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The causal interaction between innovations, specialization, start-ups, qualifications, and subsidies: a spatial VAR analysis for various industries in Germany

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Abstract

The interaction between innovation, specialization, qualification, start-ups, and public subsidy has been a topic in many papers. This paper extends the existing studies in three ways. First, various two-digit industries are studied separately so that differences among industries can be examined. Second, while all existing approaches in this field use regions as observation unit, the approach taken here uses data on the level of municipalities and aggregates this data according to travel distances. Hence, the approach is less influenced by the so-called modifiable aerial unit problem (MAUP). Third, the VAR-LiNG approach is applied, which has the advantage that causal relationships can be detected and that the direction of the causal effects can be identified. We confirm the claim of a strong importance of industries not only for innovation systems but beyond that for more local relationships between economic aspects. Overall, a quite clear finding is that nearly all relationships that contain patents, either as impulse or response, show positive effects for high-tech or medium-high and high-tech industries and mixed results for the other industries.

JEL Classification C33 · O30 · R15 · R58

1 Introduction

Regional economies and their development remain central topics in policy and science due to persistent regional inequalities and the need for economic transformation in many regions. Studying the relationships between regional-level variables such as industrial specialization, qualification, innovation (patents), firm

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foundations, and government subsidies is essential for understanding the regional dynamics that drive regional economic growth, technological progress, and unequal developments. Quantitative studies of these relationships usually examine data on the whole regional economies. However, industries differ in their characteristics, and hence, the interaction between the various aspects of regional development might also differ between industries. Understanding these differences is crucial for crafting regional policies that focus on specific industries but also for general regional policy, considering that different industries dominate in different regions. A basic step is to examine which regional relationships hold for very different kinds of industries and which relationships are industry-specific. The obtained knowledge will inform policy makers about which interactions can be built on in general and which interactions play a role for specific industries.

Regional economies are in the focus of politics in many countries nowadays, implying a need for detailed understanding of positive impacts of policy measures. Researchers have developed several very elaborated theories, such as regional innovation systems (see Asheim and Isaksen 1997) or the Triple Helix Model (university–industry–government) (see Etzkowitz and Leydesdorff 2000), to describe and understand the complex interactions on the regional level and give answers to the policy questions. But, the empirical literature outside of case studies is somehow lagging behind this development. Most of the statistical approaches focus on the explanation of one regional variable and its development, not taking into account the multiple interaction of the various variables. Furthermore, although it is well known and expressed in the literature (e.g., Malerba 2002, 2005; Malerba and Nelson 2011) that the economic mechanisms differ strongly between industries, very few studies exist that analyze industries separately (Almus and Czarnitzki 2003; Falck et al. 2008; Aschhoff 2009). Furthermore, Mitze and Makkonen (2025) show that R&D subsidies have not only effects with the region into which the subsidies flow but are transmitted further to other regions. These transmission channels differ between industries. If governments intend to support the regional or national economy by supporting R&D activities, it is important to know how much of the effects appear within the region or nation. If this differs between industries, subsidy strategies should be adapted accordingly. E.g., subsidizing research in industries with fast imitation, such as IT and communication electronics, might lead to less regional impacts, while industries with a strong local supplier network, such as automobiles, might lead to more regional impacts. However, this has not been studied in detail to our knowledge.

This paper analyses the local interaction between five variables: industrial specialization, qualification, innovations (patents), firm foundations, and government subsidies. These relationships are important not only for academic research but also for demonstrating the interaction of industries with different conditions and situations within the regional ecosystem. To address the above research gaps, the analysis goes beyond the existing studies by deviating from the standard approach in three ways.

First, we take industry-specific mechanisms into account by studying 10 two-digit industries separately. Analyzing the coevolution of regional variables considering more than one industry is rarely done in the literature so far (e.g., Brenner and

Schlump 2010; Schlump and Brenner 2010; Brenner and Duschl 2015). Analyzing industries separately allows to examine whether the interaction among innovations, regional specialization, qualification, start-ups, and public subsidies are the same for all industries or differs among them.

Second, the approach taken here uses data on the level of municipalities and aggregates this data according to travel distances (as done in Brenner and Pudelko 2019). Hence, the approach is less biased by the so-called modifiable aerial unit problem-MAUP (Openshaw 1984) than the existing studies.

Third, we use a structural vector autoregressive (SVAR) framework. More specifically, the VAR-LiNG approach (developed by Lacerda et al. 2008 and Ciarli et al. 2019) is applied here. VAR approaches have been used in various regional analyses (Brenner and Duschl 2015; Brenner and Pudelko 2019; Eberle et al. 2019, 2020; Wardenburg and Brenner 2020). In comparison to these approaches, the VAR-LiNG approach allows to identify simultaneous, immediate causal relationships between variables in both directions without predetermining the possible effect directions. This means that the coevolution of innovations, qualification, start-ups, public subsidies, and employment growth can be examined in more detail and without predetermining the direction of the effects.

Our main finding is that, indeed, the influences of the studied variables on each other strongly depend on the industry considered. There is no dependence between any pair of variables that is the same for all industries. This shows that industry-specific studies are necessary to obtain a detailed understanding.

2 Background

We examine on a regional and industrial level the impacts of governmental subsidies on industrial specialization, innovation, workers' qualification, and firm foundations and vice versa. While there is a huge theoretical and empirical literature on the effects of subsidies on the regional economy and also a quite rich literature on spatial subsidy allocation, empirical works on the influence of regional factors on subsidies flowing into regions are more limited in their scope. By this, we do not mean the design of subsidy programs that establish conditions for the eligibility of regions. Our view is more dynamic and causal, meaning that we examine whether changes in some regional characteristics cause changes in the amount of subsidies received, probably due to changed abilities in attracting funds. There is some more literature on the firm level that examines such a causal dependence, but little on the level of regions.

Most of the existing literature that studies the differences in subsidies that flow into various regions focus on identifying the characteristics of successful regions. E.g., Piro et al. (2024) find that those Southern European areas that are very successful in obtaining funding (from FP7 to Horizon 2020) mostly submit proposals with a high intensity, that is, requesting a lot of money. Furthermore, they discover that due to their high levels of R&D investments, significant research intensity, and high funding requests regions in the so-called "blue banana" are especially able to get funding in the higher education sector. Uhlbach et al. 2022 show that the effect

of subsidies from the EU Framework Program is greatest if the degree of relatedness with the new technology in the region is neither too high nor too low. Segarra-Blasco et al. (2014) find that the likelihood of receiving a public subsidy is positively impacted by cooperative projects, SMEs, or older businesses.

According to van der Vlist et al. (2004), enterprises located in centers of innovation activity tend to receive more subsidies because these centers facilitate the creation of knowledge and allow for the easiest spillovers between economic agents.

What is missing so far in this literature is a causal analysis that examines whether subsidy flows react to changes in the regional economy, similar to the various existing studies that analysis whether changes in subsidy flows impact on the regional economy. The existing evidence clearly shows that economic active and innovative regions are usually more successful in attracting subsidies. Whether an increase of innovation, specialisation, qualification, or firm founding leads to changes in subsidy flows to the region is analyzed in this paper.

A number of different theoretical and empirical literature strands exist that provide a basis for our analysis. We present those in the following. We start with the theoretical and empirical knowledge about the effects of subsidies on the firm level (Sect. 2.1), because the effects on the firm level should also be visible on the regional level. However, not only firms benefit from the governmental subsidies that we study. Part of this money is also provided to universities, research institutes and other local actors. These actors also influence the performance of regional firms, especially the innovation performance. This is comprehensively discussed in the literature on regional innovation systems, which we shortly present in Sect. 2.2. This literature is also used to transfer the theoretical arguments from the firm level to the regional level. An important aspect of our study is that we examine 10 2-digit industries separately. Therefore, we use the concept of sectoral innovation systems and other literature on sectoral differences to formulate respective expectations (Sect. 2.3). Finally, we present the rare literature on the effects of regional characteristics as well as firm characteristics on receiving governmental funds (Sect. 2.4).

2.1 Effects of subsidies on the firm level

Due to the high policy interest, there are a huge number of studies about the effects of policy measures on all variables included in our analysis. Although the importance of governmental subsidies to increase innovation and economic capacity of firms and regions is accepted by scientists and decision-makers, the issue of what kind and what level of effects public subsidies have is a matter of debate.

The literature distinguishes between three types of additionality effects of governmental subsidies (see Falk 2007; Aerts and Schmidt 2008, Antonioli and Marzucchi (2012), Dimos et al. 2021, Roper and Hewitt-Dundas 2016, Bellucci et al. 2019a): Input additionality (IA), Output additionality (OA), and Behavioral additionality (BA).

2.1.1 Input additionality

Input additionality refers to the situation in which firms increase their R&D activities and related inputs simultaneously with or after public R&D subsidies (Dimos et al. 2021). Input additionality takes a rather short-term perspective: Public subsidies are expected to increase the total innovation activity and resource allocation in firms especially while the subsidies are provided. Many papers confirm that public subsidies for R&D increase innovation activities (e.g., Almus and Czarnitzki 2003, Clausen 2009, Reinkowski et al. 2010a, 2010b, Broekel 2015). Falk (2007) finds that companies frequently increase their funding for innovation projects right away and with each additional scheme they participate in, they contribute more additional resources. Czarnitzki and Licht (2006) show that there is a high level of additionality in public R&D subsidies in terms of innovation input, as well as output. According to them, in contrast to Western Germany during the transition, input additionality has been more prominent in Eastern Germany. Besides the large positive evidence, there is also more ambiguous econometric evidence on the relation between public funding of business R&D and private R&D expenditure (e.g., Quevedo 2004). According to Aristei et al. (2017), public R&D subsidies prevented firms from scaling back their R&D efforts in the years following the global financial crisis of 2007–2008. Méndez-Morales and Muñoz (2019) find that there is a significant crowding-out effect for internal R&D expenditure of SMEs and say that SMEs pay fewer money on internal R&D after being supported. Benavente et al. (2007) discover evidence of partial crowding-out effects between the resources owned by the beneficiary firms and the subsidies provided by FONTEC, indicating that the average firm-level investment in innovation did not rise by the average subsidy's full amount. They also demonstrated that, as opposed to a resource shift to non-R&D-related expenditures, these poor results were more likely caused by a change to the portfolio of R&D projects and an underestimate of the human capital required to carry them out. Freitas et al. (2017) look at how the effects of subsidies vary across industries that have various R&D focuses and levels of competition. According to their findings, companies in high-R&D oriented businesses (and in particular those that are classified as specialized suppliers or science-based) are often more receptive to financial incentives for R&D, especially in terms of utilizing these incentives and expanding their R&D spending. Aerts and Schmidt (2008) find out that in the period of 2002–2004, funded German firms have 76–100% bigger R&D volume than firms that don't receive public support, and funded Flemish firms have 64–91% bigger R&D volume than non-funded firms.

Above it is argued that subsidies increase the number of R&D employees. This should cause an increase in the share of R&D employees among all employees and, hence, to an increase of the average qualification of the employees. This can be expected to happen in the short run. Méndez-Morales and Muñoz (2019) support this view by finding that supported firms typically employ close to ten more people than non-supported firms. They claim that due to the possibility that these workers have high skills, subsidies for innovation lead to high-value employment. However, Afcha and Quevedo (2016) find that although R&D subsidies impact on the number of R&D workers, there is no effect on the average level of qualification of R&D

workers who work in subsidized firms. But, they find positive results in the long term on hiring PhD holders. There is also no other evidence in the literature supporting the expectation of a short-term increased average qualification in subsidized firms.

The literature provides very less theoretical arguments on the effects of subsidies on the start-up activity from an input additionality perspective. Falk (2007) finds that there is no significant input-additionality effect of public subsidies on newly established (within the last 5 years) companies, while these companies rather conduct bigger and long-term projects to extend their scale.

2.1.2 Output additionality

The effects of R&D subsidies on outputs, primarily product innovations, are denoted as output additionality (Dimos et al. 2021). According to Falk (2007), regarding the rise in innovation outputs (such as patents, products, etc.) or innovation outcomes (such as sales from new or updated goods, etc.) resulting from public support for R&D, output additionality adopts a results-based perspective.

Output additionality implies that companies receiving public subsidies are expected to produce more innovations in the short term. Whether this also holds in the long term is less clear. Many empirical studies confirm the short-term effect. E.g., Czarnitzki and Hussinger (2004) that publicly encouraged R&D results in additional patenting activity in German firms (for each unit payment of R&D funding is 0,24-for all firms and 0,63-for SMEs). Hewitt-Dundas and Roper (2010) find positive results for innovation that is supported by the government and significant results for new product additionality impacts. Savitskaya et al. (2010) discover that governmental supports have a positive and significant additionality impact on companies' R&D output when examining the barriers to open innovation in China. Radicic et al. (2014) find that innovation reinforcement programs positively affect SME innovation in traditional manufacturing industries of seven EU countries. Czarnitzki and Hussinger (2018) find that patents as R&D outcomes are positively impacted by both wholly privately supported R&D and publicly induced R&D. Dimos et al. (2021) find significant and positive effects of R&D subsidies on R&D outputs with a three-year lag after receipt of R&D subsidies. However, there are also some opposite findings. Lewandowska et al. (2022) use a sample of 14 EU members (98,809 firms) to examine the effects of public financial support from the EU budget. Their findings suggest that straightforward governmental tools, like grants or subsidies, may not be entirely effective, at least not in short-term, in promoting innovation output. According to Prencipe et al. (2023), the impacts of the output additionality of innovation funding support are more pronounced for large firms and less pronounced for medium firms. According to their results, very large enterprises, which do not benefit in terms of output additionality, however, see a weak impact.

Higher R&D inputs can be expected to cause also higher R&D outputs, such as innovations. This can be expected to happen with a short delay, hence in the short and medium run. Many papers confirm this assumption (e.g., Brenner and Pudielko 2019; Broekel 2015; Broekel and Schlump 2009; Afcha and Quevedo 2016; Söderblom et al. 2015). E.g., Czarnitzki and Licht (2006) show

that subsidies lead to increases in R&D inputs and outputs. Bronzini and Piselli (2016) find that the effect of subsidies on the number of patent applications depends on the size of the firm and is higher for smaller firms. If subsidies cause higher R&D activities in firms, this implies the need of more R&D employees, on average. Therefore, we can expect that the number of employees, especially R&D employees, should increase due to the subsidies. This is confirmed by Afcha and Quevedo (2016), who find that R&D subsidies cause increases in the number of R&D employees in Spain. Their results also show that there is no effect of governmental R&D supports on non-R&D employment in the short run, but this effect can be seen in the long run. Fornaro et al. (2020) found that an increase in the subsidy amount of 1% led to an increase in the number of R&D employees of around 1.4%. Furthermore, according to their research, public R&D financing tends to contribute to the development of R&D jobs for up to six years after funding starts. Of course, we might expect that the higher innovation activity resulting from the higher R&D activities should finally also lead to a growth of the firms, also in terms of employment. However, this should hold independent of the type of additionality. According to Söderblom et al. (2015), the number of employees increased for the entire seven years after the subsidy was received. Butler et al. (2016) find that the effect of the BAE (Buenos Aires Empreende) program on employment is significant, and firms create about three additional jobs by participating in projects within the scope of the program. There is also some counter-evidence. E.g., Dugiel et al. (2022) find that the regional public support for firms that operate in the Special Economic Zones of Poland has no influence on the number of employees in the period 2007–2017.

The perspective of output additionality does not imply an immediate increase in employment. However, as stated above, due to an increase in innovation output, employment can be expected to increase in the long run. Gabe and Kraybill (2002) examine the difference between actual (two years after expansion) and declared (target) employment growth. Their findings suggest that while public support has a high impact on the target employment growth of firms, it has very small and sometimes even negative effects on the actual employment growth of firms in Ohio, USA.

Output additionality implies that newly founded firms that receive subsidies are more successful due to increased outputs. Indeed, Söderblom et al. (2015), arguing with output additionality, find that new businesses that receive financial and human resources via subsidies are more likely to succeed than their non-subsidized counterparts because their affiliation with prestigious government institutions supports their legitimacy. According to Howell (2017), when a start-up receives subsidies at early stage, it approximately doubles the likelihood of that firm receiving venture capital later on. Further findings from this study show that while early-stage public support produces large positive effects on patenting and revenue, these effects are stronger for more financially constrained firms. Of course, this does not imply that firm foundations become more frequent due to subsidies. However, a higher success rate of firm foundations might well encourage potential founders to found a firm in the medium run.

Subsidies provide companies with additional financial means. Companies might use these financial means to increase the qualification of their employees which

would be another additional output of the subsidies. Busom and Vélez-Ospina (2021) find that obtaining support helped enterprises to protect and increase their investment in R&D human capital relative to non-participants. However, this is the only evidence that we found in this direction.

2.1.3 Behavioral additionality

Behavioral additionality refers to induced changes in the firms' innovation behaviors, such as making them more collaborative or encouraging partnerships with further types of partners (Broekel et al. 2017; Wanzenböck et al. 2013). Often this also leads to permanent changes in firm behavior after the subsidies (Georgiou 1997; OECD 2006), which leads to further impacts of the subsidies. The flexibility of firm structures and habits has a significant impact on determining the duration and severity of the behavioral impact (Dimos et al. 2021).

Compared to the other types of additionality, behavioral additionality has a specific focus on the long-term effects of subsidies, implying that innovation activity increases especially in the long run due to changes in the underlying activities. There are quite some findings in the literature that are consistent with these expectations. Roper and Hewitt-Dundas (2016) claim that, through a quality ladder effect, R&D support in particular may be anticipated to contribute over time to the quality of a firm's product range and, consequently, to the long-term success of enterprises' innovation and exporting. Dimos et al. (2021) conclude from their empirical analysis that subsidies impact on innovation behavior. Furthermore, they state that the behavioral additionality effect increases with the temporal gap between receiving R&D subsidies and engaging in innovation. Heijs et al. (2022) find that firms which participate in more than one program exhibit more additionality, albeit this impact is less pronounced for firms that receive extremely high quantities of support. They also find that the degree of additionality is related positively to firm innovativeness and negatively to dimensions that indicate a more market-oriented R&D.

Behavioral additionality also implies various long-term changes in other aspects. The findings by Roper and Hewitt-Dundas (2016) are consistent with this expectation: While R&D subsidies only have legacy effects that are mitigated by earlier innovation, subsidies for new product development result in a legacy of broadly-based capabilities development. Their findings demonstrate that new product development subsidies appear to have mostly behavioral legacy effects, with subsidies producing longer-term advantages through improvements in the innovation benefits of plants' human capital and network ties. Orlic et al. (2019) find significant results of behavioral additionality in SMEs in six Western Balkan Countries. They discover that public support does not encourage collaboration with clients and suppliers, only weakly encourages cooperation with rivals and universities, and highly encourages cooperation with government agencies and consultants from the private sector. These findings confirm the effects on networking and employment qualification in the long run.

According to the general statement above, employment should increase in the long-run due to all the effects mentioned above, especially due to the increased innovation output.

Especially in the context of firm foundations, behavioral additionality should be a strong driver. Successful firm foundations with public subsidies can be expected to trigger further firm founding in the region. In addition, increasing innovativeness in firms receiving R&D subsidies can trigger employee spin-offs. Hence, medium- and long-term significant positive effects can be expected.

2.1.4 The role of the industrial differences on additionality

Since one of the important objectives of this study is to analyze the situation of different industries, it is necessary to discuss the classification of industries here. The existing literature indicates that there are a few approaches to classifying industries.

More ambitious and refined concepts that went beyond the high versus low technology divide in terms of technological regimes had developed in the early 1980s (Peneder 2003). One of the most significant early study in this field was Pavitt's (1984) taxonomy. He creates four groups of industry: 1) Supplier-dominated: Traditional manufacturing (e.g., textiles, agriculture) relying on external innovation sources. 2) Scale-intensive: Large-scale producers (e.g., automotive) with both internal and external innovation efforts. 3) Specialized suppliers: Smaller firms producing specialized machinery or high-tech instruments with tacit knowledge. 4) Science-based: High-tech sectors (e.g., pharmaceuticals, electronics), heavily relying on in-house R&D and university science, with strong appropriability regimes. This classification is also helpful for our analysis and used in the following deduction of expectations. According to the findings presented above, larger firms show more output additionality, which means that output additionality should be higher in scale-intensive industries.

Some studies in the literature have explored the possibility that subsidies may result in different levels of input, output, and behavioral additionality across firms in various sectors (e.g., Callejón and García-Quevedo 2005; Fier et al. 2006; Hsu et al. 2009; Wanzenböck et al. 2013; Freitas et al. 2017). These works find differences between industries. According to Callejón and García-Quevedo (2005), medium-high and medium-low sectors are more likely than high-tech sectors to experience input additionality. Fier et al. (2006) find that belonging to the service sector does not positively affect behavioral additionality, particularly in the context of the probability of continuation of any type of cooperation in Germany.

Hsu et al. (2009) find behavioral additionality, especially in commercialization, to be more important in the chemical and material industry than in the biotechnology and pharmacy industry of Taiwan. Output additionality, particularly patent performance, is stronger in the machinery and equipment industry than in the biotechnology and pharmacy industry.

Wanzenböck et al. (2013) find a significant higher collaboration additionality for the service sector, while they do not discover statistically significant sector-specific effects for the scale additionalities. They explain this by saying that companies in the industry sector have more expertise with R&D collaboration than companies in the service sector. As a result, they have a higher chance of forming new partnerships to carry out R&D for projects with public funding.

Firms in R&D-oriented industries are more likely to apply for R&D fiscal incentive schemes and have higher input and output additionality effects, according to Freitas et al. (2017). They find that input additionality tends to be higher in sectors that emphasize R&D, particularly among science-oriented and specialized suppliers, and stronger in sectors with higher concentration. In contrast, the highest estimated output additionality occurs in scale-intensive industries and low-concentration sectors in Norway. In Italy, the most pronounced output additionality is seen in specialized suppliers and low-concentration industries, while in France, it is notably stronger for specialized suppliers and supplier-dominated industries.

A study conducted by the Centre for European Economic Research (ZEW) covering 12 different manufacturing industries shows that companies in East Germany increase their innovation activities by around four percentage points when they receive public R&D support (Almus and Czarnitzki 2003). In another research, ZEW-Zentrum für Europäische Wirtschaftsforschung finds that Direct R&D Project Funding (DPF) had a positive impact on R&D initiatives (input) and new products and services launched on the market (output) in manufacturing and knowledge-intensive service sectors companies receiving such funding (Aschhoff 2009). The Bavarian-wide cluster program (Cluster Initiative, established in 1999) raised the probability of innovation by a firm in the targeted of manufacturing industry by 4–7 percentage points, according to Falck et al. (2008).

Summing up, the results on the relationship between industries and the different kinds of additionality are rather inconclusive. There seems to be rather evidence for a higher output additionality in high-tech industries. Input additionality seems to be stronger in the Pavitt-categories of specialized suppliers and science-based industries. There is no clear picture for behavioral additionality.

2.1.5 Deducing expectations

For the temporal structure of the different kinds of additionality we found one paper that provides results: Dimos et al. (2024) found that input additionality tends to occur in the year following the receipt of the subsidy, while behavioral additionality takes three years after the receipt of the subsidy to occur. They found no evidence of output additionality. We follow these findings and assume that all effects of input additionality are strongest in short term, while all effects of behavioral additionality are strongest in medium and long term. In the case of output additionality, the literature presented above argues that effects of innovations are rather short term and that the effects on employment and firm foundations are consequences of these, which follow in the medium and long term.

Putting the arguments above together results in the expectations presented in Table 1.

Table 1 Expected effects of subsidies according to the different types of additionality

Local factor	Input additionality	Output additionality	Behavioral additionality
Employment	Stronger in the short run and in specialized industries and science-based industries	Stronger in the medium and long run and in high-tech and scale-intensive industries	Stronger in the medium, but mainly long run
Qualification	Stronger in the short run and in specialized industries and science-based industries	Stronger in the medium and long run and in high-tech and scale-intensive industries	Stronger in the medium, but mainly long run
Innovation	Stronger in the short run and in specialized industries and science-based industries	Stronger in the medium and long run and in high-tech and scale-intensive industries	Stronger in the medium, but mainly long run
Firm foundation	Not expected	Stronger in the medium and long run and in high-tech and scale-intensive industries	Stronger in the medium, but mainly long run

2.2 Regional innovation systems

As connected to the previous section, regional innovation systems provide the link between firm-level and regional-level dynamics. While individual firms may benefit directly from subsidies, the cumulative effect of many firms innovating in the same region can shape the overall innovation climate. R&D subsidies at the firm level are often part of a broader set of regional innovation policies that aim to create synergies among firms, universities, research centers, and public institutions. The effects of R&D subsidies emerge not only in individual firms, but also influences how innovations, knowledge, and expertise spill over and create positive externalities. Hence, the theory of regional innovation system (RIS) provides an important basis for our study on the regional level.

The term “regional innovation system” designates a geographic area where businesses, universities, technology transfer offices, and other institutions collaborate to create and apply knowledge for innovation (OECD 2013). The impact of the regional innovation system is determined by the power of economic, institutional/organizational and social links, learning processes, knowledge diffusion and commercialization in interrelated fields (Fritsch et al. 2019). According to Kindt et al. (2022) and Agrawal et al. (2014), whether there is a university in the region and the firm composition (number and distribution of large, medium and small-sized firms) also play a major role in the effectiveness of the regional innovation system.

The most important aim of a regional innovation system is to improve the innovation capability, effectiveness, intensity and quality of the region through innovation policy and support. To achieve this aim, many national and regional authorities, institutions, and decision makers use different policy tools and support mechanisms for different regional development levels, sectors, and firm sizes in their regional innovation systems. SMEs supported in regional innovation systems are more successful innovators (Tödtling and Kaufmann 2002) and have access to financial resources and long-term loans with low interest rates more easily and in a shorter time (Bellucci et al. 2019b). Besides, direct or indirect funding methods are very important in terms of effects. For example, while direct public financing positively affects innovation efficiency, pre-tax extra deduction negatively affects firm investment in innovation in RISs of China (Liu and Bai 2021). Findings for Czechia show that direct R&D support in the advanced regional innovation system has been found to be negatively linked with company competitiveness (Květoň and Horák 2018). Government R&D funding has positive effects on innovation quality in RSIs of China (Li and Wu 2021). And intermediary agencies (e.g., regional innovation agencies) play a major role in increasing the effect of innovation supports in the RSIs of Italy (Fiore et al. (2011)).

The connection of regional innovation systems with qualification is very central. Accessing and employing qualified employees is an important factor that increases the innovation capacity of companies. According to Sternberg (2007), two of the benefits of integration into a RIS for new knowledge-based firms are high-qualified staff recruitment and access to individuals (such as star scientists) at universities or R&D institutions. In addition, the number and qualification of local R&D employees are important for big firms that benefit from RISs (Agrawal et al. 2014) and a lack of

skill development within an RIS might hinder necessary developments, such as the transition to Industry 4.0 (Sandulli et al. 2021).

Universities and scientific knowledge play an important role in improving the innovative skills of firms and the potential of RISs. Because these institutions are powerful sources of knowledge and technology for many companies (especially for SMEs and start-ups). Researchers find significant and positive evidence that cooperation and collaboration between firms (mostly SMEs and start-ups) and academic institutions increase the chance of R&D achievements and the commercialization of scientific breakthroughs in RISs (e.g., Lee and Park 2006; Lenger 2008; Kindt et al. 2022; Li and Qi 2023).

Studies examining the effects of public subsidies and structural funds on regional employment have detected significant positive effects (e.g., Bilbao-Osorio and Rodríguez-Pose 2004; Koski and Pajarinen 2013; Caliendo and Künn 2014; Cantner and Kösters 2009; Puigcerver-Peñalver 2007; Eberle et al. 2019, 2020). In contrast, Dettmann et al. (2016) discover that subsidies have positive impacts on regional gross value-added and productivity growth, but did not find any impacts on employment growth and gross wage growth.

Kostić and Květoň (2022) investigate how effective innovation supports and firm age are in a regional innovation system in Central Europe. They explore that there is a significant increase in the turnover, added value and number of employees of the start-ups that receive public support in the regional innovation system. They find that, the supported start-ups experienced the fastest growth, aside from the first dynamic growth process, during the second and third year after entering the program.

While all these empirical studies examine the direct, maybe delayed effects of subsidies on one aspect of the innovation system, the idea of innovation systems goes beyond that. The main element of innovation systems is their interactive character. This implies that effects of subsidies on one aspect of a regional innovation system might well trigger further effects on other aspects due to the improvement of the regional innovation system. Such indirect effects might appear with quite some delay, extending the delays usually considered in the empirical studies. For example, the output additionalities effects of a subsidy might be visible in a higher innovativeness, which might in turn attract more firms to the region or might lead to an increase in the founding activity. These effects will appear with a delay. The approach we use is especially designed to capture also such indirect effects (see method section).

2.3 Characteristics influencing the receipt of funds

Factors affecting the receipt of public funds can be examined at the firm or the regional level. Although there are many studies at the company level in the literature, there are fewer studies at the regional level. What is especially missing so far in this literature is a causal analysis that examines whether subsidy flows react to changes in the regional economy, similar to the various existing studies that analysis whether changes in subsidy flows impact on the regional economy. The existing

evidence clearly shows that economic active and innovative regions are usually more successful in attracting subsidies. Whether an increase of innovation, specialisation, qualification, or firm founding leads to changes in subsidy flows to the region is analyzed in this paper.

The effects of employment growth on other local economic variables are rarely studied in the literature. The scientific interest so far focuses on the opposite direction of causation. Hence, we can build only on very scattered evidence on this issue and our results will mainly enter new scientific ground. Higher employment numbers imply more economic activity and, therefore, also a higher potential to apply for subsidies. However, if only production capacities are increased, a higher likelihood to apply for subsidies, which are mainly research-oriented, is not an automatic consequence. Empirical studies show that being located in a cluster makes it possible to receive more public subsidies for firms (Devereux et al. 2007, Broekel et al. 2015, Crass et al. 2019). In places where there are fewer facilities currently operating in their industry, businesses respond less favorably to government subsidies (Devereux et al. 2007). Crass et al. (2019), who distinguished three types of clusters, found that SMEs in a knowledge cluster have a far higher chance of obtaining public support (Crass et al. 2019). Similar findings are reported by Broekel et al. (2015), who attribute a higher likelihood of biotechnology firms located in technological clusters to getting subsidies from international programs compared to enterprises not in such clusters. The few empirical studies on the regional level confirm the impact of regional specialization on subsidy flows. Mewes and Broekel (2020) focus on project-based R&D subsidization of the federal government and technological diversification across German regions. Their empirical results show that the allocation of R&D subsidies tends to be positively biased toward related activities in regions. By focusing on 255 NUTS-2 regions and by using data on joint research projects funded by the fifth European Framework Programme (FP), Scherngell and Barber (2011) find that spatial factors have significant impacts on patterns of industrial R&D collaboration, while these impacts are much smaller in the public research sector. In the context of spatial factors, while neighboring regions and countries have positive impacts, geographical distance between regions has negative impacts. Besides, their results indicate that the most important factor for both industry and public research cooperative activities is technological distance. Focusing on Spanish companies, Forés (2025) examines whether the criteria for allocating public funding vary by industrial sector, distinguishing between clean and dirty industries based on their levels of pollution. This study shows that companies with proactive eco-innovation strategies receive greater levels of public funding, based on data from the Spanish Technological Innovation Panel (PITEC) between 2009 and 2016. It can be concluded that regions that specialize in clean or eco-innovative firms are more likely to receive additional public funding.

Bouvet and Dall'erba (2010) investigate which economic and political variables determine the allocation of EU Structural Funds. Their results show that economic criteria are not the sole determinants of fund allocation; besides, the political situation within a country and region, as well as the relationships among various levels of governance, influence the allocation process.

Lewandowska et al. (2022) claim that the success of Spanish companies in delivering multidimensional additionality from public support may be due to differences in company characteristics between European countries because the Spanish companies have more experience than companies from Central and Eastern Europe in applying for and utilizing R&D support from the EU to support their innovation operation. One incentive, although not the most important one, for patenting innovations is the increase of a company's reputation (e.g., Blind et al. 2006). As a side effect, increased reputation is likely to improve the chances of a company to receive governmental subsidies.

Cantner and Kösters (2012) point out that being an academic spin-off and showing high degree of innovativeness enhances the probability of getting R&D subsidies. In addition, Galope (2014) finds that three types of start-ups have an advantage in getting public subsidies: start-ups with an owner who has a post-graduate education, start-ups with an owner who has prior R&D experience and a patent record, and start-ups in high-tech industries. Hence, we can expect some positive effects of firm foundations on subsidies, especially in high-tech industries. Besides this latter result, which shows some relevance of qualification in start-ups for receiving subsidies, we did not find further studies on the impact of qualification in firms on subsidy success.

It is clear that developed and effective regional innovation systems and public subsidies in these systems provide strong support to firms to create a stronger additionality (input, output, and behavioral) effect. According to the innovation system argument, improving the innovation system in one aspect has consequences also for other parts due to the interactive character. Hence, beyond the findings on subsidy flows in the literature, improvement of a regional innovation system might, in general, lead to indirect increases in the ability of firms to attract subsidies.

However, transferring the above finding to our analysis is difficult. Most of this research takes a more cross-sectional approach, identifying firms or regions that are more likely to receive subsidies. The studies do not examine how the amount of subsidies flowing into a regions changes due to a change in other characteristics. However, the above literature is to only existing empirical basis that can be used to deduce expectation. The few information on industry-dependence are used summarize in Table 2 the findings obtained from the literature. No expectations about the temporal structure of the effects can be deduced from the literature.

Table 2 Expected effects of local factors on receiving subsidies

Local factor	Predicted effect on subsidies	Industry differences
Employment	+	Should be stronger in high-tech industries and industries clustering (probably scale-intensive and science-based industries)
Qualification	?	Unclear
Innovation	+	Due to reputation effects it should be stronger in high-tech industries
Firm foundation	+	Innovative start-ups should matter more so that high-tech industries should be more affected

We expect local factors such as employment, innovation, and firm foundation to have positive effects on receiving subsidies, while the predicted effects of qualifications on receiving subsidies are not clear.

The expectations (Table 2) and hypotheses we have created within the scope of the literature on additionality, regional innovation systems and sectoral innovation systems that we have discussed in the previous sections will be tested in the next sections.

3 Methodological approach

3.1 Data sources

Since our analysis is conducted on the level of municipalities, all data are required to be available on this level. The respective data availability allows us to study the development of five variables—location quotient, qualification, patents, firm foundations and government subsidies—for the years 1999 until 2011 and 26 2-digit industries (all industries that appear in the patent data, listed in Table 7 in the appendix).

We use the location quotient (LQ) for each industry relative to population instead of working population, meaning that the location quotient is calculated as

$$LQ_{i,r} = \frac{\frac{e_{i,r}}{e_i}}{\frac{p_r}{P}}$$

where $e_{i,r}$ denotes the number of employees in industry i and region r , e_i represents the number of employees in industry i in whole Germany, p_r is the population in region r and P denotes the whole German population. We use the population-related location quotient because it also increases for a region if employment increases in all industries in this region while employment stays constant in other regions. The intention is to use a variable that represents employment in relation to the size of the region (population) while correcting for the employment development in the industry in Germany. The data on employment originates from the Institute for Employment Research (IAB, Institut für Arbeits—und Berufsforschung), while population data are obtained from the German Statistical Office (Statistisches Bundesamt).

Qualification is calculated for each industry and region by dividing the number of employees with university degree by the total number of employees in this industry and region. The respective data are obtained from the Institute for Employment Research (IAB).

The used patent data are distilled from the PATSTAT database of the European Patent Office. Patents are assigned to municipalities, using fractional counting, by the inventors' addresses (if the addresses contain postal code and city name). For our approach, it would be better to use the locations at which the innovation takes place, meaning the respective company sites. However, this is not available because many firms apply for patents from their central unit. In our approach, we

build for each municipality a patent count by including all surrounding places weighted according to their travel distance. The spatial weights are inspired by commuting behavior. Assuming that inventors live in usual travel distance from their working place, our approach matches all possible living places to a potential working place. Hence, our approach corrects for the inventor-applicant problem of patent data better than all usually used regions. The PATSTAT database contains for each patent an industry classification. This classification is directly used to assign patents to industries. In many cases, several industries are assigned to a patent. Fractional counting is also used in these cases.

The number of firm foundations (start-up) has been calculated using the Orbis databases (provided by Bureau van Dijk) 2003, 2006, 2009, 2013, and 2016. All small (to exclude the foundations of subsidiary companies) firms occurring for the first time in these databases are assumed to be foundations at their location and founding year declared in the database.

Subsidies are obtained from the so-called ‘Förderkatalog’ (“funding catalogue”). In this database, the German Federal Ministries (mainly the Ministry for Education and Research) provide comprehensive data on their subsidies, including addresses of the executing actors and a classification of the activities. We restricted the used data to those subsidies provided from the German Ministry for Education and Research, so that we consider only subsidies intended to enhance research or education activities. The largest part of the subsidies are R&D subsidies. Nevertheless, our data also contain some other subsidies, so that we use “subsidies” to refer to them in the following, although R&D subsidies dominate. Unfortunately, the classification of the subsidies does not match any standard industry classification. As a consequence, it is not possible to assign the subsidy classes to industries, in general. Some literature uses a concordance that was developed by the Halle Institute of Economic Research on the basis of a matching of firms in the subsidies and patent databases (Mewes and Broekel 2020). However, such an approach does not take into account subsidies provided to public science or education institutions that do not patent. Such subsidies might be important for the regional development, especially in the long run. Hence, we use a much simpler approach. We looked into the denotation and the set of subclasses of each category in the classification system (LPS) of the German Ministry of Education and Research and identified those classes that match, at least somewhat, the usual definition of industries (2-digit level). By this, we identified 10 2-digit industries with related subsidy classes. We are aware that by this rather rough assignment the relationship between the subsidies and the regional development might well be underestimated. Subsidies that fall into a LPS class are very heterogeneous (Brökel 2025). This implies that subsidies in one LPS class have effects on many different industries and cannot be assigned to one industry only. Our approach assumes that, despite this heterogeneity, the industry assigned to a LPS class benefits more from the subsidies in this class than an average industry. This would be sufficient to expect a relationship between the matched subsidy and industry classes (see Table 3). Nevertheless, this is a clear limitation of our empirical approach, which is further discussed in Sect. 3.4.

The list of industries contains very different industries belonging to the manufacturing and service sector and being low-, medium- and high-tech as well as

Table 3 List of industries and used classes from the subsidies database

Industries (NACE Rev. 2)	Subsidies classes	Type of industry (European Commission and Pavitt classification*)
10: Manufacture of food products	DA: food	Low-tech manufacturing, supplier-dominated
12: Manufacture of tobacco products	DA: food	Low-tech manufacturing, supplier-dominated
21: Manufacture of basic pharmaceutical products and preparation	AA: health research and health economy	High-tech manufacturing, science-based
23: Manufacture of other non-metallic mineral products	KB: materials engineering	Medium–low-tech manufacturing, scale-intensive
26: Manufacture of computer, electronic and optical products	GC: electronics, GD: microsystem technology, and L: optical technologies	High-tech manufacturing, science-based
29: Manufacture of motor vehicles, trailers and semi-trailers	HA: vehicle and traffic technologies	Medium–high-tech manufacturing, scale-intensive
30: Manufacture of other transport equipment	HB: maritime technologies, IA: aviation, and IB: aeronautic technologies	Medium–high-tech manufacturing, specialized suppliers
42: Civil engineering	NB: construction research	Other services, scale-intensive
43: Specialized construction activities	NB: construction research	Other services, scale-intensive
62: Computer programming, consultancy and related activities	GA: software systems	High-tech knowledge-intensive services, science-based

According to Pianta et al. 2021

belonging to the different types of industries according to the Pavitt classification (Pavitt 1984). Hence, it is adequate to examine whether such industry characteristics matter for the relationships.

3.2 Spatial approach

Hence, data on five variables, namely innovation, qualification, start-up, public subsidy, and clustering, are available for each industry and each municipality. In order to detect causal dependencies among these five variables, we use a VAR-LiNG approach (Lacerda et al. 2008; Moneta et al. 2013; Ciarli et al. 2019). This approach requires a clear definition of observations. If municipalities would be used as observational units, the situation in small villages would influence the results in the same way as the processes in big cities. The same issue occurs if administrative districts are used, which usually differ strongly in their inhabitant numbers. This implies that activity in rural areas matter more for the statistical results than activities in big cities (see Celebioglu and Brenner 2024, for a discussion on this problem). Furthermore, spatial interaction is important and should be reflected in the approach.

Therefore, for all variables and all municipalities, spatially weighted values are calculated. This means that the value of each variable for each municipality is not simply taken from the data but is calculated by including all activities in other municipalities according to a distance decay function. A log-logistic decay function is used and distance is measured by traveling time with car. The decay function reflects well the empirical findings on commuting behavior. Applying this approach leads to a value for each variable and each municipality that reflects all activities in the surrounding of the municipality (see Scholl and Brenner 2016, Scholl et al. 2016 and Brenner and Pudelko 2019). As mentioned above, this approach takes care of inventor–applicant problem in patent data. It also leads to better approximation of industry specialization, because it considers the surrounding of a location that is relevant for interaction. Assuming that interaction is stronger within a range in which people commute, this also fits to the theory of regional innovation systems that states a high relevance of interaction. Indeed, this approach seems to better represent the idea of a regional innovation system than an approach that is based on administrative districts that do not reflect the likelihood of interaction between actors. Hence, what we measure for each municipality is the activity in the relevant surroundings of this municipality. Hence, our unit of observation is not a municipality but the surroundings of a municipality. By this, we still analyze the activities within a certain kind of spatial units. However, the borders are fuzzy because each place is weighted according to its distance with weights that decrease from nearly 1 to nearly 0 for traveling time between 30 and 60 min. Furthermore, the spatial ranges of the observation units are determined by traveling times and, hence, by functionally meaningful considerations. This decreases the MAUP problem strongly compared to the usual approach.

This implies two problems that have to be dealt with. First, using municipality surroundings as observation unit implies that each municipality is part of many

observation unit. Second, we still have to above declared problem that the municipalities are very different in size. Both problems have a common solution: We do not use all existing municipalities. An algorithm is used that calculates the optimal set of municipalities such that the sum of weights for each municipality matches most adequately the population in these municipalities. This implies that the total influence of a municipality on the statistical estimation matches as good as possible its inhabitant number. This is similar to a regression approach with weighted observation units, which is not possible in the case of a VAR approach. In total, 1165 municipalities result from the algorithm. Big cities and their surrounding municipalities are more frequent in this set than smaller villages in rural areas. By this, the spatial population distribution in Germany is adequately represented.

3.3 Statistical approach

We use a Vector Autoregressive—VAR (based on Sims 1972) model that is a tool to examine the dynamic relationships between variables. As a structural equation model, all variables in VAR model are modeled dependent on themselves and all other included variables at the current time as well as on all variable's values at preceding points in time (e. g. the prior year or more years in the past). We tested up to 8-year time dependencies based on Akaike Information Criterion and found that a 1-year lag model is most suitable for our analysis. Our structural equation model can be written as follows:

$$\log(Y_{i,t}) = A.\log(Y_{i,t}) + B.\log(Y_{i,t-1}) + \varepsilon$$

where $Y_{i,t}$ is the vector of the n (5) included variables for municipality i in year t . A is a nxn -matrix that represents the instantaneous effects of the variables on each other. B is a nxn -matrix representing the delayed effects of the variables on each other. ε denotes the various error terms. In addition to a standard error term, we include a spatial error term to control for spatial autocorrelation and individual fixed effects. Tests for multicollinearity (VIF test) and spatial autocorrelation (Moran's I) show no problems.

VAR model provides two important contributions in terms of our analysis. First, VAR results explains mutual dependencies among our variables, including the direction of the relationships. Second, the VAR approach includes potential endogeneity within the considered variables. Endogenous relations and processes affect regional developments, and the VAR model explicitly contains the mechanisms of endogeneity in the model and helps to reduce endogeneity issues.

In the VAR approach, we use a panel regression with time as well as individual fixed effects. Thus, many local characteristics such as border location of a municipality, specific infrastructure, historical singularities or other specific geographic conditions are considered (Brenner and Pudelko 2019).

In many papers, researchers use VAR-LiNGAM approach (see Shimizu et al. 2006; Hyvärinen et al. 2010; Moneta et al. 2013 for more details) to define the direction of the lagged effects between variables. In contrast, we follow Lacerda et al. (2008) and Ciarli et al. (2019) and use the VAR-LiNG model. While the LiNGAM approach requires an acyclicity structure of immediate effects, the LiNG approach allows for concurrent causal feedback loops between variables even if within a year. For the identification of A and B in Eq. (1) from the panel estimations we follow the approach taken and described by Lacerda et al. (2008), Moneta et al. (2013) and Ciarli et al. (2019).

The results are examined on the basis of impulse response functions (IRFs). IRFs are calculated by assuming a fictive change in one variable at time t_0 and using the estimated equation to calculate the dynamics of all variables in the following years (Swanson and Granger 1997; Brenner et al. 2018). Hence, IRFs allow to examine the reactions of variables to changes in other variables including indirect (transmitted via other variables) and delayed effects. It is instrumental to answer our research question because of the potentially complex time structure of the effects that we study.

The IRFs are calculated and analyzed as follows: For each IRF, the value of one variable is increased by one standard deviation compared to the normal development at time $t=t_0$. For all following times t ($t=t_0+0, t_0+1, \dots, t_0+20$) it is calculated how the values of all other variables changes in response to the one-time change in the chosen variable. IRFs are calculated for each pair of variables representing the reaction over time of one variable to a one-time change in the other variable's value. In this way, the response of each variable to the change of each other variable (including both direct and indirect effects) is calculated (Brenner et al. 2018 and see also Swanson and Granger 1997, Kilian and Lütkepohl 2017).

To detect the significance of these IRFs, the VAR LiNG analysis is repeated 1.000 times, each time using 1165 randomly chosen municipalities. According to the 2.5 and 97.5% quantiles, the confidence intervals are figured out. The timing of significant positive and negative reactions is used to classify the effects for each pair of variables as described below.

3.4 Empirical limitations

Our empirical approach has several shortcomings. First, while our spatial approach is less impacted by administrative spatial boundaries than the usual approaches in literature, it is far from perfect. We still use municipalities as a spatial unit, implying that all activities within a municipality are considered as happening at the same place. Especially for large cities, this is a strong assumption. However, compared to approaches that use administrative districts, it is less problematic, and we also avoid putting the same statistical power to all districts independent of their size. Second, due to the large number of locations

and the panel approach (13,980 observations in total) our approach is quite sensitive. This implies that specific developments in an industry in a few places might cause significant results. We are aware of the shortcoming that we should expect some falsely significant results given the large number of relationships studied and the high number of observations. Third, the operationalizations of our variables are driven by data availability. Innovation activity is measured by patents, qualification by employees with a university degree and firm foundation by the firms and dates provided by the Orbis database, which is known to contain missing firms and mistakes. Fourth, and most severe, we measure government subsidies based on the 'Förderkatalog' database. This database contains only a certain part of governmental subsidies and is structured into classes according to policy consideration. Hence, especially the matching with industry classes is problematic. Our use of these classes assumes that the matched subsidies influence the respective industry development, at least, to some extent and more than other industries. We are aware of two consequences: 1) We clearly underestimate the effects because only part of the matched subsidy class really impacts on the respective industry. This part might well be such small that no significant effects are measured. While insignificant statistical results do not imply non-existing relationships in general, we have to expect even more insignificant results in our approach due to the unprecise matching. 2) The part that impacts the matched industry varies strongly between the industries. Hence, in some industries effects are well measured while in other industries effects are measured only partly or in a biased way. Consequently, we do not base our interpretation on the results for single industries but focus on the overall picture that results.

4 Results

Finally, there are eight estimated impulse response functions (IRFs) for each of the ten industries, meaning 80 IRFs all together. Instead of presenting them, we classified the IRFs into the following seven categories:

- *No significant impact*: if the confidence interval always contains zero.
- *Short-term positive impact*: if the impact is significantly positive shortly after the impulse but becomes insignificant no later than 6 years after the impulse.
- *Long-term positive impact*: if the impact is significantly positive shortly after the impulse and stays significantly positive at least up to 6 years after the impulse.
- *Negative, turning positive*: if the impact is significantly negative shortly after the impulse but becomes significantly positive after a few years.
- *Short-term negative impact*: if the impact is significantly negative shortly after the impulse but becomes insignificant no later than 6 years after the impulse

- *Long-term negative impact*: if the impact is significantly negative shortly after the impulse and stays significantly negative at least up to 6 years after the impulse.
- *Positive, turning negative*: if the impact is significantly positive shortly after the impulse but becomes significantly negative after a few years.

As mentioned above (Sect. 3.4), the high number of observations and the quite rough matching of subsidy classes to industries imply that the results might be biased for some industries. Only the average results are reliable. Hence, we will not discuss each result for each industry separately but will look at the overall picture that is obtained for each examined relationship including all industries' results for this relationship. This overall picture is more reliable than the individual results.

4.1 Effects of subsidies

The positive effects of subsidies on employment, which are mostly found in the literature, are not clearly supported by our findings. Our results are quite mixed, in line with the findings by Dettmann et al. (2016) and Brenner and Pudelko (2019): In general, we do not detect clearly positive effects of subsidies on regional employment. However, we find a clear distinction between manufacturing and service industries. For the studied manufacturing industries, we find significant positive effects (short- or long-term) or nonsignificant results, while we find significant negative effects for the service industries, which turn positive over time in the software industry (62). The subsidies that we are examining are mainly research subsidies. The negative relationships for service industries, especially in the construction sectors (42 and 43), might indicate that mainly process innovations are triggered by subsidies in these industries and that they reduce employment, at least, within the region. For the other industries our results are rather in line with positive effects of subsidies on employment. The relationships are found more frequently for high-tech industries, but especially it is found for the scale-intensive manufacturing industries (23 and 29). Our results suggest effects to be rather long-term, but also visible already short-term. All these findings are in line with the above argument of output additionality and, therefore, also in line with the only more consistent finding in the literature that high-tech industries rather show output additionality (Table 4).

More clearly, we find positive effects of subsidies on qualification. Negative effects are only found for the construction industries (42 and 43) with one of them turning positive in the long run. Positive effects are found for four industries. All of these positive effects are long-term, fitting better the arguments of behavioral additionality. Interestingly, in contrast to the findings for employment, significant results are found for all low-tech, supplier-dominated manufacturing industries (10 and 12). This contrasts the expectations deduced above. It might signal that in low-tech

Table 4 Effects found in the impulse response functions of the other variables on changes in government subsidies

	Long-term positive	Short-term positive	Negative, turning positive	Positive, turning negative	Short-term negative	Long-term negative	No significant impact
Subsidies → Specialization	29, 30	23	62			42, 43	10, 12, 21, 26,
Subsidies → Qualification	10, 12, 29, 30		43			42	21, 23, 26, 62
Subsidies → Patents	12, 26, 30	23, 42	10		21	29, 62	43
Subsidies → Foundations	26	10, 23, 30	42, 43, 62			12	21, 29

industries research- and education-oriented subsidies lead to a behavioral change in firms toward more qualification-based activities.

While the literature provides clear evidence on a positive effect of subsidies on innovation, our results are not in line with such an effect: We observe positive effects for five industries and negative effects for three industries, plus one industry with a negative effect turning positive. At least, positive effects are more frequent. Further insights are obtained from the details. Interestingly, positive effects are more frequently found for (medium)-high-tech industries. We do not find a higher frequency of positive effects for high-tech or science-based industries, as expected. Science-based industries even show more often negative effects in our analysis. Industrial specialties seem to play a role. Maybe bandwagon effects are higher in some industries than in others. A weak finding is that long-lasting positive effects are rather found for (medium)-high-tech industries, while short-term effects are rather found for (medium)-low-tech industries. Another interesting finding of our analysis is that the positive effects are more often long-term, while the negative effects are found to be half-half long-term or short-term. The literature frequently discusses whether subsidies increase innovation only while they are given and without a long-lasting effect. Our results rather suggest the opposite: If positive effects follow from subsidies, they are, on average, more likely to be long-lasting. This fits rather to the arguments of behavioral additionality. Although there is no clear industry-picture, this seems again to be somewhat more given in low-tech manufacturing industries.

The clearest overall picture of positive effects is found in our analysis for the effects of subsidies on the founding activity in a region. This is very interesting because the subsidies data included in our analysis are restricted to mainly subsidies from the ministry for education and research. Only a small part of these subsidies directly supports firm foundation, while a large part increases qualification and, especially, public as well as private R&D activities. Hence, we might conclude that these subsidies create conditions (more qualification, more research) that favor the occurrence of firm foundations. This is in line with the finding that the effects are mainly long-term, in quite a number of cases turning from a negative response to a positive one. Interestingly, all service industries in our sample show such a turn from immediate negative effects to positive long-run effects. Hence, subsidies in the service sector seems to first lower the potential for firm foundation but generate in the long-run additional opportunities. This is again more in line with the arguments of behavioral additionality. However, we observe also positive short-run effects in our analysis, which are more in line with output additionality.

Considering the types of additionality in light of all results, we find the strongest evidence for behavioral additionality. This holds especially for the low-tech manufacturing and the service industries. Hence, in industries that are less research- and education-based, subsidies seem to lead to behavioral changes with long-lasting effects. For the (medium-) high-tech manufacturing industries (21, 26, 29 and 30), we obtain some evidence supporting output additionality as the dominant effect. In fact, such output additionality in high-tech industries was the only clear finding in the literature. Our results are in line with this. We also find most effects for the (medium-) high-tech industries,

implying that they benefit most from the subsidies by the ministry for education and research. Most of the identified effects are long-lasting, implying that besides output additionality we also see behavioral additionality. For (medium-) low-tech industries we find a mixture of long-lasting effects on qualification and patents in some cases and short-term effects on firm foundation and patents in some other cases. Hence, the picture is not that clear for these industries and seems to depend more on the influenced variable that is considered. Given the limitation of our approach, no statement is possible in this context. The picture seems to be somewhat clearer for the service industries: All positive effects that we detect, besides one, are only long-term. Hence, behavioral additionality seems to be more relevant in the service sector.

4.2 Effects on subsidies

As stated above, the literature provides only a few studies on the effects of other variables on receiving subsidies, especially on the regional level. The results from our analyses are presented in Table 5 and show overall rather positive effects.

Above, we deduced the expectation of positive effects of regional employment on receiving subsidies, especially in high-tech industries due to clusters. Corresponding with this expectation, our analysis detects positive long-term effects, especially in four of our five (medium-) high-tech industries. For the low-tech industries, we find some immediate negative effects. However, most of these turns positive in the long-run. Hence, our results are in line with the expectation that more specialization in a region increases the likelihood of receiving subsidies, especially in high-tech industries. There are two potential explanations: First, a concentration of industry-employment in a region might increase the potential to apply for subsidies. This would also be in line with the time that takes for the effect to establish in some industries. Second, the government might be more willing to support firms in clusters.

We did not find any literature on the effects of qualification on receiving subsidies. Our results (Table 5) suggest a rather positive effect. A negative short-run effect is only found for two industries, with one of them turning positive in the long-run. In total, for eight out of ten industries, our analysis finds positive significant long-run effects. A clear industrial structure is not visible. Nevertheless, on average, our results suggest that increasing the share of qualified workers in a location is followed by an increase in subsidies that go to this region. Our approach does not allow to detect the mechanism responsible for this, so that we can only speculate: Qualified workers might be more successful in applying for subsidies, qualified workers might have been employed to increase innovativeness and subsidies, or qualified worker employment has been a reaction to expected subsidies, with the latter not in line with the often-long-lasting effects.

In line with our expectations above, we find positive effects of patents on subsidies for most industries. Furthermore, we find a clear separation between industries. While all (medium)-high-tech and medium-low-tech industries show significant long-term

Table 5 Effects found in the impulse response functions of the other variables on receiving subsidies

	Long-term positive	Short-term positive	Negative, turning positive	Positive, turns negative	Short-term negative	Long-term negative	No significant impact
Specialization → Subsidies	21, 29, 30, 42, 62		12, 43			10	23, 26
Qualification → Subsidies	12, 23, 26, 29, 30, 43, 62		42		21		10
Patents → Subsidies	21, 23, 26, 29, 30, 62			12	10	43	42
Foundations → Subsidies	29, 43	42	10, 26	62		23, 30	12, 21

positive effects, the low-tech industries show negative or insignificant results. Furthermore, all science-based and the one specialized supplier industries show significant positive effects, according to our analysis. Hence, our results suggest that patent activities matter for receiving subsidies in non-low-tech industries, but not necessarily in low-tech industries. We can think of two reasons for the positive effects: either increases in the innovativeness of firms cause them to apply more for subsidies or having filed a patent is a signal that makes obtaining subsidies more likely.

The results for the effects of firm foundations on subsidies are mixed: We find positive and negative relationships. Furthermore, the expected difference between more innovative industries and less innovative industries is also not found. Hence, we are not able to draw a conclusion. The results seem rather to be random and might be the result of the large number of observations and the data quality (see Sect. 3.4), causing small spurious relationships due to biases.

5 Conclusions

In this paper, we studied the relationships of four variables, namely specialization, patents, qualification, and firm foundations with subsidies, for ten 2-digit industries separately on the local level in Germany. The first take-away message from our analysis is that the relationships strongly depend on the industry analyzed. Hence, we confirm the claim of a strong importance of industries not only for innovation systems (e.g., Malerba 2002, Malerba and Nelson 2011, Malerba 2005) but also especially for the interaction between economic variables and subsidies.

Our approach, especially with respect to the matching of data, has some limitations, so that the results for individual industries are not sufficiently reliable and we focus rather on the overall picture. Taking the overall perspective, we obtain some general findings about the studied relationships that go beyond the results presented in the literature. Due to the limitations of our approach, we interpret the findings as first tentative results that must be confirmed by further studies. Some tentative general findings are discussed in the following, while the individual findings for each relationship are summarized in Table 6.

Overall, our findings suggest that the effects of subsidies on low-tech industries are more long-term and, hence, more in line with behavioral additionality. Furthermore, subsidies seem to have stronger effects on employment in high-tech industries and on qualification in low-tech industries. For the opposite direction, the effects of regional economic characteristics on receiving subsidies, our analyses produce more significant findings for high-tech industries.

To sum up, we approached some research gaps concerning the relationships between several regional economic variables (specialization, qualification, patents, and firm foundations) and subsidies and provided some first tentative results on these relationships as well as on their industry-specific and temporal features. Especially, our results suggest a clear positive impact of qualification on receiving subsidies, a relationship not studied so far on the regional level.

Table 6 Summary of findings

	Identified effects of subsidies	Identified effects on subsidies
Specialization	Mainly positive for manufacturing, rather for high-tech and scale-intensive industries	Mainly positive, rather for high-tech industries
Qualification	Mainly positive, rather for low-tech industries and rather long-term	Mainly positive
Patents	Mixed results, identified positive effects are rather long-term	Positive only for non-low-tech industries
Foundations	Positive, rather long-term	Mixed results

However, our results also point to an issue on which further research is needed: We detected strong differences between industries for most studied relationships. Studies that analyze industries separately in the same way are rare so far. Our results suggest that such an approach should be taken more often. While some of our detected differences can be clearly assigned to differences between high- and low-tech industries, other differences might be related to industry life-cycle stages or industry-specific developments. More research on this is necessary to understand the relationships studied here in more detail.

Appendix

See Table 7.

Table 7 List of industries that occur in the Patstat database

Industries (NACE Rev. 2)
10: Manufacture of food products
11: Manufacture of beverages
12: Manufacture of tobacco products
13: Manufacture of textiles
14: Manufacture of wearing apparel
15: Manufacture of leather and related products
16: Manufacture of wood and products of wood and cork
17: Manufacture of paper and paper products
18: Printing and reproduction of recorded media
19: Manufacture of coke and refined petroleum products
20: Manufacture of chemicals and chemical products
21: Manufacture of basic pharmaceutical products and preparation
22: Manufacture of rubber and plastic products
23: Manufacture of other non-metallic mineral products
24: Manufacture of basic metals
25: Manufacture of fabricated metal products
26: Manufacture of computer, electronic and optical products
27: Manufacture of electrical equipment
28: Manufacture of machinery
29: Manufacture of motor vehicles, trailers and semi-trailers
30: Manufacture of other transport equipment
31: Manufacture of furniture
32: Other manufacturing
42: Civil engineering
43: Specialized construction activities
62: Computer programming, consultancy and related activities

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