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Gauging two sides of regional economic resilience in Western Germany – Why resistance and recovery should not be lumped together

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Abstract:

The paper empirically investigates the economic resilience of Western German regions in the wake of the Great Recession of 2008/2009. In particular, the focus is laid on the influence of regional agglomeration economies (arising from specialization, related and unrelated variety) and the explicit subdivision of short-term resilience into resistance and recovery. The necessity to distinguish between different factors and phases is well documented by means of the OLS regression results as all three types of agglomeration economies reveal varying, if not opposing directions of influences across the resistance and recovery phase. A pregnant example refers to regional specialization. Not only does it show a negative impact on resistance while exerting a positive influence during the recovery phase, but it is also mediated by the regional share in manufacturing workforce. This workforce reveals opposing phase-specific effects itself. Hence, ignoring the two-component structure of short-term resilience entails the risk of imprecise, if not false conclusions on the driving mechanisms stabilizing and/or destabilizing regional economies in times of crisis.

Keywords: regional economic resilience, resistance, recovery, agglomeration economies, industry structure

JEL Classifications: R11, R12, E32

1 Introduction

Ever since the Great Recession of 2008/2009, the concept of resilience has gained growing attention among regional economists and economic geographers. Eventually, the crisis has revealed a long-suspected side-effect of growing internationalization, which makes regions become more and more exposed to the ups and downs of the globalized world economy. As the ability of a region to withstand exogenous shocks crucially influences both its short-term prosperity and long-term development, it is not surprising that the augmentation of resilience capacities has also become a major goal among regional policy makers.

However, despite the increasing number of studies in this field, current research is still characterized by a mismatch between theoretical groundwork and empirical evidence. On the one hand, there is a growing consensus that resilience is not a monolithic but a multidimensional phenomenon. The most common distinction so far is attributable to Martin (2012) who identifies four components of regional resilience: resistance, recovery, renewal and re-orientation. Resistance and recovery can be interpreted as dimensions of a short-term engineering resilience, renewal and re-orientation capture the mid- and long-range resilience by stressing the evolutionary perspective. Similar to this multi-component structure, researchers widely acknowledge that regional resilience crucially depends on the given industry structure as well as on its associated externalities (see Wink 2011, Martin 2012, or Martin and Sunley 2014). In this regard, the relevant literature distinguishes between specialization-driven externalities in the sense of Marshall (1890), Arrow (1962) and Romer (1986) (MAR), diversity-based Jacobs' externalities and – most recently – externalities stemming from either unrelated or related variety (Frenken et al. 2004, 2007).

On the other hand, empirical evidence on the specific relationship between regional externalities and economic resilience is still very rare. Although a large number of studies already explored the impact of externalities on regional economic performance in general (e.g., Boschma and Iammarino 2009, Bishop and Gripaios 2010, Boschma et al. 2012, Hartog et al. 2012, Brachert et al. 2013, van Oort et al. 2015), only Duschl (2014) and Sedita et al. (2015) explicitly addressed the externalities-resilience nexus so far. Besides, both studies arrive at different empirical results. While Duschl (2014) investigates the resilience of German regions and finds no impact for related and a partly negative impact for unrelated variety, Sedita et al. (2015) confirm a positive influence for both unrelated and related variety in terms of Italian regions. It can be assumed that these opposing findings are partially due to the different regional samples. Another reason, however, could be the missing distinction between resistance and recovery, i.e. the two components of short-term resilience, which might lead to precipitate or even incorrect conclusions through masking important phase-specific attributes (see section 2). Although we observe a growing consensus on how to measure economic resilience in numerical terms (prominent examples include Bristow et al. 2014, Martin and Sunley 2014, and Reinhart and Rogoff 2014), an advanced distinction between regional resistance and regional recovery is still pending.

Another gap in resilience research refers to the particular role of knowledge-intensive industries and their related spillover effects. The absence of empirical evidence in this field appears to be surprising since knowledge spillovers rate as the deciding drivers of dynamic regional externalities and are thus likely to influence the resilience capacities of regions (see Glaeser et al. 1992 for an overview). Still, we have knowledge of only one empirical study that further categorizes related variety into low-, medium- and high-tech industries and thereby reflects different levels of knowledge-intensity. This work of Hartog et al. (2012), however, concentrates on the variety-driven effects on regional employment in Finland from 1993 to 2006 and does not make regional resilience a subject of discussion.

In view of the aforementioned research gaps, our paper consequently examines the impact of various types of agglomeration economies on two sequential phases of economic resilience, namely the resistance and the recovery of regional economic systems. As for the agglomeration economies, we distinguish between specialization-driven MAR-externalities and externalities stemming from related and unrelated variety. Furthermore, we account for the knowledge-intensity of the industry structures involved. The original contribution of our paper is thus threefold: First, we establish a direct link between the economies of agglomeration and regional economic resilience; second, we detect potentially contrary agglomeration effects on shock-resistance on the one hand and on the subsequent recovery on the other hand; third and finally, we control for different levels of knowledge-intensity within industry structures in order to further specify the impact of spillover effects on short-term resilience.

The remainder of our paper is structured as follows. Section 2 introduces our theorizing and hypotheses. Section 3 describes the methodological design of our analysis including variables, OLS model structure, and databases used. Section 4 presents the empirical results including a thorough discussion of the central findings. Section 5 eventually provides some key implications for policy makers as well as for further research.

2 Theory and hypotheses

Originating in an abrupt decline in global demand, the Great Recession of 2008/2009 meets all the criteria of a sudden, exogenous shock event. Likewise, it can be clearly separated from a 'slow burn' that rather describes the gradual transformation of regional economies in the long run (e.g., Pendall et al. 2010, 80f.; Martin and Sunley 2014, 16f.). As it evidently qualifies as a shock event, we can link the Great Recession, which is at the core of our investigation, to the conceptual framework of Martin (2012). Martin understands economic resilience as a shock-induced process that can be grouped into four components: resistance, recovery, renewal and re-orientation. Resistance relates to the first direct response to a recessionary shock. It measures the intensity and the extent of the (possible) decline in economic performance and thereby delineates a regional economy's sensitivity. Recovery, in comparison, refers to the velocity and degree of how the economy manages to bounce back from the shock-induced downturn and return to its pre-shock growth trend or level, respectively (see section 3 for the empirical implementation). Whether the economy resumes its original growth path or skips to a new state, is subject of the renewal phase. The final component, re-orientation, eventually examines to which extent the region successfully adapts to shock-induced changes in the economic environment (see Martin

(2012, 11ff.) for a detailed description and Martin and Sunley (2014, 14ff.) for a slightly different approach).

As an important result, regional resilience capacities can be grouped into short-term and long-term components. While resistance and recovery depict the immediate reaction and velocity of coping with a shock event, the competences of renewal and re-orientation describe the long-term development and continual adaptation of a regional economy in succession to a shock event. The empirical analysis of this paper, however, focuses on the short-term components: resistance and recovery. This occurs for two reasons: First, we expect regional externalities to exert opposing effects particularly during these successive, though contrasting stages of the resilience process (see section 2). Second, data for a further reaching analysis of the long-term capacities, renewal and re-orientation, is not available yet as the post-crisis period is still relatively short. In consequence, recovery will serve as our only proxy to cover the coping abilities of regional economies.

A region's economic structure is widely considered a deciding determinant of economic resilience (see, for instance, Wink 2011, Martin 2012, Martin and Sunley 2014, or Martin et al. 2016). Its influence can be measured on different levels. On a high level of aggregation such as the one-digit NACE level, the sectoral shares provide information on the fundamental orientation of the regional economy by disclosing, for instance, the proportion between production and service industries. On a more detailed level, the NACE classification allows further statements on the specific composition and interrelatedness of these sectors. Sectoral composition and interrelatedness in turn can shape the form and availability of regional externalities which are commonly categorized into specialization-driven localization or MAR-externalities (Marshall 1890, Arrow 1962, Romer 1986), diversity-based Jacobs' externalities (Jacobs 1969) and – as an advancement of the variety-concept – externalities stemming from either unrelated or related variety (Frenken et al. 2004, 2007). However, despite the comprehensive body of theoretical and empirical literature on the nature, mechanisms and effects of regional agglomeration economies, their impact on the resistance and recovery of regional economies still is barely explored. This is where the derivation of hypotheses starts off.

2.1 The resistance phase

To start with, we expect the impact of regional agglomeration economies to be varying in dependence upon their specific manifestation (specialization, related and unrelated variety), the involvement of knowledge-intensive industries and – most important – the dimension of economic resilience (resistance vs. recovery). Our first hypothesis is directed to the resistance phase and it reads as follows:

Hypothesis H1:

The *resistance* of a regional economy is *positively* influenced by

a) Unrelated variety, by
b) Specialization in non-knowledge-intensive industries, and by
c) Related variety in non-knowledge-intensive industries.

It is *negatively* influenced by

d) Specialization in knowledge-intensive industries.

Following Martin (2012, 12) we define economic resistance as the 'degree of sensitivity or depth of reaction of [the] regional economy to a recessionary shock" (for further empirical operationalization see section 3.1). As stated in the first part of hypothesis 1, we presume that the economic resistance of regions is positively influenced by diverse but unrelated industry structures (e.g., Frenken et al. 2007, 688; Boschma 2014, 736). This presumption might appear counter-intuitive at first since diversified rather than specialized regions would open a wider 'route of entry' for sector-specific shocks – at least if diversity comes along with a higher number of sectors that could possibly be affected. On the other hand, though, unrelatedness between sectors, defined as the absence of complementarities in terms of shared knowledge bases, work skills, technologies or product characteristics (Boschma and Iammarino 2009, 293; Brachert and Titze 2012, 210f.), helps to limit shock-induced downturns to the directly affected sectors while conserving the economy as a whole. Hence, if an industry x was affected by a sector-specific crisis, the x-associated shockwaves would not spread over the other, unrelated sectors of the regional economy. In other words: the shock induced spillovers stemming from x would be minimized or even inhibited. Due to this shock absorbing function, we assume a positive influence of unrelated variety on regional economic resistance, irrespective of whether the unrelated industries are knowledge-intensive or not (H1a).

With regard to specialization and the originating MAR-externalities, respectively, it is often assumed that regional economies with a strong dominance of only one or very few sectors tend to be particularly vulnerable. This results from the fact that shock events in dominating sectors directly affect great parts of their home economy and can thus trigger a regional recession (Augustine et al. 2013, 5; Martin and Sunley 2014, 27). We term this situation as 'dominance effect' accordingly. In the case of Western Germany, the 'dominance effect' is especially applicable to knowledge-intensive industries that tend to hold greater shares in international markets than non-knowledge-intensive sectors and thus heavily depend on the global economic development and its cyclical fluctuations (e.g., Gehrke et al. 2009, 8ff.; Gehrke and Schiersch 2016, 34ff.). Hence, we deduce that a specialization in these knowledge-intensive industries leads to a lowered regional resistance to exogenous shocks (H1d). By comparison, non-knowledge-intensive sectors can be regarded as less dependent on international markets and on global economic cycles, respectively (e.g., Vogel and Wagner 2008, 16; Gehrke et al. 2009, 8ff.). As a consequence from the lesser integration in world markets, non-knowledge-intensive industries also tend to be less affected by global economic turbulences which in turn can help to stabilize regional economic systems (for a similar argument see Brakman et al. 2014, 2). Put differently, the 'dominance effect' fails to exert influence. We therefore expect regional specialization in non-knowledge-intensive sectors to be resistance-improving (H1b).

Related variety occurs if industries are related in terms of shared or complementary competences (e.g., knowledge bases, technologies) (Boschma and Iammarino 2009, 293; Brachert and Titze 2012, 210f.) and as such, constitute a 'diversified specialization' (Frenken et al. 2007, 686, 696).

This feature - as being a cross between variety and specialization - complicates hypothesizing the impact of related variety on economic resistance since the direction of its influence lacks clarity. On the one hand, it can be argued that related variety results in a lower regional resistance since a sector-specific shock would affect all related branches as a direct consequence of their interconnectedness (Martin and Sunley 2014, 28). As the shock would spread over related channels, this setting is referred to as 'contagion effect'. On the other hand, as relatedness could help to distribute the shock-associated disturbances more evenly among the connected sectors, the average impact on each sector unit may be lowered. This, in turn, would help to stabilize the affected industries and, by means of positive spillovers, the regional economy as a whole. We label this scenario as 'distribution effect'. However, uncertainty concerning the direction of influence applies more to knowledge-intensive industries than it does to others. This is primarily due to different degrees of internationalization. As stated above, knowledge-intensive sectors in Germany tend to be highly integrated in world markets, which makes them be significantly exposed to global economic cycles and crises. Consequently, it remains unclear whether the 'contagion' or the 'distribution effect' will dominate. This is why we dispense with a corresponding hypothesis. Then again, the dependence of non-knowledge-intensive industries from international markets can be considered relatively low. Accordingly, we expect the 'distribution effect' to control the 'contagion effect' and thus hypothesize a resistance-enhancing effect of related variety in non-knowledge-intensive industries (H1c).

2.2 The recovery phase

Our second hypothesis is related to the recovery phase and it mostly reads – for good theoretical reasons – as the exact opposite of hypothesis 1:

Hypothesis H2:

The recovery of a regional economy is *positively* influenced by

a) Specialization in knowledge-intensive industries.

It is *negatively* influenced by

b) Unrelated variety, and by
c) Specialization in non-knowledge-intensive industries.

Adopting a key aspect of the 'engineering'-concept (Martin 2012, 5) we define recovery as the ability of a region to quickly bounce back from a shock and to return to its pre-crisis welfare level, respectively (for further empirical operationalization see section 3.1). Starting with specialized industry structures, we postulate a supportive impact on regional recovery in case that specialization occurs in knowledge-intensive industries (H2a). A specialization in these sectors facilitates growth enhancing spillovers in the form of MAR-externalities that support firms in creating and implementing incremental innovations (e.g., Frenken et al. 2004, 6f.). Such innovations are pointed at gradual product- and process-improvements and especially lead to increases in terms of productivity. Hence, the dynamics in these sectors should enable firms to quickly respond to cyclical fluctuations on their traditional target markets by which they promote recovery at the superordinate regional level as well. This reasoning is supported by Wink (2015, 58), who considers innovation an essential criterion for a quick recovery of regional economies.

Put in a nutshell, we expect specialization in knowledge-intensive industries to be sort of a two-edged sword: While it lowers the economy's sensitivity to shocks that hit regional core industries (see H1d in section 2.1), it in turn enforces the speed of recovery through the benefit of MAR-externalities (Martin and Sunley 2014, 27ff.).

A similar dichotomy applies to the influence of specialization in non-knowledge-intensive industries and of unrelated variety. On the one hand, as exposed in section 2.1, we assume that both factors exert a stabilizing influence on regional economies during the resistance phase. On the other hand, though, we expect both features to be obstructive for the recovery process. The recovery-impeding effect of non-knowledge-intensive specialization (H2c) can be traced back to the limited emersion of growth enhancing spillovers from these sectors (see also Gehrke and Schiersch 2014, 2) that otherwise would strengthen the coping capacities of the regional economy. Instead, a deficit in innovation activities is likely to rigidify a critical development path with gradually decreasing growth rates and a decline in regional competitiveness per se. The decelerating recovery-effect that stems from unrelated variety (H2b) can be explained with the technological distances between unrelated sectors that hamper spillover effects in the knowledge-intensive as well as in the non-knowledge-intensive industries. Here too, the lack of inter-industry knowledge transfers reduces the number of recovery-enhancing externalities (see also Frenken et al. 2004, 8). Admittedly, knowledge exchange between unrelated sectors is not impossible per se but happens to occur only randomly wherefore it shows no systematic relation to the recovery of regional economies (see also Frenken et al. 2004, 8).

Regions that are characterized by a high degree of related variety provide good prerequisites to ensure high economic resilience in general (Sedita et al. 2015, 6). Again, this is especially true for relatedness between knowledge- and technology-intensive industries that generate enhanced intersectoral knowledge spillovers and knowledge diffusion. At the same time, firms in these industries are in possession of high absorptive capacities and thus are capable of efficient learning effects which helps to develop new sales markets by means of product innovations (Hartog et al. 2012, 461f.). However, product innovations through related spillovers are not likely to happen 'overnight' because, unlike with specialization-driven MAR-externalities, firms that receive spillovers from related industries normally need to bridge slight technological distances first (Boschma and Frenken 2011, 67f.). Therefore, we expect the growth enhancing effects of related variety to evolve in a long-term rather than in a short-time perspective. The same applies to the impact of 'skill-relatedness' (Otto et al. 2014, 135ff.) which provides the opportunity to absorb and reallocate shock-released workforce between related industries. To summarize, we do not assume a significant contribution of related variety to a quick short-term recovery. We do, however, postulate a positive long-term influence on the 'renewal' and 're-orientation' of regional economies (Martin 2012, 12) through creating new growth paths and avoiding the threats of technological or cognitive lock-ins.[1]

[1] Unfortunately, the database of this article (ending in 2012) does not allow for the examination of a long-term perspective which is why we must abstain from testable hypotheses on the renewal and re-orientation period.

Finally, we expect no significant influence from regional related variety in non-knowledge-intensive industries – neither in a short- nor in a long-term perspective. Neither does it – for the same reasons as stated for knowledge-intensive relatedness – contribute to a quick regional recovery, nor does it generate enhanced knowledge spillovers (see also Gehrke and Schiersch 2014, 2) necessary to support economic renewal or re-orientation.

3 Methodological design

3.1 Computing the dependent variables: resistance and recovery

Our analysis focusses on short-term 'engineering' (Martin and Sunley 2014, 3f.) economic resilience in the form of resistance and recovery. As a basis for numerical computation, Martin (2012, 6f.) suggests to capture the crisis-induced instabilities of employment numbers and/or the fluctuations in economic output. As for this article, we choose economic output (or rather: the percentage growth in regional GDP) over employment numbers because the latter show a deferred reaction to abrupt drops in economic demand as occurred in the Great Recession of 2008/2009. Further distortions would result from the fact that the labor market impacts of the recession were significantly moderated by the massive promotion of short-time working, especially in Western Germany (Schwengler and Hecht 2011, 124, 128; Zarth 2011, 103f.). To assess the shocks' immediate and unadulterated impact on regional economic performance, we thus select GDP development as basis for our calculations.

Our overall observation period stretches from 2008 to 2012. 2008 serves as reference year for the pre-crisis growth level[2] in every region included in our sample (see section 3.4 for more details on the data sample). The respective duration of the resistance and recovery phase is determined by the region-specific low point in terms of GDP growth. Concurrently, the low point marks the transition between the two successive phases. This can also be seen from formulas (F1) and (F2), respectively.

Like Martin (2012, 12), we define resistance as the 'degree of sensitivity'. Calculated for each region individually, sensitivity is measured by means of the real GDPs growth from 2008 to the respective regional low point. This allows for cross-regional comparisons of the relative economic declines (for similar approaches see Bristow et al. 2014, and Reinhart and Rogoff 2014):

$$Sensitivity = \frac{GDP_{real_{regional\ low}} - GDP_{real_{2008}}}{GDP_{real_{2008}}} \qquad \text{(F1)}$$

The region's capacity to recover is measured accordingly, i.e., by means of the real GDPs growth rate from the region's individual low point to the year of 2012:

[2] It is important to note that – due to restrictions in data availability – the dependent variables are calculated on the base of annual, not quarterly data. Hence, we define 2008 as pre-crisis reference since no German region experienced a GDP decline in 2008's annual average (although some did in the fourth quarter).

$$Recovery = \frac{GDP_{real_{2012}} - GDP_{real_{regional\ low}}}{GDP_{real_{regional\ low}}} \qquad \text{(F2)}$$

Intentionally broadly defined, (F2) captures the capacities of the already fully recovered regions as well as of those whose recovery is still pending in 2012. This gives us two advantages: First, it allows us to analyze the recovery phase in a reasonably comprehensive sense. Second, it offers a systematic comparison between two successive dimensions of economic resilience as nearly the same regions are included in both model lines of the linear regression analyses ('resistance' and 'recovery'). Finally, both dependent variables are scaled metrically. Compared to dichotomous attempts, in the sense of 'resilient'/'non-resilient', 'recovered'/'non-recovered' etc. (e.g., Augustine et al. 2013), a metric measurement provides more detailed information on the intensity of the regional economic downturn as well as on the speed and extent of recovery.

3.2 Computing the independent variables: specialization, unrelated and related variety

3.2.1 Specialization

Specialization[3] is captured by the Gini-Index for regional specialization (G_j). Unlike other indices that measure a region's specialization in relation to other regions or in proportion to the average of a superordinate spatial unit, the Gini-Index provides information on the actual degree of a region's specialization in specific sectors (Farhauer and Kröll 2013, 300ff.). As such, it is measured as follows (Farhauer and Kröll 2013, 304ff.):

$$Specialization\ (G_j) = \frac{2}{G^2 \bar{R}} \sum_{g=1}^{G} \lambda_g \left(R_g - \bar{R}\right) \qquad \text{(F3.1)}$$

The specialization of each region is computed at the two-digit level according to the industry classification of the Federal Employment Agency. Each two-digit industry ($g = 1, 2, \ldots, G$) is represented by a specific g, while G describes the number of all two-digit industries occupied in Western Germany. R_g depicts g's regional share in the total employment of region *j* in proportion to g's total share of employment in the total employment of Western Germany:

$$R_g = \frac{s_{gj}^s}{s_g},\ with\ s_{gj}^s = \frac{E_{gj}}{E_j}\ and\ s_g = \frac{E_g}{E} \qquad \text{(F3.2)}$$

E_{gj} describes g's total employment in region *j*, while E_j represents the total employment in region *j*. Similarly, E_g embodies g's total employment in Western Germany, while E describes the total employment of all two-digit industries in all Western German regions. λ_g represents g's rank position determined by ranking the individual values of R_g for each region j in ascending order. This method was chosen to face the problem that some regions exhibit no employment in specific two-digit industries. Thus, if vacant sectors occur the arithmetic mean of their ordinal ranks can

[3] All three industry indicators (specialization, unrelated, and related variety) are calculated for both non-knowledge-intensive and knowledge-intensive sectors according to the 'NIW/ISI/ZEW'-list by Gehrke et al. (2010).

be assigned to the particular R_g (Pflaumer et al. 2001, 126f.). $\bar{R}$ eventually describes the mean value of all R_g and therefore represents the average degree of specialization:

$$\bar{R} = \frac{1}{G}\sum_{g=1}^{G} R_g \qquad \text{(F3.3)}$$

At that point and as noted in (F3.1), differences between each R_g and $\bar{R}$ are weighted with their respective rank before they are summed up. Then, this sum is multiplied by the term $\frac{2}{G^2\bar{R}}$ to establish a homogenous range from 0 to $\frac{G-1}{G}$ for all index values of each single region (Farhauer and Kröll 2013, 305f.). At the reporting date (31.03.2008), three out of eighty-eight two-digit industries exhibit no employment in Western Germany. Therefore, the range of the G_j index reaches from 0 to 0,988[4]. Hence, values close to 0,988 imply a strong regional specialization in specific industries. Values close to 0, on the other hand, denote only little specialization indicating a relatively even distribution of employment across the two-digit industries within regions (Farhauer and Kröll 2013, 304ff.). Looked at another way, high G_j-values imply a weakly diversified regional industry portfolio while low G_j-values point towards a strong regional diversification in the sense of Jacobs.

3.2.2 Unrelated and related variety

The variables of unrelated and related variety are calculated through entropy measures, a methodology introduced by Frenken et al. (2004, 2007) and frequently adopted in further regional studies (see, for instance, Boschma and Iammarino 2009, Boschma et al. 2012, Brachert and Titze 2012, and Hartog et al. 2012). According to present knowledge in the literature, the entropy method is the only approach that measures Jacobs' externalities not only in the form of unrelated variety (e.g., Herfindahl-Index), but extends the analysis by the effects of related variety (Essletzbichler 2005, 14; Bishop and Gripaios 2010, 447).

Following Boschma and Iammarino (2009), Boschma et al. (2012), Frenken et al. (2007) and Hartog et al. (2012), respectively, we compute unrelated variety at the two-digit level according to the industry classification of the Federal Employment Agency:

$$Unrelated\ variety = \sum_{g=1}^{G} P_g \, log_2\left(\frac{1}{P_g}\right) \qquad \text{(F4)}$$

P_g describes each industry's employment share in total regional employment at the two-digit level. Following the concept of entropy, two-digit industries are separated through segmented, not overlapping competences (e.g., knowledge bases, technologies) and thus exhibit no systematic economic exchange. The higher the value of unrelated variety (F4), i.e. the higher the degree of sectoral unrelatedness, the more evenly is the distribution of employees across the two-digit industries.

In a next step, related variety is calculated as the weighted sum of entropy *within* the two-digit industries (Frenken et al. 2007, 689):

[4] (85-1)/85 = 0,988

$$Related\ variety = \sum_{g=1}^{G} P_g\, H_g, \quad \text{(F5.1)}$$

$$with\ H_g = \sum_{i \in S_g} \frac{p_i}{P_g} log_2 \left(\frac{1}{\frac{p_i}{P_g}} \right)\ and\ P_g = \sum_{i \in S_g} p_i \quad \text{(F5.2)}$$

The employment shares of each two-digit industry P_g are calculated by summing up the *associated* four-digit industries shares p_i. Sectors are assumed related at the four-digit level when they share the same superordinate two-digit class. The higher the value of related variety (F5.1), the more evenly the distribution of employees across the four-digit industries *within* the according two-digit level, and the higher the four-digit relatedness in terms of shared or complementary competences (e.g., knowledge bases, technologies).

3.2.3 Control variables

With a share of more than 24 percent in total employment, the manufacturing sector in Germany is still a supporting pillar of the national economy (Federal Statistical Office 2016). Hence, an analysis of resilience-driving determinants in German regions must not omit a set of control variables that takes this noteworthy industrial imprint into account. These (regional) controls include the 'share of manufacturing workforce in total employment' and the 'share of large enterprises' (as a source of economies of scale). Further variables are 'R&D-employment' and 'labor productivity' which help us to control for the economic capacity of each region in general. Moreover, we insert a dummy-variable labelled 'urban region' to control for urbanization effects arising from urban size and density. Restricted to the 'recovery' models, we finally include regional 'sensitivity' as another control variable to be able to relate the regions' recovery to the extent of their preceding decline.

3.3 OLS estimation procedure

The OLS regression models are grouped around the two dependent variables 'sensitivity' (F1) and 'recovery' (F2). For each dependent variable, we conduct two further model groups: the first model group estimates the influence of 'regional specialization' (F3.1), while the second group is directed at the impact of 'unrelated' (F4) and 'related variety' (F5.1). We proceed this way because the first group already provides implicit information on the impact of Jacobian diversification as low (high) values of specialization inversely indicate high (low) values of diversification (see section 3.2.1). Therefore, the second model group analyzes the 'nature' of diversification in more detail. This added up, we obtain four basic model groups that can be written in the following elementary form:

Sensitivity = β_0 + β_1 Specialization + Error term *(F6)*

Sensitivity = β_0 + β_1 Unrelated Variety + β_2 Related Variety + Error term *(F7)*

Recovery = β_0 + β_1 Specialization + Error term *(F8)*

Recovery = β_0 + β_1 Unrelated Variety + β_2 Related Variety + Error term *(F9)*

Furthermore, each model group comprises three supplementary sector-categories covering 'all sectors', 'knowledge-intensive sectors', and 'non-knowledge-intensive sectors'. Finally, we conduct robustness checks for every model by controlling for influencing factors other than industry structure (as listed in section 3.2.3). For the example of 'sensitivity' and 'specialization', each supplementary group can be portrayed as follows (the other three basic model groups are alike):

$$Sensitivity = \beta_0 + \beta_1 Specialization^{all\ sectors} + \gamma_n Control\ Variable + Error\ term \qquad (F6.1)$$

$$Sensitivity = \beta_0 + \beta_1 Specialization^{knowledge\text{-}intensive\ sectors} + \gamma_n Control\ Variable + Error\ term \qquad (F6.2)$$

$$Sensitivity = \beta_0 + \beta_1 Specialization^{non\text{-}knowledge\text{-}intensive\ sectors} + \gamma_n Control\ Variable + Error\ term \qquad (F6.3)$$

The underlying OLS model assumptions for unbiased and efficient estimation results are sufficiently met (Backhaus et al. 2011, 77ff.; Wooldridge 2013, 68ff.; von Auer 2016, 133ff.): The sample covers a predefined population of German labor market regions (LMR) whilst comprising more observations (n=189 resp. 182; see section 3.4) than model parameters (k ≤ 7 resp. 6). The model is linear in parameters, i.e. Y can be calculated as a linear function of a set of X_i (Linearity)[5]. No X is constant and collinearity amongst X_i does not occur (No Multicollinearity, see Appendix A1-A4). Mutual causation between Y and X_i is obviated by implementing lagged variables if necessary (No endogeneity, see Appendix B1-B3). Also, there is no evidence for distance-related dependencies among neighboring regions (No spatial autocorrelation). We find, however, indications of heteroscedasticity which is why we calculate robust standard errors to ensure efficient estimators (Homoscedasticity). Finally, the error terms are normally distributed (Normality of Error Term) which is a precondition for performing statistical significance tests.

3.4 Data sample

All data is calculated at the level of Western German LMR[6]. In contrast to historically grown administrative districts and cities, LMR represent functionally connected areas based on commuter linkages which depict regional economic activities accurately in terms of labor market centers and their surroundings (Eckey et al. 2007, 6f.; Jakubowski et al. 2013, 351; Milbert 2014). Therefore, LMR enable us to analyze the resilience capacities of coherent regional economic entities.

There is a total of 204 LMR in Western Germany. Eight of which (Mainz, Mühldorf, Cham, Neumarkt, Coburg, Erlangen, Kulmbach, and Dillingen) prove to be resistant to the recessionary shock of 2008/2009, i.e. they have experienced no negative growth rates in GDP following the shock. Consequently, they offer no factual low point that is required to compute the measure of 'sensitivity' (F1) and 'recovery' (F2), respectively. For this reason, we have to exclude these eight regions from our regression analyses. Two further regions (Nordenham and Heidenheim) must be removed due to uninterpretable erratic variations in growth performance. Moreover, we

[5] For this purpose, we have logarithmized the predictors 'R&D-employment' and 'Labor productivity'.
[6] Eastern German regions are not considered due to insufficient comparability resulting from changes in the administrative boundaries during the observation period.

detach five regions by reason of missing data on large-scale firms. Finally, in order to ensure better comparability, we further cut off seven regions that reached their respective low point *after* 2009 from the 'recovery'-models. Accordingly, this algorithm leads us to two different sample sizes: We obtain n=189 regions for the regression models on 'sensitivity' (Table 1 and Table 2) and n=182 regions for the models on 'recovery' (Table 3 and Table 4).

3.5 Data sources

The dependent variables (see section 3.1) are calculated using data from the regional databases of the German Statistical Federal Office and the Statistical State Offices of the German 'Länder', respectively. As the original data on nominal GDP is only available at the level of administrative districts and cities, we needed to aggregate it at the level of LMR according to the reference scheme of the 'Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR)'. Real GDP values are computed by using the deflators for the individual years of the observation period.

The three independent variables 'specialization', 'unrelated variety' and 'related variety' (see section 3.2) are computed using data on employees who are within the scope of national insurance and thus registered in the Federal Employment Agency. As data on employees is available on a quarterly basis, the reporting date 31/03/2008 is chosen to depict the economic situation immediately prior to the shock. Finally, data for the control variables (see section 3.2.3) is retrieved from the INKAR[7] database and the BBSR. As data for the controls is only available on a yearly basis, the reporting year 2007 is chosen as a proxy for the economic conditions prior to the Great Recession of 2008/09.[8]

4 Empirical results and discussion

4.1 Resistance and recovery in German regions

As set out in section 3.4, our predefined sample covers up to 189 (out of 204) LMR in Western Germany. At the end of 2012, a majority of 139 LMR can be considered fully recovered, i.e. they have successfully restored or exceeded their pre-crisis growth level. The remaining 50 LMR have at least passed their individual low point and are on the road to recovery, respectively. The decisive question, however, refers to the phase-related determinants that help to shape the regions' capacities to resist and bounce back at the best possible rate. To begin with, we reflect upon the spatial patterns of how resilience capabilities differ throughout phases and between regions. As displayed in Figure 1, a below-average resistance (denoting a greater decrease in GDP than the Western German average and therefore a higher degree of 'sensitivity') can be observed for most regions in Hesse and Baden-Wuerttemberg as well as for significant parts of North Rhine-Westphalia and Lower Saxony. Interestingly enough, Figure 2 reveals that the majority of these

[7] INKAR is the abbreviation for '**IN**dikatoren und **KA**rten zur **R**aum- und Stadtentwicklung' which can be translated as 'indicators and maps on spatial and urban development'.
[8] Appendix B1-B3 contains full information on operationalization and data sources of all dependent and independent variables (including controls).

areas (except for Hesse) accomplish an above-average recovery in turn (denoting a greater increase in GDP than the Western German average), which gives us a first indication of a possible negative relationship between regional resistance and recovery. Furthermore, Figure 1 and Figure 2 suggest a simultaneous occurrence of 'double plus'-regions that profit from an above-average resistance and an above-average recovery (e.g., Bavarian regions) and, on the opposite, 'double minus'-regions that experience a below-average resistance and a below-average recovery (e.g., parts of the Ruhr region). This observation is interesting insofar as it points to a potentially divergent economic development among regions throughout the crisis.

Fig. 1 Spatial patterns of resistance

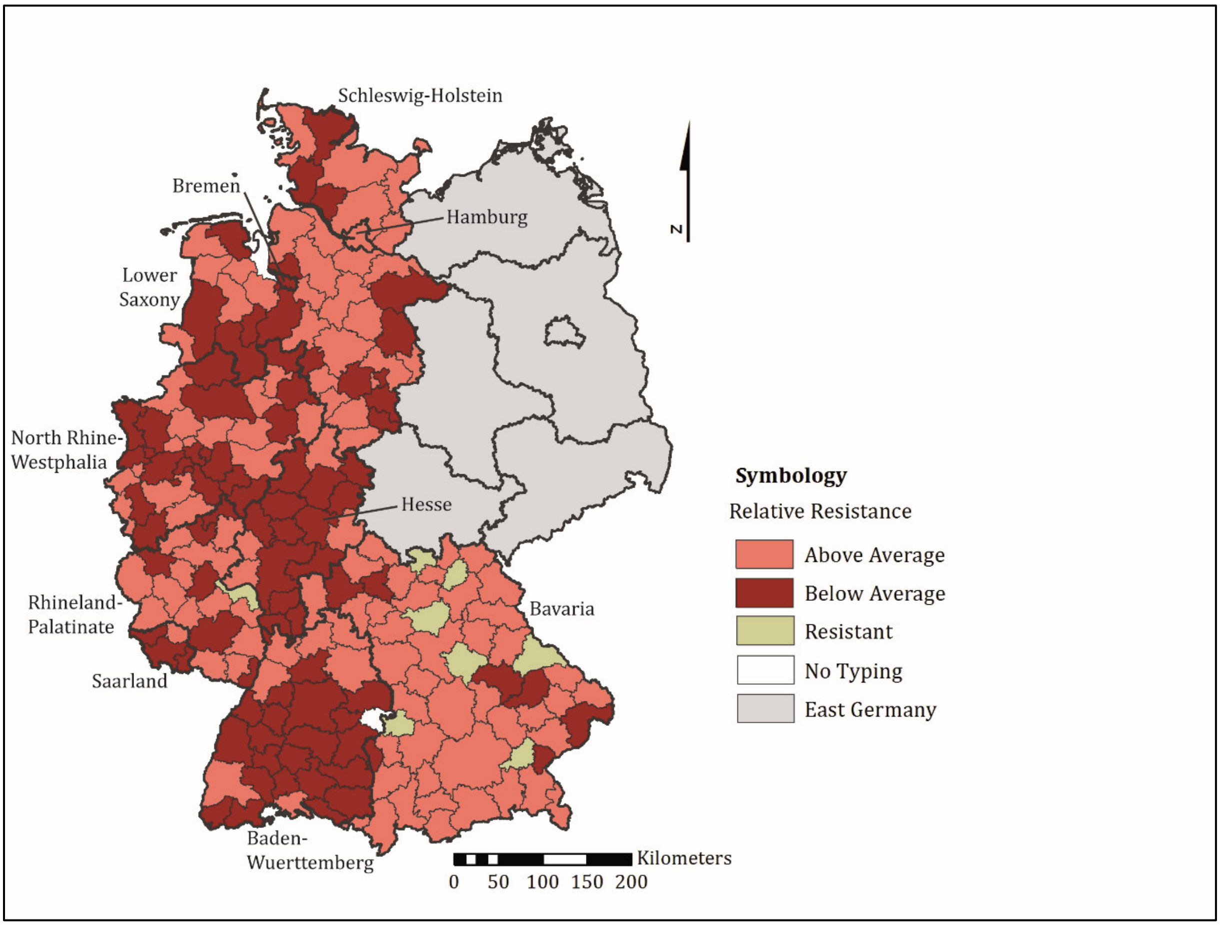
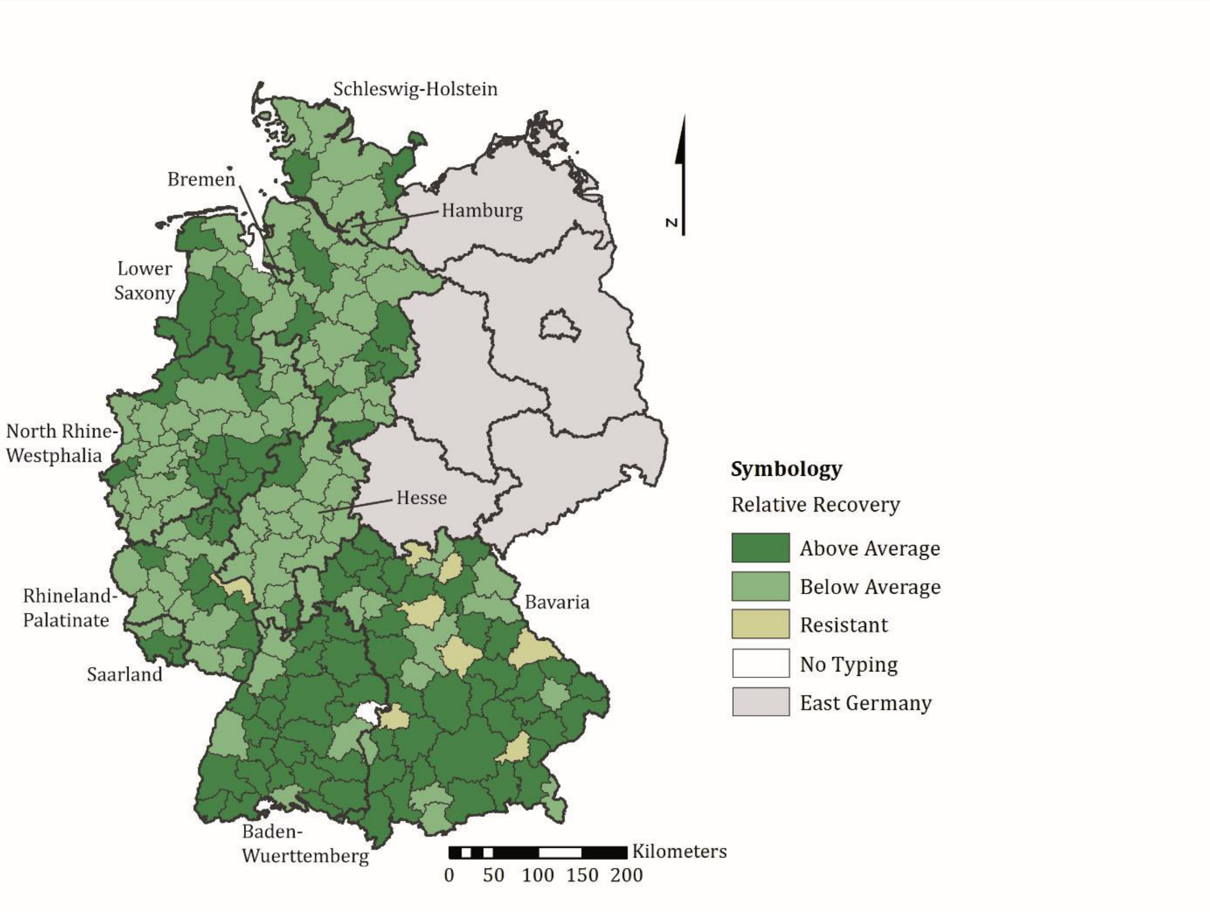


Fig. 2 Spatial patterns of recovery



4.2 Regression results and hypotheses

The spatial distribution as illustrated in Figure 1 and Figure 2, respectively, implies a moderate negative correlation between regional resistance and recovery. In fact, the corresponding Pearson coefficient takes on a value of (-) 0.413 and is significant at the level of 0.01 (two-sided). We thus can conclude that regions with a high degree of sensitivity also tend to perform better in terms of the subsequent recovery. This observation is supported by the OLS regression outcomes: Not only do the results confirm a significant negative relation between the (preceding) sensitivity and the regions' speed of recovery (Table 3 and 4); we also find an opposing, phase-specific impact on resistance (Table 1 and Table 2) and recovery (Table 3 and Table 4) from most of the independent variables. Furthermore, the differing impacts of unrelated and related variety on resistance (Table 2) and on recovery (Table 4) demonstrate the need to distinguish between different types of variety and analyze the 'nature' of diversification in more detail (see section 3.3).

Table 1: OLS regression results: Resistance models with ‘specialization’

Dependent Variable	**Growth Rate of Real GDP (2008 to Low Point)**					
	All Sectors		Knowledge-Intensive Sectors		Non-Knowledge-Intensive Sectors	
	Ia	Ib	IIa	IIb	IIIa	IIIb
Constant	***	**	***	**	**	*
	(0,109)	(0,116)	(0,105)	(0,115)	(0,110)	(0,116)
SPECIALIZATION	- 0,174*	- 0,025	- 0,271***	- 0,125^{+}	- 0,072	0,056
	(0,024)	(0,022)	(0,024)	(0,024)	(0,026)	(0,022)
R&D-Employment (Log)	0,026	0,154	0,044	0,144	0,030	0,173^{+}
	(0,008)	(0,008)	(0,007)	(0,007)	(0,008)	(0,008)
Labor Productivity (Log)	- 0,309***	- 0,266**	- 0,324***	- 0,283**	- 0,290**	- 0,255**
	(0,061)	(0,067)	(0,059)	(0,067)	(0,063)	(0,067)
Urban Region (Ref.: no)	- 0,294***	- 0,310***	- 0,321***	- 0,335***	- 0,248**	- 0,285***
	(0,006)	(0,006)	(0,006)	(0,006)	(0,006)	(0,006)
Large-Scale Firms		0,035		0,027		0,038
		(0,033)		(0,032)		(0,033)
Manufacturing Workforce		- 0,368***		- 0,323***		- 0,393***
		(0,000)		(0,000)		(0,000)
R^2	0,192	0,291	0,229	0,300	0,174	0,292
Adjusted R^2	0,174	0,267	0,212	0,277	0,156	0,269
F	9,970***	11,320***	12,547***	11,059***	9,180***	11,882***
N	189	189	189	189	189	189

heteroskedasticity-consistent standard errors in parantheses
***: significant at the level of 0,001 (two-sided), **: significant at the level of 0,01 (two-sided), *: significant at the level of 0,05 (two-sided), $^{+}$: significant at the level of 0,1 (two-sided)

(Source: own research based on table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014; the employment statistics of the 'Bundesagentur für Arbeit', version: June 2015; INKAR, issue 2014; 'Raumabgrenzungen', BBSR 2015)

Table 2: OLS regression results: Resistance models with 'unrelated' and 'related variety'

Dependent Variable	**Growth Rate of Real GDP (2008 to Low Point)**					
	All Sectors		Knowledge-Intensive Sectors		Non-Knowledge-Intensive Sectors	
	IVa	IVb	Va	Vb	VIa	VIb
Constant			**	**	$^{+}$	*
	(0,111)	(0,127)	(0,096)	(0,111)	(0,123)	(0,131)
UNRELATED VARIETY	0,298***	0,222**	0,347***	0,205*	0,070	0,044
	(0,013)	(0,012)	(0,006)	(0,006)	(0,017)	(0,015)
RELATED VARIETY	0,009	- 0,099	0,012	- 0,004	0,180^{+}	- 0,026
	(0,015)	(0,013)	(0,011)	(0,010)	(0,012)	(0,011)
R&D-Employment (Log)	0,040	0,134	0,036	0,126	0,034	0,157^{+}
	(0,008)	(0,007)	(0,008)	(0,008)	(0,008)	(0,007)
Labor Productivity (Log)	- 0,321***	- 0,292**	- 0,352***	- 0,311***	- 0,319***	- 0,265**
	(0,058)	(0,066)	(0,058)	(0,066)	(0,062)	(0,069)
Urban Region (Ref.: no)	- 0,316***	- 0,308***	- 0,363***	- 0,365***	- 0,324***	- 0,295***
	(0,006)	(0,006)	(0,006)	(0,006)	(0,006)	(0,006)
Large-Scale Firms		0,040		0,031		0,040
		(0,032)		(0,032)		(0,033)
Manufacturing Workforce		- 0,324***		- 0,288**		- 0,377***
		(0,000)		(0,000)		(0,000)
R^2	0,249	0,316	0,259	0,313	0,203	0,292
Adjusted R^2	0,229	0,290	0,239	0,287	0,181	0,264
F	11,724***	11,680***	11,594***	9,777***	8,437***	9,710***
N	189	189	189	189	189	189

heteroskedasticity-consistent standard errors in parantheses

***: significant at the level of 0,001 (two-sided), **: significant at the level of 0,01 (two-sided), *: significant at the level of 0,05 (two-sided), $^{+}$: significant at the level of 0,1 (two-sided)

(Source: own research based on table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014; the employment statistics of the 'Bundesagentur für Arbeit', version: June 2015; INKAR, issue 2014; 'Raumabgrenzungen', BBSR 2015)

Table 3: OLS regression results: Recovery models with 'specialization'

Dependent Variable	**Growth Rate of Real GDP (2009 to 2012)**								
	All Sectors			Knowledge-Intensive Sectors			Non-Knowledge-Intensive Sectors		
	VIIa	VIIb	VIIc	VIIIa	VIIIb	VIIIc	IXa	IXb	IXc
Constant	$^{+}$	$^{+}$		*	*			$^{+}$	
	(0,256)	(0,212)	(0,252)	(0,253)	(0,218)	(0,253)	(0,255)	(0,206)	(0,250)
SPECIALIZATION	0,263*	0,035	0,191*	0,350***	0,100	0,255**	0,190^{+}	0,003	0,153*
	(0,056)	(0,044)	(0,044)	(0,055)	(0,047)	(0,044)	(0,057)	(0,041)	(0,044)
R&D-Employment (Log)	0,205*	0,025	0,199*	0,164^{+}	0,026	0,168*	0,214*	0,019	0,208*
	(0,014)	(0,012)	(0,012)	(0,014)	(0,012)	(0,011)	(0,015)	(0,012)	(0,012)
Labor Productivity (Log)	0,223^{+}	0,182^{+}	0,107	0,239*	0,193^{+}	0,128	0,204^{+}	0,176^{+}	0,090
	(0,142)	(0,120)	(0,144)	(0,140)	(0,122)	(0,143)	(0,143)	(0,118)	(0,143)
Urban Region (Ref.: no)	- 0,001	0,045	- 0,127	0,022	0,062	- 0,101	- 0,043	0,034	- 0,156^{+}
	(0,012)	(0,011)	(0,011)	(0,012)	(0,010)	(0,011)	(0,011)	(0,010)	(0,010)
Large-Scale Firms		- 0,153*			- 0,147*			- 0,154*	
		(0,048)			(0,048)			(0,048)	
Manufacturing Workforce		0,583***			0,552***			0,594***	
		(0,001)			(0,001)			(0,001)	
Sensitivity[a]			- 0,400***			- 0,366***			- 0,418***
			(0,182)			(0,181)			(0,188)
R^2	0,130	0,379	0,258	0,178	0,384	0,281	0,108	0,378	0,250
Adjusted R^2	0,110	0,357	0,237	0,159	0,363	0,260	0,087	0,357	0,229
F	3,283*	12,175***	8,597***	5,225***	11,839***	9,349***	2,483*	12,131***	8,124***
N	182	182	182	182	182	182	182	182	182

[a]: Growth Rate of Real GDP (2008 to Low Point)

heteroskedasticity-consistent standard errors in parantheses

***: significant at the level of 0,001 (two-sided), **: significant at the level of 0,01 (two-sided), *: significant at the level of 0,05 (two-sided), $^{+}$: significant at the level of 0,1 (two-sided)

(Source: own research based on table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014; the employment statistics of the 'Bundesagentur für Arbeit', version: June 2015; INKAR, issue 2014; 'Raumabgrenzungen', BBSR 2015)

Table 4: OLS regression results: Recovery models with 'unrelated' and 'related variety'

Dependent Variable	**Growth Rate of Real GDP (2009 to 2012)**								
	All Sectors			Knowledge-Intensive Sectors			Non-Knowledge-Intensive Sectors		
	Xa	Xb	Xc	XIa	XIb	XIc	XIIa	XIIb	XIIc
Constant					+				
	(0,245)	(0,216)	(0,241)	(0,222)	(0,207)	(0,237)	(0,250)	(0,211)	(0,245)
UNRELATED VARIETY	-0,322*	-0,198+	-0,210+	-0,397***	-0,155	-0,276**	-0,106	-0,072	-0,072
	(0,034)	(0,030)	(0,030)	(0,014)	(0,014)	(0,012)	(0,037)	(0,027)	(0,029)
RELATED VARIETY	-0,069	0,113	-0,070	-0,044	0,001	-0,044	-0,263*	0,060	-0,194*
	(0,035)	(0,032)	(0,030)	(0,020)	(0,017)	(0,017)	(0,024)	(0,024)	(0,020)
R&D-Employment (Log)	0,176+	0,037	0,177*	0,179+	0,042	0,177*	0,192+	0,020	0,189*
	(0,014)	(0,012)	(0,012)	(0,015)	(0,013)	(0,012)	(0,014)	(0,012)	(0,012)
Labor Productivity (Log)	0,224+	0,199+	0,121	0,256*	0,212*	0,144	0,239*	0,176+	0,123
	(0,137)	(0,123)	(0,143)	(0,135)	(0,126)	(0,145)	(0,140)	(0,123)	(0,144)
Urban Region (Ref.: no)	0,020	0,030	-0,095	0,056	0,081	-0,072	0,037	0,016	-0,095
	(0,013)	(0,011)	(0,011)	(0,012)	(0,011)	(0,011)	(0,013)	(0,011)	(0,011)
Large-Scale Firms		-0,163*			-0,151*			-0,162*	
		(0,047)			(0,047)			(0,047)	
Manufacturing Workforce		0,558***			0,528***			0,603***	
		(0,001)			(0,001)			(0,001)	
Sensitivity[a]			-0,346***			-0,336**			-0,385***
			(0,189)			(0,188)			(0,186)
R^2	0,195	0,398	0,283	0,208	0,392	0,290	0,151	0,383	0,267
Adjusted R^2	0,173	0,374	0,258	0,186	0,367	0,266	0,127	0,358	0,242
F	4,471***	11,211***	7,981***	4,509***	12,102***	7,680***	3,875**	10,645***	7,583***
N	182	182	182	182	182	182	182	182	182

[a]: Growth Rate of Real GDP (2008 to Low Point)
heteroskedasticity-consistent standard errors in parantheses
***: significant at the level of 0,001 (two-sided), **: significant at the level of 0,01 (two-sided), *: significant at the level of 0,05 (two-sided), +: significant at the level of 0,1 (two-sided)
(Source: own research based on table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014; the employment statistics of the 'Bundesagentur für Arbeit', version: June 2015; INKAR, issue 2014; 'Raumabgrenzungen', BBSR 2015)

With respect to our hypotheses, we obtain the following results. Starting with regional specialization, we find preliminary support for hypotheses H1d and H2a according to which specialization in knowledge-intensive industries depresses regional resistance (H1d, Table 1) as well as it supports the subsequent recovery (H2a, Table 3). As described in section 2, we explain H1d by the presence of a regional 'dominance' effect, while we refer to productivity-driven efficiency as a reason for H2a. Empirical robustness checks, however, reveal that the opposing influence of knowledge-intensive specialization – negative in the case of resistance and positive during recovery – is not independent from the regional share of manufacturing workforce. Instead, we find evidence for the fact that the relationship between the independent variable X (knowledge-intensive specialization) and the dependent variable Y (real GDP growth rate) is either fully (H2a, Table 3) or at least partially mediated (H1d, Table 1) through the mediator variable M (share of manufacturing workforce).[9] It thus seems justified to conclude that the

[9] As a test for mediation, we successfully perform the four-step-procedure as proposed by Baron and Kenny (1986) and confirm the results by means of the Sobel test (1982) for both the resistance and recovery period.

specialization-driven impact on economic resilience is attributable to specialized manufacturing industries and not to specialization per se.[10]

This finding quite fits into the economic landscape of Western Germany which is marked by a number of highly competitive manufacturing clusters with a strong presence in the world markets (Federal Ministry for Economic Affairs and Energy 2016). Prominent examples are the chemical industry, the automotive sector, and machine engineering. Each of these leading industries is not only knowledge-intensive but also strongly export-oriented which explains their high exposure to the worldwide recession of 2008/2009 (see also Eltges et al. 2009, 3). In turn, the German exporting industries significantly contribute to the subsequent recovery as they derived above-average benefit particularly from the high demand for investment goods in the emerging economies (Lucke 2011). Furthermore, the export industries happened to be the main beneficiaries of some vital anti-cyclical policy measures taken by the national government in the form of car scrappage schemes or extended short-time working (see for instance Schwengler and Hecht 2011).

While we can provide support for the nevertheless mediated impact of knowledge-intensive specialization, we find no statistical evidence to underpin hypotheses H1b and H2c. Neither does specialization in non-knowledge-intensive industries strengthen a region's resistance to shocks (H1b), nor does it impede its capability to recover (H2c) (see Table 1 and Table 3). If at all, we obtain weak evidence for the opposite effect in case of H2c: non-knowledge-intensive specialization does not impede but tends to facilitate the recovery process, although to a much lesser (and statistically not robust) extent than knowledge-intensive specialization. This allows for two interpretations: In the first option, specialization in non-knowledge-intensive industries complements specialization in knowledge-intensive manufacturing clusters, which is why they are both exposed to the same mediation mechanism. An alternative interpretation, though, could read that non-knowledge-intensive specialization contributes to short-term regional stabilization through the absence of pro-cyclical reinforcements (which is a typical feature of knowledge-intensive specialization in export-oriented industries). It should, however, be kept in mind that non-knowledge-intensive specialization plays a less important role for economic resilience than knowledge-intensive specialization does, at least in the case of the highly developed Western German economy.

In line with hypotheses H1a and H2b, our results confirm a positive economic impact of unrelated variety in the resistance period (H1a) and a negative impact during the recovery phase (H2b). Although the statistical significance is reduced once we control for manufacturing industry workforce, the effects remain significant at the level of 0.01 (resistance) and 0.10 (recovery), respectively (see Table 2 and Table 4). As explicated in section 2, we substantiate H1a with the shock-mitigating absorption effect of unrelatedness, while we explain H2b with a lack of inter-industry knowledge transfers. Notwithstanding these results, we observe that the relation between unrelated variety and recovery growth is – similar to our findings for knowledge-

[10] Further evidence for this interpretation is provided by the positive and significant correlation between the degree of regional specialization as computed by means of (F3.1) and the regional share of manufacturing employment (R_g).

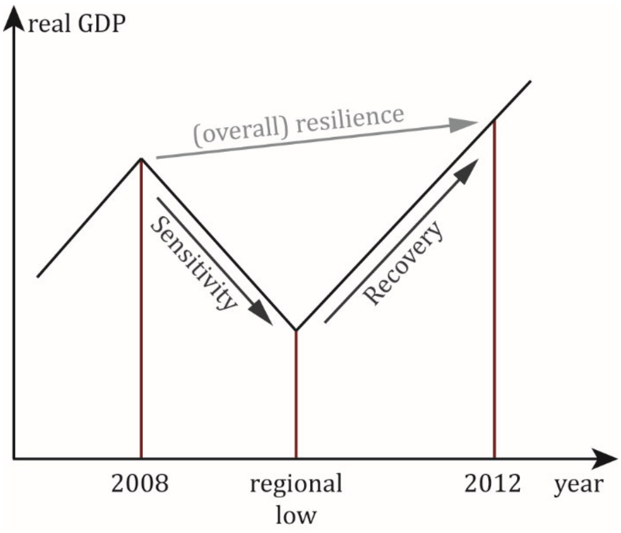
intensive specialization – at least partially mediated: the higher the share of manufacturing workforce, the lesser the obstructing impact of unrelated variety on recovery. Apparently, the resilience-relevant influence of the German manufacturing sector is to some extent independent from other regional characteristics of the industry structure.

Furthermore, the results hint at a two-fold impact of related variety among non-knowledge-intensive industries: For one thing, it tends to strengthen regional resistance as a presumable result of the 'distribution' effect (H1c, see section 2). Then again (and contrary to our assumptions), it seems to reduce the region's capacities to bounce back, which indicates an unexpected disruptive effect stemming from non-knowledge-intensive relatedness. Both effects, however, are not statistically robust and are mediated by the regional manufacturing workforce, respectively. Finally, we find no significant influence of related variety among knowledge-intensive industries, neither in the resistance phase nor during the recovery process. These two findings are in line with our theoretical reasoning: We take into consideration that the 'contagion' and the 'distribution' effect might cancel each other out (referred to the resistance phase) as well as we argue that the beneficial effects from related spillovers are likely to evolve in a long-term rather than in a short-time perspective (see section 2). The question, whether our empirical observations allow for useful recommendations for policy makers, will be addressed in the next section.

5 Conclusions and implications for future research

Compared to previous studies, our approach is multi-faceted in a sense that it takes into account both two subsequent components of regional economic resilience (resistance and recovery) and three different forms of agglomeration economies (specialization, related and unrelated variety) including a further distinction in terms of knowledge-intensity. The necessity to distinguish between different phases and factors is well documented by means of our regression results. As presented in section 4.2, both agglomeration economies and important controls as manufacturing workforce, labor productivity and others reveal varying, if not opposing directions of influences across the resistance and recovery phase (see Table 1 to 4). Hence, ignoring the two-component structure of short-term regional resilience would suppress the phase-specific downs and ups that are directly resulting from the shock (see Fig. 3). Consequently, the impact of resilience-related determinants, be it industry structure, innovative capacities or others, would not be estimated correctly. This entails the risk of imprecise, if not false conclusions on the driving mechanisms stabilizing and/or destabilizing regional economies in times of crisis. We assume that the missing distinction between resistance and recovery is an important reason why previous studies on regional resilience yielded rather inconsistent results (see section 1).

Fig. 3 Two-component structure of short-term resilience



For policy makers, our results convey three important messages: First, a relatively strong specialization in manufacturing industries not only leads to a higher vulnerability to exogenous demand shocks and thereby puts regional economic resources at risk. It also limits the self-healing capacities and makes it dependent from exogenous stimuli. In the case of Western Germany, it took both fiscal incentives in the form of, for instance, the car scrappage scheme and extended short-time working arrangements and the re-strengthening of international demand for long-term investment goods. From an economic perspective, this is a mixed blessing. On the one hand, exogenous stimuli ensure a comparatively quick stabilization and support recovery. On the other hand, though, they reinforce already existing industry structures and thereby foster further specialization which caused vulnerability in the first place. Therefore, policy makers should understand the specific crisis trajectory of specialized regions not as a success story at last. Instead, they are well advised to interpret it as a warning shot that reminds of the necessity of a more balanced and diversified economic portfolio to prevent negative path dependencies and regional lock-ins.

Second, although the results suggest an increasing exposure to exogenous shocks in case of knowledge-intensive specialization (see Table 1), this certainly does not constitute a recommendation to scale back the knowledge capabilities of a regional economy. Of course, the higher vulnerability does not result from knowledge-intensity per se, but from the mostly export-oriented nature of the associated industries, which especially holds true for the case of Western Germany. Rather, the findings highlight the risks that usually correlate with a strong dependence on export markets which calls for a broader risk spread including a stronger role of the domestic market. The essential function of knowledge for long-term economic prosperity (according to the broad body of theoretical and empirical literature on new growth theories) is, however, not put into question.

The third important policy message is that diversification should not be directed at unrelated variety. According to our analysis, unrelatedness undermines the region's capacity to recover which points to deficiencies in the synergetic re-allocation of production factors between regional industries. Against this background, it at least seems questionable if unrelated variety could contribute to regional economic renewal and re-orientation in the long run. This eventually leaves us with related variety or diversified specialization as a guiding principle for regional policy, preferably among knowledge-intensive industries. So far, the beneficial impact of relatedness on renewal and re-orientation has only been supported by theoretical considerations (as set out in section 2) since our empirical analysis – along with other studies on this subject - does not include the required data series which finally brings us to the requirement of future research.

In our assessment, future research on regional economic resilience could be centered around five keystones. First, longer data series along with longitudinal analyses could help not only to gain reliable insights in the long-term impact of related (knowledge-intensive) industries. They would also allow for comparisons between effects from various kinds of economic shocks (as a drop in demand is only one of them) including coincident challenges stemming from 'slow burns' (Martin and Sunley 2014, 16f.). Second, exploring the variation of so far independent variables (agglomeration economies and alike) could help answering the question of how specialized and unrelated industry structures could be transformed into relatedness and thus deliver basics for a new policy design. Third, cross-country comparisons are desirable to identify specific macroeconomic, institutional, and cultural settings that shape and determine the framework for the resilience capacities at lower levels. Fourth, further regression analyses necessarily need to include the micro level since firms – and not regions – are the actual agents of economic resilience (Martin 2012, 28). Modelling the firm level would as well help to lower the risk of ecological fallacies (Robinson 1950; Coleman 1991); an appropriate instrument for the integration of different spatial levels (e.g., firms, regions, and nations) is provided by multi-level analysis (Hundt and Sternberg 2014; Hundt and Sternberg 2016). Fifth, qualitative case studies are necessary to overcome the traditional boundaries of regression-based approaches by adding so far concealed insights from the complex relational structures among regional actors and decision makers (e.g., Hundt et al. 2017).

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Appendices

Appendix A1-A4 Variance Inflation Factors (VIF) for the OLS models

Dependent Variable	Growth Rate of Real GDP (2008 to Low Point)					
	All Sectors		Knowledge-Intensive Sectors		Non-Knowledge-Intensive Sectors	
	Ia	Ib	IIa	IIb	IIIa	IIIb
	VIF		VIF		VIF	
SPECIALIZATION	1,396	1,620	1,251	1,554	1,311	1,450
R&D-Employment (Log)	1,209	1,393	1,198	1,353	1,228	1,418
Labor Productivity (Log)	1,415	1,565	1,413	1,566	1,398	1,545
Urban Region (Ref.: no)	1,463	1,515	1,389	1,441	1,396	1,462
Large-Scale Firms		1,401		1,405		1,397
Manufacturing Workforce		1,388		1,486		1,322

Dependent Variable	Growth Rate of Real GDP (2008 to Low Point)					
	All Sectors		Knowledge-Intensive Sectors		Non-Knowledge-Intensive Sectors	
	IVa	IVb	Va	Vb	VIa	VIb
	VIF		VIF		VIF	
UNRELATED VARIETY	1,816	1,909	1,593	1,975	1,225	1,240
RELATED VARIETY	2,126	2,301	1,241	1,271	1,793	2,269
R&D-Employment (Log)	1,207	1,361	1,243	1,421	1,201	1,392
Labor Productivity (Log)	1,405	1,563	1,521	1,729	1,425	1,607
Urban Region (Ref.: no)	1,575	1,632	1,447	1,504	1,639	1,709
Large-Scale Firms		1,399		1,429		1,403
Manufacturing Workforce		1,575		1,548		1,601

Dependent Variable	Growth Rate of Real GDP (2009 to 2012)								
	All Sectors			Knowledge-Intensive Sectors			Non-Knowledge-Intensive Sectors		
	VIIa	VIIb	VIIc	VIIIa	VIIIb	VIIIc	IXa	IXb	IXc
		VIF			VIF			VIF	
SPECIALIZATION	1,382	1,596	1,423	1,251	1,557	1,339	1,305	1,440	1,315
R&D-Employment (Log)	1,226	1,389	1,226	1,217	1,339	1,217	1,253	1,429	1,254
Labor Productivity (Log)	1,415	1,545	1,520	1,417	1,550	1,537	1,400	1,525	1,491
Urban Region (Ref.: no)	1,461	1,528	1,585	1,405	1,468	1,554	1,387	1,468	1,478
Large-Scale Firms		1,387			1,391			1,384	
Manufacturing Workforce		1,372			1,479			1,309	
Sensitivity			1,256			1,306			1,229

Dependent Variable	Growth Rate of Real GDP (2009 to 2012)								
	All Sectors			Knowledge-Intensive Sectors			Non-Knowledge-Intensive Sectors		
	Xa	Xb	Xc	XIa	XIb	XIc	XIIa	XIIb	XIIc
		VIF			VIF			VIF	
UNRELATED VARIETY	1,825	1,926	1,966	1,591	1,955	1,769	1,222	1,240	1,231
RELATED VARIETY	2,157	2,320	2,157	1,277	1,305	1,277	1,797	2,256	1,838
R&D-Employment (Log)	1,220	1,355	1,220	1,260	1,412	1,260	1,217	1,384	1,217
Labor Productivity (Log)	1,403	1,538	1,525	1,531	1,711	1,685	1,429	1,584	1,545
Urban Region (Ref.: no)	1,574	1,637	1,727	1,441	1,512	1,643	1,633	1,705	1,783
Large-Scale Firms		1,392			1,411			1,396	
Manufacturing Workforce		1,554			1,534			1,582	
Sensitivity			1,370			1,380			1,278

Appendix B1-B3 Operationalization and data sources of the dependent and independent variables (incl. control variables)

Dependent variables	
Variable	**Sensitivity**
Operationalization	Growth rate of real GDP from 2008 to regional low point
Data source	Table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014
Variable	**Recovery**
Operationalization	Growth rate of real GDP from regional low point to 2012
Data source	Table 426-71-4 of the 'Regionaldatenbank Deutschland', state of calculation: August 2014

Independent variables	
Variable	**Specialization**
Operationalization	Gini-Index for regional specialization at the two-digit level of the industry classification of the Federal Employment Agency (WZ 2008)
Data source	Employment statistics of the Federal Employment Agency ('Bundesagentur für Arbeit'), employees subject to social insurance contributions by 'Wirtschaftsabteilungen' (two-digits) and 'Wirtschaftsklassen' (four-digits) of the industry classification (WZ 2008) in administrative districts and cities, reporting date 31.03.2008, Nuremberg, version June 2015
Variable	**Unrelated Variety**
Operationalization	Entropy at the two-digit level of the WZ 2008
Data source	Employment statistics of the Federal Employment Agency ('Bundesagentur für Arbeit'), employees subject to social insurance contributions by 'Wirtschaftsabteilungen' (two-digits) and 'Wirtschaftsklassen' (four-digits) of the industry classification (WZ 2008) in administrative districts and cities, reporting date 31.03.2008, Nuremberg, version June 2015
Variable	**Related Variety**
Operationalization	Weighted sum of entropy at the four-digit-level within the respective two-digit industries of the WZ 2008
Data source	Employment statistics of the Federal Employment Agency ('Bundesagentur für Arbeit'), employees subject to social insurance contributions by 'Wirtschaftsabteilungen' (two-digits) and 'Wirtschaftsklassen' (four-digits) of the industry classification (WZ 2008) in administrative districts and cities, reporting date 31.03.2008, Nuremberg, version June 2015

Control variables	
Variable	**R&D-Employment**
Operationalization	Employees in R&D per 1 000 employees subject to social insurance contributions (2007)
Data source	Indicators and maps on spatial and urban development. INKAR, version 2014. Ed.: 'Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)', Bonn 2015 © 2015 Bundesamt für Bauwesen und Raumordnung, Bonn
Variable	**Labor Productivity**
Operationalization	GDP in 1 000 EUR per gainfully employed person (2007)
Data source	Indicators and maps on spatial and urban development. INKAR, version 2014. Ed.: 'Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)', Bonn 2015 © 2015 Bundesamt für Bauwesen und Raumordnung, Bonn
Variable	**Urban Region**
Operationalization	Is the LMR an urban region? (Ref.: no); 1 = yes, 0 = no
Data source	Spatial distinctions: reference data and maps. Labor Market Regions: types of settlement structure. BBSR Bonn (Accessed 12 September 2016)
Variable	**Large-Scale Firms**
Operationalization	Share of firms with more than 250 employees subject to social insurance contributions in all firms in ‰ (2007)
Data source	Indicators and maps on spatial and urban development. INKAR, version 2014. Ed.: 'Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)', Bonn 2015 © 2015 Bundesamt für Bauwesen und Raumordnung, Bonn
Variable	**Manufacturing Industry Workforce**
Operationalization	Share of gainfully employed persons in manufacturing in all gainfully employed persons * 100 (2007)
Data source	Indicators and maps on spatial and urban development. INKAR, version 2014. Ed.: 'Bundesinstitut für Bau-, Stadt- und Raumforschung (BBSR) im Bundesamt für Bauwesen und Raumordnung (BBR)', Bonn 2015 © 2015 Bundesamt für Bauwesen und Raumordnung, Bonn