-run perspective. However, by combining public third-party funds received by regional universities and technical colleges (labelled as higher education institutes), the estimated responses suggest significant positive effects on regional technological, employment and GDP development. Finally, an increase in the (public) third-party funds received by technical colleges is associated with increases in the regional physical capital investment, employment and human capital rate.

The empirical findings for Chinese provinces suggest that R&D subsidies to firms contemporaneously crowd out private R&D investments. Conversely, a significant positive impact on the R&D personnel of firms is identified, hinting at a partial crowding-out effect because total R&D inputs of firms rise. Although R&D subsidies do not incentivise additional private R&D investments, Chinese provinces gain from positive secondary effects on the provincial patent activity and the physical capital and residential building investment rate. However, carefully speaking, the latter finding suggests a partial misallocation of R&D subsidies to non-R&D related projects.

Figure 7.1 Significant *unconditional* effects of the analysed German and Chinese policy measures



The conducted analyses on the complex economic effects of different policy measures account for mutual dependencies across the input and output factors in a regional economic system. Figure 7.1 is based on the estimated significant economic responses in Sections 2, 4, 5 and 6 and shows that, with the exception of regional fiscal equalisation payments, the analysed policy measures have a multifaceted impact dimension by triggering significant positive effects on different economic input and output factors. Consequently, the analysed regional policies do not have a multifaceted impact dimension per se, but at least the economic effects of structural funding and public research activities go beyond the expected transmission channel(s). That said, the first general implication that can be drawn from the findings is that public polices foster regional development and add to regional economies in a complex and reciprocal fashion. This should be accounted for by scholars and policy makers, who should not fall short of focussing their interest solely on regional GDP measures (applies for Germany and China).

Research Question 2: Do the analysed German policy measures add to regional development via different transmission channels and can unique characteristics be identified? (Unconditional effects)

At first, all analysed German policy measures positively affect the regional employment rate.[117] However, only regional fiscal equalisation payments do not trigger statistically significant effects on additional economic variables. Consequently, regional fiscal equalisation does not have a unique characteristic in fostering regional development.

Second, German structural funding has a more comprehensive impact on regional economies because the funding increases are also associated with positive effects on both human capital and regional GDP development. Similar to structural funding, an increase of public third-party funds to higher education institutes also corresponds to an increased regional GDP per workforce. Accordingly, these two policy measures are the most likely ones to trigger regional GDP development.

Third, a distinctive characteristic of public third-party funds to higher education institutes is that the funds are successful in transforming research activities into significant increases in the regional patent activity. Because no other analysed policy measure is associated with significant positive effects on the regional patent activity, this finding reveals a unique characteristic of higher education institutes for regional development in Germany.

[117] The discussion of research question 2 is restricted to Germany because only one Chinese policy is analysed in this doctoral thesis.

Fourth, a distinctive character of technical colleges and public research institutes is that they trigger significant positive effects on industry-related variables, such as the private physical capital investment rate. Moreover, like structural funding, research activities of technical colleges are positively connected to regional human capital development.

Table 7.1 Policy implications *unconditional* effects of the analysed German policy measures

Target variable	Policy Implication
GDP per workforce ***y***	Provide **GRW funding** (infrastructure and total funding) and/or provide public third-party funds to **higher education institutes** (technical colleges and universities combined).
Private physical investment rate s_k	Stimulate regional research activities of **public research institutes** and/or provide overall third-party funds to **technical colleges**.
Human capital ***h***	Provide **GRW funding** (industry, infrastructure and total funding) and/or provide public third-party funds to **technical colleges**.
Technological growth rate ***g***	Provide public third-party funds to **higher education institutes** (technical colleges and universities combined).
Employment rate λ	Provide **GRW funding** (industry, infrastructure and total funding) and/or provide **regional fiscal equalisation payments** and/ or provide public third-party funds to **technical colleges** and/ or provide public third-party funds to **higher education institutes** (technical colleges and universities combined) and/ or stimulate regional research activities of **public research institutes**.

The second main contribution of the thesis is to identify unique characteristics of the analysed German policies. The empirical findings hint at different transmission channels of the analysed policies in stimulating regional development. Table 7.1 formulates concrete implications for each economic input and output variable. With the exception of regional technological development, the economic input and output variables are affected in a statistically significant way by several regional policy measures. It can be drawn from the empirical results that policy makers are flexible to pick different policy options to stimulate the development of a particular economic input and output factor, except the technological development. However, it is also highly important that future allocation decisions are more attuned to regional needs. In the first instance, it becomes increasingly important for policy makers to concretely identify regional economic components that are not well developed. Thereupon, it becomes necessary to provide only these policy measures that predominately stimulate the development of the identified less developed economic components (applies to Germany).

Research Question 3: Do economic responses to an increase in German structural funding and regional fiscal equalisation funding depend on conditioning factors such as a region's absorptive capacity, economic freedom and political-economic conditions? (Conditional effects)

The empirical findings of the conditional effects of German structural funding and fiscal equalisation payments give rise to a more sophisticated look at policy evaluations and conceptual designs by explicitly incorporating regional conditions of target regions.

For the most part, the effects of structural funding on the human capital rate are similar and largely independent on regional initial conditions (applies especially for the absorptive capacity), while the findings hint at significant positive effects on the employment rate solely in regions with a high level of economic freedom. In these regions, the estimated responses of the employment rate to a funding increase are also statistically significantly higher.

Furthermore, traditional funding channels of structural funding via the private sector-investment rate are predominantly associated with low levels of absorptive capacity and economic freedom. Conversely, significant positive responses of the regional patent activity and GDP per workforce are rather connected with high levels of absorptive capacity and economic freedom. The estimated responses of these two variables are also statistically significantly higher in regions with high levels of absorptive capacity and economic freedom.

The effects of regional fiscal equalisation funding reveal slightly different response patterns between Eastern and Western German regions as well as between Social Democratic Party (SPD) and Christian Democratic Party/Christian Social Party (CDU/CSU) preferring regions. At first, the empirical findings suggest statistically significant positive effects on the employment rate in Western German regions and on the investment rate in Eastern German regions. Furthermore, fiscal equalisation increases are not associated with statistically significant positive effects on the remaining economic variables in this setting. Second, the response patterns of the regional human capital and investment rate are significantly positive in pro-business CDU/CSU preferring regions, while the estimated response of the GDP per workforce is significantly positive solely in SPD preferring regions (in the short run). In addition, fiscal equalisation increases are associated with positive effects on the employment rate in CDU/CSU and SPD preferring regions. That said, the estimated responses to an increase in the equalisation payments in East and West Germany as well as in CDU/CDU and SPD preferring regions appear to be statistically significantly different only in single years. Thus, in contrast to structural funding, the concluded effect heterogeneity should be interpreted more carefully.

The third contribution of the thesis is made up of the analysis of conditioning factors on the effective use of structural funding and regional fiscal equalisation in Germany. The empirical findings suggest that regional initial conditions serve as a fertile ground for an efficient use of public investments in Germany. The resulting implication is that policy makers should, on the one hand, identify and improve these regional initial conditions. On the other hand, policy makers should provide a particular policy measure (especially structural funding) predominantly according to prevailing regional initial conditions. This would facilitate an efficient use of public means, which is especially important in times of easing funding volumes (applies for Germany). Table 7.2 provides an overview of the implications to foster the development of different variables (based on statistically significant responses in Sections 3 and 4).

Table 7.2 Policy implications *conditional* effects of structural funding and regional fiscal equalisation

Target variable	Structural funding (GRW)	Regional fiscal equalisation*
GDP per workforce y	Provide funding to regions with **high** levels of absorptive capacity and/or **high** levels of economic freedom (industry, infrastructure and overall GRW funding).	**Eastern German** regions should not use this policy to foster this variable and/or improve the returns on payments in **CDU/CSU** preferring regions (and/or provide payments to **SPD** preferring regions).
Private physical investment rate s_k	Provide funding to regions with **low** levels of absorptive capacity (industry and overall GRW funding) and/or **low** levels of economic freedom (industry, infrastructure and overall GRW funding).	**Eastern German** regions should use this policy to foster this variable and/or provide payments to **CDU/CSU** preferring regions.
Human capital h	Provide funding to regions **irrespective** of regional levels of absorptive capacity (infrastructure and overall GRW funding) and/or **low** levels of economic freedom (industry and overall GRW funding).	Provide payments to **CDU/CSU** preferring regions.
Technological growth rate g	Provide funding to regions with **high** levels of absorptive capacity and/or **high** levels of economic freedom (industry and GRW overall funding).	Do not increase payments.
Employment rate λ	Provide funding to regions **irrespective** of regional levels of absorptive capacity (industry, infrastructure and overall GRW funding) and/or **high** levels of economic freedom (industry, infrastructure and GRW overall funding).	**Western German** regions should use this policy to foster this variable and/or provide payments to **CDU/CSU** preferring regions (and/or provide payments to **SPD** preferring regions).

Notes: *Policy implications in parentheses are based on empirical findings that are not statistically significant in all estimated settings.

7.2 Discussion of limitations

The presented findings are based on a flexible VAR approach and IRF analysis, which have been used rarely in policy evaluation studies so far (Rickman, 2010). The choice of the econometric strategy is briefly discussed in Section 1.3 as well as in the research papers. In general, the major concern for empirical studies aiming at making a causal statement about a particular relationship is the choice of a proper econometric identification strategy. On top of that, the use of adequate data and technical issues for the implementation of the research aims are further challenges the researcher faces. Data issues are already discussed in more detail in the research papers, the focus in this section is on potential drawbacks of the applied econometric strategy and technical limitations for the analysis.

In the case of VAR models, causality statements are valid if the full set of relevant variables is included (no omitted variable bias) and if the causal structure at time *t* across the included variables is properly identified (here: theory-guided ordering), where the latter is especially a highly challenging task (see Hoover, 2012, for a discussion). Both requirements are, as in any empirical studies, impossible to prove by means of econometric analysis but only by argumentation. As discussed in the following, the conducted analyses in this thesis take into account several econometric issues.

Although the selection of economic core variables is theory-guided and based on a regional production function, (spatial) control variables are additionally included in each research paper for Germany (Sections 2 to 5) to control for a potential omitted variables bias and spatial dependencies on the small-scale regional level. Adding further control variables does not considerably alter the empirical results of the IRF analyses, neither whether regional age structures (Section 2) nor funding intensities of additional German policy measures (Section 4) nor several time-variant regional characteristics are included as control variables (Section 6). Furthermore, time dummies are included in every regression model to control for business cycles and external shocks that may influence the regression results.

In addition to an omitted variable bias or an inadequate definition of the contemporaneous causal structure, the selection of a proper estimator may also impair the validity of conducted empirical analyses. The inclusion of the time-space lag of the particular dependent variable causes a bias of the applied bias-corrected fixed-effects estimator (Everaert and Pozzi, 2007) that only corrects for the dynamic panel bias. Therefore, the time-space lag of the particular dependent variable are excluded and several robustness checks are performed. The conducted robustness checks do not hint at a severe bias of the core variables in the VAR models (Sections 3 to 5), which is why the bias-corrected fixed effects estimator is used for estimation in this thesis. In addition, tested alternatives – such as the System Generalized Method of Moments (GMM) estimator (Arellano and Bover, 1995; Blundell and Bond, 1998) – confront the econometrician with several issues especially when it comes to instrument validity.[118]

Finally, as mentioned in Sections 3 and 4, the empirical results may be influenced by potential endogenous composite indicators, which are used for the subdivision of regions (absorptive capacity, economic freedom, political-economic conditions). However, this issue is accounted for by constructing the composite indicators for the presample period to ensure predeterminedness of the applied composite indicators.

To sum up, the conducted empirical analyses in this thesis control for many potential econometric drawbacks to identify unbiased (and causal) policy effects. Nevertheless, causality statements and the formulated policy implications above should be interpreted carefully.

Regarding the technical limitations, the conducted analyses mainly focus on the simulation of overall spatially direct effects to an increase in the respective policy intensity, while the spatially indi-

[118] The System GMM estimator transforms, on the one hand, the data to remove fixed effects (First-differenced GMM, Arellano and Bond, 1991), and, on the other hand, instruments endogenous variables (like $y_{i,t-1}$) with internal instruments that are uncorrelated with the fixed-effects (System GMM, Arellano and Bover, 1995; Blundell and Bond, 1998). However, a robust implementation is difficult as changes in the lag structure of the chosen instruments considerably affect the estimated coefficients in the model of this thesis. Moreover, as mentioned by an unknown referee, there are serious doubts regarding the use of internal instruments because these may be not truly exogenous or weak. This weak instrument problem is proven for the System GMM approach (Bun and Windmeijer, 2010).

rect effects are neglected (see Figure 1.3), with the exception of regional fiscal equalisation payments in Section 4. This brings out one limitation of the thesis and implies the need of future research by adding two aspects: First, future research may draw on the applied VAR model of this thesis to simulate the overall spatially indirect effects of public policies. Second, the conducted analyses focus on the computation of isolated and unlinked short-term policy effects. Thus, a second challenging task for future research is a current technical limitation: the extension and especially the implementation of long-term (spatially direct and indirect) effects in statistical software's, which would allow researchers to simulate comprehensive full space-time response functions (e.g. Di Giacinto, 2010).

7.3 Future lines of research in the discipline of policy evaluation

Empirical policy evaluation remains an important scientific field to improve the future design of policy measures worldwide and thus to increase the incomes and living conditions of human beings. The conducted research sheds light on the need for future research in this discipline.

First, system equation (VAR) approaches are not applied to examine the effects of European structural and cohesion funds so far. Using a similar approach as in the thesis at hand may shed light on the multifaceted transmission channels of European development funds. Second, the empirical results of this thesis emphasise the existence of regional conditional effects of policy measures. As it exceeds the content of the doctoral thesis, future research should focus on the regional abilities to use public means efficiently (e.g. by examining regional conditions that improve the outcomes of public research activities in Germany and R&D subsidies to firms in China). Third, the empirical findings suggest rather minor effects of the analysed polices in Germany on regional patent activities. This may hint at minor effects on regional structural changes and innovation capacities. However, Germany is facing major structural challenges, such as the pull-strategic retreat from coal mining or the aspired change to an environmentally friendly energy production and traffic system. These challenges induce the massive need for future research that investigates which policies support these aims by explicitly triggering structural changes and uncovering (additional) innovation capabilities. Fourth, the thesis carries out a variety of empirical analyses. The empirical findings may be a starting point for qualitative studies that explicitly examine the working of particular policies in case studies. Additional qualitative research would help to gain further insights into the working of policies and may identify best practice examples.

7.4 Final remarks

Policy and economic growth evaluation studies contribute to an important and much applied scientific discipline that has the ability to directly influence the incomes and living conditions of human beings. This thesis contributes to this fascinating discipline and aims to improve the understanding of the working of various policy measures in Germany and China. The applied novel methodology in this research discipline, the comprehensive analyses on different policies and the consideration of potential conditioning regional factors hopefully influence the scientific and political discourse and, in the best case, add to future policy designs, evaluation strategies, incomes and living conditions of human beings.

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Erklärung

Ich erkläre an Eides statt, das ich meine Dissertation mit dem Titel

„Effects of public policy measures on regional economic growth: Evidence from German labour market regions and Chinese provinces“

selbstständig und ohne unerlaubte Hilfe angefertigt und mich dabei keinerlei anderen als der von mir genannten Quellen und Hilfen bedient habe.

Die Dissertation wurde in der jetzigen oder einer ähnlichen Form noch bei keiner anderen Hochschule eingereicht und hat bislang noch keinen sonstigen Prüfungszwecken gedient.

Marburg/Lahn, den 4. Juni 2019

Jonathan Nikolai Daniel Eberle