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Regional resilience and fat tails: A stochastic analysis of firm growth rate distributions of German regions.

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Abstract:

This paper breaks down the distributional analysis of firm growth rates to the domain of regions. Extreme growth events, i.e. fat tails, are conceptualized as an indicator of competitive regional environments which enable processes like structural adaptation or technological re-orientation. An understanding of the heterogeneous dynamics at the level of firms, the "turbulence underneath the big calm" (Dosi et al. 2012), provides a micro-funded empirical perspective on the evolutionary dimension of regional resilience. Therefore, the flexible Asymmetric Exponential Power (AEP) density is fitted to firm data for each German region during the years of economic downturn (2008-2010). Peculiarities of employment growth are explicitly taken into account by applying a new maximum likelihood estimation procedure with order statistics (Bottazzi 2012). The estimated parameters, which measure the tails' fatness, are then related to various region-specific factors that are discussed in the literature on regional resilience. Results show that firm growth rate distributions remain asymmetric and fat tailed at the spatially disaggregated level, but their shape markedly differ across regions. Extreme growth events, i.e. firm-level turbulences, are primarily a phenomenon of economically better performing regions at the aggregate level and further intensified by the presence of a higher qualified workforce. Besides, the fatness of the tails depends on the regions' industrial structure.

Keywords: regional resilience, firm growth, growth rates distributions, fat tails, asymmetric exponential power, evolutionary perspective

JEL Classifications: R11, L16, C46

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1. INTRODUCTION

The concept of regional resilience, popular among scholars and politicians who are concerned with the development of regions, seeks to understand how regional economies are able to cope with disturbances like the recent economic crisis (MARTIN 2012). Empirical attempts to measure regional resilience usually look at changes in regional indicators, like the unemployment rate, employment or income level, to assess the impact of an external shock on a regional economy's growth path or the time it needs to recover. Besides a vast amount of case studies of individual regions, only few systematic cross-sectional studies exist (e.g., CHAPPLE & LESTER 2010, FINGLETON et al. 2012). In most of these studies, an equilibrium-oriented neoclassical notion is prevalent. In contrast hereto, the evolutionary perspective on regional resilience is strongly related to internal processes like adaptation and structural re-orientation. These processes work at the level of firms, which FRENKEN & BOSCHMA (2007) call the true agents of change. For instance, new technological trajectories have to be explored by the region's firms, leading to "turbulence underneath the big calm" (DOSI et al. 2012). A significant share of extremely growing as well as shrinking firms indicates a region's potential to de-lock from its old path and to re-invent itself. Hence, the questions arise how the way firms grow differ across regions. More precisely, which region-specific factors are related to the occurrence of extreme growth events and, consequently, might contribute to regional resilience from an evolutionary point of view.

To answer these questions, the stochastic analysis of firm growth rates is broken down to the domain of regions. Meanwhile, it counts as a stylized fact that their distribution shows fat tails and an asymmetric shape. By fitting the flexible Asymmetric Exponential Power density (AEP) to firm data for each German region during the years of economic downturn (2008-2010), the estimated parameters, which measure the tails' fatness, can be related to various region-specific factors that are discussed in the literature on regional resilience. Peculiarities of employment growth are explicitly taken into account to improve the quality of estimation. Therefore, a conceptual model is provided which distinguishes between firms that retain their number of employees, and firms that actually do grow by expanding or reducing their number of employees. The latter events, discrete by nature, can best be modelled with continuous probability distributions by leaving out the central part of the distribution around zero. This approach is legitimized by the commonly high number of zero growth events in firm data. A new maximum likelihood estimation procedure with order statistics (BOTTAZZI 2012) is applied to estimate only both tails of the distributions.

Results show that firm growth rate distributions remain asymmetric and fat tailed at the spatially disaggregated level, but their shape markedly differ across regions. Extreme growth events are more likely to occur in regions which show a stronger aggregate performance and have a higher number of employees with university degree. The latter confirms GLAESER et al. (2011) who ascribe the workforce skill a key role in making regions resilient. Furthermore, the fatness of the tails depends on the regions' industrial structure.

The remaining paper is structured as follows. Section 2 bridges three different streams of literature. Firstly, it shows how the theoretical concept of regional resilience can be enriched by considering the heterogeneous responses and dynamics at the level of firms. Secondly, it extends the literature of firm growth rate distributions to the domain of regions, allowing for new insights by systematically comparing other moments than the distributions' mean across regions. Thirdly, it argues that due to the discrete nature of employment changes, additional measures have to be taken into account when fitting continuous distribution functions like the AEP. Finally, the main propositions to be investigated are presented. Section 3 discusses both the firm level and regional level data, while section 4 introduces into the AEP distribution function and the estimation procedure. After setting up regression models to explain the regional differences in the estimated distributional parameters, section 5 discusses the results. Finally, section 6 evinces some limitations of this approach and concludes.

2. LITERATURE

2.1. Regional resilience – insights from growth processes at the level of firms

The theoretical concept of resilience, which originates from studies of ecological dynamics and socio-ecological systems (WALKER & SALT 2006), is increasingly applied to the domain of regional development, in particular to analyse responses of regions to major recessionary shocks and the effects of recessions on regional growth paths. Being a rather broad and multifaceted concept, MARTIN (2012) identifies four dimensions of regional resilience: resilience as resistance, recovery, structural re-orientation and renewal or resumption of a growth path. The first two roughly correspond to the concepts of engineering resilience, which focus on the resistance of a system to disturbances and the speed it takes to return to its pre-shock state, and ecological resilience, which analyse the magnitude of shocks that can be absorbed before the system changes form, function or position (HUDSON 2010). The two latter dimensions provide a rather evolutionary perspective. Resilience as a dynamic process can mean the ability of a regional economy to reconfigure and adapt its structure in order to maintain an acceptable growth path or the ability to create new variety or novelty in response to external shocks (MARTIN 2012). The creation of novelty, the "ultimate cause of endogenous change" (WITT 2008), is ascribed a prominent role. However, the ability of a region to permanently re-invent itself might be blocked by the regional socio-economic conditions (GILBERT 2012). In this context, disturbances, which are often reinforced by recessions, can have positive effects by releasing potential for structural adaptation: "A deep recession may sweep away outmoded and unproductive activities, the removal of which opens up opportunities for the development of new sectors and a new phase of growth" (MARTIN 2012: 11).

Already REGGIANI et al. (2002: 215) distinguished between the robustness and changeability of a system: "resilience points out the 'possibility to change', while stability emphasises the 'impossibility to change'". Empirical studies (e.g., FINGLETON et al. 2012, DAVIES 2011), on contrary, find it rather difficult to go beyond resistance and recovery: an evolutionary view can be hardly conceptualized by remaining at the level of regions and industries. Evolutionary processes work at the level of firms, which are the true agents of change, and might be hidden by spatial or industrial aggregation (FRENKEN & BOSCHMA 2007). For example, new technologies or business models emerge within firms, but are reflected only decades later in the static industrial classification scheme. As MARTIN (2012) states, a key to understand regional resilience is the analysis of reactions and adjustments of firms, which ultimately determine the aggregate regional outcomes. The (un)successful adaptation of firms translate into their economic performance, resulting into turbulences, which are often reinforced by external conditions and might even push the whole regional economic system beyond thresholds of bifurcation points to new stability domains. Essentially, such turbulences, i.e. significant and specific historical moments (MARTIN & SUNLEY 2012), are required to de-lock from path dependencies (SIMMIE & MARTIN 2010). Moreover, ARCHIBUGI et al. (2013) uncovered that the crisis led to a concentration of innovative activities within a small group of fast growing new firms and those firms already highly innovative before the crisis. They argue that during phases of economic uncertainty about technological trajectories, demand conditions and new market opportunities, the exploration of new products and markets become even more important. Firms engaging in this risky strategy will be more exposed to either success or failure. To conclude, turbulences, manifested by extreme negative and positive growth events at the level of firms, are the driver of evolutionary development processes and the related adjustment to recessions. As SETTERFIELD (2010: 8) put it, “extreme experiences that propel a system sufficiently far from its current state are thought to result in structural change”. Plotting the frequency distribution of firm growth rates, fat tails are an indicator of highly dynamic, vibrant and re-inventing regional economies.

Arriving at the level of firms, one has to ask which role the firms’ location plays in shaping their dynamics. BARBOSA & EIRIZ (2011) distinguish between two ways why the spatial dimension matters, namely by general environmental factors, which are external to firms, unevenly distributed across space and imperfectly mobile, and by the role of proximity. The latter has recently become popular in studies analysing the effects of industrial agglomerations, although its roots can be traced back to MARSHALL’s (1890) trinity of external economies. Mostly focusing on spatially bounded knowledge spillovers, empirical studies have analysed the impact of agglomerations, industrial clusters, access to universities, or regional innovation systems, with the notion of interactive learning and innovation, on the growth of firms (see FRENKEN et al. 2011 for a survey on the empirical literature). These studies also indicate that the regional dimension is especially relevant for highly shrinking and expanding firms (e.g., FORNAHL & OTTO 2008, DUSCHL et al. 2011). Briefly stated, the way how firms grow is shaped by factors external to them, but internal to regions.

Moreover, the dynamics at the level of firms are a key to understand processes and outcomes at the level of regions. However, the responses of firms to economic crises, which might be mediated or constrained by regional factors (HOOGSTRA & VANDIJK 2004), are far from straightforward: “Some firms prosper in recessions while others fare very badly” (GEROSKI & GREGG 1996: 551). What these authors call selectivity is a ubiquitous and persistent heterogeneity of firms and their responses, letting DOSI et al. (2010) make a plea for considering entire distributions instead of averages for assessing the relationship between the micro and the macro. This is confirmed by HIGSON et al. (2004) or HOLLY et al. (2013), who find that firm growth rate distributions change systematically over business cycles and also contribute to shaping macroeconomic fluctuations. An example may illustrate what firm dynamics reveal about the resilience of a regional system. The regional economies A and B, both with an unchanging number of total employees, might show at the same time quite different dynamics at the level of firms. In A, not any single firm is growing, whereas B is confronted with turbulences due to many shrinking and expanding firms. The long-term outcomes of both regions probably will differ: B seems to be more able to reconfigure its structure and to adapt to changing environments, hence ultimately exploiting new technological opportunities. I argue that the evolutionary dimension of regional resilience is hidden in the dynamics of firms and thus can be uncovered by analysing their distribution of growth rates. Hereby, the average growth rate has little to tell, because it obscures turbulences, as the example has demonstrated. Besides, most firms are able to withstand external forces and even remain unaffected at all by macroeconomic recessions. Only after exceeding a certain threshold, some firms are badly hit, while others might benefit strongly from such path-breaking crisis. Put differently, the secret lies in the tails of the distribution.

2.2. The distribution of firm growth rates – a regional perspective

The previous section argues that the entire distribution provides a more complete picture than single moments like the arithmetic mean. Although knowing the distributional form of a specific phenomenon is a valuable insight by itself, further information is revealed by comparing it to a reference distribution. As such, three options are conceivable.

First, empirically estimated distributions can be used to verify expectations derived from theoretical models. GIBRAT's (1931) "law of proportionate effect", meanwhile a common starting point in the literature of industrial organizations, requires in its strong version to hold normal distributed growth rates (AMARAL et al. 1997, COAD 2009). But instead of a bell-shaped normal curve, a tent-like shaped symmetric exponential one, also known as the Laplace distribution, is observed on basis of firm level data from several countries (e.g., STANLEY et al. 1996 for US, BOTTAZZI et al. 2002 for Italy) and at the disaggregated level of industries (BOTTAZZI et al. 2001 for the pharmaceutical industry). To account for this stylized fact, new stochastic models of firm growth have been developed (e.g, FU et al. 2005, BOTTAZZI & SECCHI 2006, COAD 2012). Subsequently, empirical evidence was reported for the income growth rates of countries, that is, at a much higher level of economic aggregation (e.g., LEE et al. 1998, AMARAL et al. 2001, MAASOUMI et al. 2007, FAGIOLO et al. 2008). Only recently, a research gap at the intermediate level of industries (CASTALDI & SAPIO 2008) and spatial aggregation (DUSCHL & BRENNER 2013) was filled, indicating that these models can be generalized to hold for the growth of all complex economic organizations irrespective of the level of aggregation. Besides, empirical evidence is emerging that these distributions show tails significantly fatter than the Laplacian ones and an asymmetric shape (e.g., BOTTAZZI et al. 2011, DUSCHL & BRENNER 2013, REICHSTEIN & JENSEN 2005), provoking BOTTAZZI & SECCHI (2011) to develop the even more flexible five-parameter AEP. This refined evidence still waits to be explained by new stochastic models more accurately.

Secondly, distributions can be conditioned on further variables, enabling the analysis of their impact by comparing the shape of the conditional and unconditional distribution. For instance, this exercise is found in BOTTAZZI et al. (2012) or MAASOUMI et al. (2007: 499). The latter already note that in the residual growth rates "control is only achieved on the mean of the growth rates, and the variables may continue to impact on other distributional characteristics". This is one reason why this approach has been rather rarely applied.

Thirdly, distributions of the same type of observational unit can be compared by taking empirical snapshots in various contexts.[1] Growth rate distributions of firms belonging to different industries (e.g., BOTTAZZI & SECCHI 2003) are used to confirm that predictions from stochastic models survive at different levels of industrial disaggregation. Introducing the time dimension, DOSI et al. (2012) point out the heterogeneous impact of the Euro adoption on the performance of Italian manufacturing firms. At the regional level, BARBOSA & EIRIZ (2011) investigate the way how firms grow by visually comparing the evolution of the firm size densities of 19 Portuguese regions. The paper at hand aims to uncover the region-specific factors leading to differences in the distributional characteristics of the regions' firm growth rates by relating them to the estimated parameters. It focuses particularly on

[1] Each of the three strategies has its own advantages in highlighting specific aspects of a complex phenomenon. The latter approach of systematically comparing estimates of distributional parameters is particularly insightful in situations in which a high number of samples are available. By letting the data speak, it is a response to difficulties of theoretical models and simulation studies, which are confronted by the existence of a hypothetically unlimited number of economic mechanisms that may be able to explain the emergence of fat-tailed distributions (ALFARANO & MILAKOVIC 2008).

explaining the tails of the distribution, which are, as has been argued above, a measure of internal turbulences and, as such, an indicator of the regions' resilience capacity.

2.3. Estimation of the AEP density – specificities of employment growth

Up to here, nothing has been said about the various measures of firm growth, like sales, turnover, productivity or employment, all governed by distinct mechanisms (COAD 2009). Whereas the first three primarily concern business managers, employment growth is of utmost relevance for regional policy makers, even more so during times of economic crisis (MARTIN 2012). All measures share the common property that the underlying change events are not, strictly speaking, continuous. An inherent discreteness becomes particularly apparent for employees, which are by nature indivisible. COAD (2012: 17) takes this reasoning seriously by putting the reactions of firms to growth stimuli at the heart of his stochastic model: "The lumpy nature of resources within a firm implies that firm expansion is characterized by non-constant marginal costs that depend on the degree of utilization of the firm's resources". Consequently, fat tailed distributions of growth rates emerge as firms tend to a critical state of full utilization of resources: if resources are already more or less fully employed, then growth will only be possible with addition of extra resources, while the "interdependent nature of discrete resources may lead to triggering off of a series of additions to a firm's resources". The resulting growth process might show non-linearities as firms add indivisible resources to arrive at efficient levels of production.

The incentive to exploit unused resources provides an intentional perspective on growth, in contrast to GIBRAT's law and island models (e.g., IJIRI & SIMON 1997, SUTTON 1998, BOTTAZZI & SECCHI 2006), in which growth opportunities are passively absorbed and accumulated (COAD 2009). Taking both perspectives into account, a conceptual two-step firm growth model is proposed, which disentangles the outcome of a change in the number of employees from the actual growth processes. Put simply, in a first step each of the N firms is confronted with the options to grow or not grow based on its internal resource composition and the external business opportunities. The choice between both options can be modelled as a binomial process with probability p, in which $p*N$ firms prefer to change the number of employees and $(1-p)*N$ firms prefer to remain at the previous level. In a second step, all of those firms which experience a kind of growth impulse because of the mismatch between opportunities and their level of resources try to respond by integrating new or by releasing existing resources. This ultimately leads to h expanding and k shrinking firms. The remaining $p*N - (h+k)$ firms are composed of those that prefer to grow but are not able to, and thus delaying their growth momentum.

Leaving aside the question whether or not both steps represent analytically distinguishable phenomena, they are appropriate from a stochastic point of view. Assuming a continuous probability distribution function, the realization of a specific empirical value occurs in the limit with zero probability. This clearly contrasts with the observed occurrences of zero-growth events in typical databases – in Bureau van Dijk they amount for up to 50% of all events, and COAD & HÖLZL (2009) even report that 65% of small establishments listed in the Austrian Social Security files do not display any changes in employment from one year to the next. This abundance of zero-growth events calls for an explanation. Firstly, following the proposed model, firms simply may prefer to remain at the previous level of employees. This can be an economically rational choice in absence of any changes in business opportunities, but it can also be the preferred choice in cases when opportunities have changed. To name just a few examples, firms might be reluctant to expand because the inclusion of new employees is costly as it implies re-organisation of internal tasks and management functions, the labour market might only insufficiently meet the demand for (qualified) workers, or the fear of losing control might frighten some managers (COAD 2009). In a similar vein, firms can be reluctant to shrink despite reduced business opportunities. Firms invest in building up redundancies in difficult times instead of immediately dissolving existing working contracts, or managers might be not fully aware of the necessary down-sizing. Secondly, there are those firms that prefer to grow but are not able to do so. This is due to the discrete nature of employees, which inhibit a firm to marginally increase or decrease their size by, say, a quarter of employee. Instead, these firms first respond by re-organizing tasks internally. Although it is still an issue for actually growing firms, it becomes statistically less and less relevant as the number of employees to change increases. Around zero, however, the discreteness is fully noticeable to the firms' ability to grow. Thirdly, firm databases sometimes lack a regular updating of their entries, resulting in many zero-growth events as simple extrapolations. Briefly stated, zero-growth events arise due to the choice of avoiding growth, the inability to grow and data problems. The latter makes it impossible to recover *p*, restricting the analysis to the actual growing firms. However, an entire exclusion of zero-growth rates would bias the estimation of a continuous probability distribution function because those firms not able to grow due to the discrete nature of employees would be dismissed. Therefore, this paper deals with a method for estimating the AEP while at the same time leaving out the central part around zero.

2.4. Main propositions

Placing dynamics of firms' employees at the heart of regional resilience, two general propositions are stated:

- **Proposition 1:** A region's firm growth rate distribution is asymmetric and fat tailed, but its exact shape, especially its tail behaviour, differs across regions.
- **Proposition 2**: The tails' fatness systematically depends on regional factors, which provides a first assessment of the potential for evolutionary resilience.

The first proposition arises from the empirical observations which show that the way how firms grow depend on factors specific to the region they are located in (see section 2.1). Nevertheless, two stylized facts of firm growth rate distributions, namely fat tails and asymmetry, should already become visible when taking regions as the reference system. The second proposition needs to be further elaborated. The underlying firm dynamics of a regional economy reveal whether it is resilient from an evolutionary view. As CAPASSO et al. (2011) state it: "one of the major economic implications of heavy tails is that fast-growing firms account for a non-neglible share of an industry population and drive the industry dynamics entirely". Positive fat tails indicate the ability of a regional system to adapt its structure: extreme positive growth events result from the exploration of new technologies or business models, which creates new opportunities to spur growth. The other side of the coin is that evolution driven by the creation of new variety implies that existing modes of activities become outdated. But only in competitive regional environments, firms unable or unwilling to adapt will perform worse, thus increasing the likelihood of extreme negative growth events. In short, a regional economy with fat tails on both sides of the firm growth rates distribution is assumed to have a higher adaptive capacity. This is defined as resilience from an evolutionary perspective.

3. DATA

3.1. Firm level data

This paper analyses growth processes of firms and compares their stochastic properties across different regions. Firm level data are retrieved from the BvD Amadeus database in early 2012. It provides the most comprehensive data entries for the time period from 2007 to 2010, which roughly concurs with the years of macroeconomic downturn. However, it is not free of data problems. For instance, zero growth rates make up 44.5% of all entries. Although excluded from further consideration, they still could bias the results insofar as growth rates in the subsequent year must be artificially higher. Several heuristics are applied to identify zero growth events stemming from data inconsistencies based on extrapolation, and the subsequent non-zero growth rates are eliminated.[2]

The Amadeus database discloses the address of the firms' headquarter location. As operational and strategic decisions are often made within this organizational unit, their regional environment will be most decisive in affecting their growth prospects (BEAUDRY & SWANN 2009). This rationale breaks down for larger firms, which tend to be less focused on their headquarters, but disperse their activities in many establishments across the country and beyond. Therefore, the analysis is restricted to firms with no more than an annual average of 1000 employees. Also very small firms with less than 5 employees, which growth processes are known to be rather erratic and which have limited abilities to generate jobs, are excluded (COAD 2009). Furthermore, industries are affected differently by macroeconomic recessions. Following PORTER (2003), traded cluster industries can be distinguished from local cluster, resource based cluster and non-cluster industries. This paper focuses exclusively on firms from traded cluster industries, as delimited within the EU Cluster Observatory Project, because on the one hand, these industries are more exposed to the global economy just as they depend on their regional environment, and on the other hand, they are expected to be more influential in shaping long-term technological trends within their home region.

3.2. Regional level data

Labour market regions as defined by ECKEY et al. (2006) serve as the regional reference space for firm locations. Combining insights from empirical studies of firm growth and regional resilience, several region-specific variables that might be related to the underlying micro-dynamics are identified. These variables can be classified into four broader categories: the region's 1) general socio-economic conditions, 2) innovation conditions, 3) workforce quality, and 4) industrial structure.

Being an obstacle to the ability to adapt, unfavourable general socio-economic conditions are expected to reduce regional resilience. These are approximated by the population density (*PopDensity*), the unemployment rate (*UnemplRate*) and the aggregate regional growth performance (*RegGrowth*). *PopDensity*, being rather independent from the surrounding industrial structure, reflects urbanization economies (BUERGER et al. 2012). The *UnemplRate* indicates the vitality of the regional labour markets. Some studies even regard it as a fully-fledged measure of regional resilience (BRIGUGLIO et al. 2009). In the special case of Germany, it also accounts for structural differences along the east-west and north-south divide. Data for both variables is obtained from the German Federal Statistical Office (destatis). Finally, *RegGrowth*, the (logarithmic) change in the number of regional employees in the study period from 2007 to 2010, controls for the resistance of a region's economy to macroeconomic

[2] For example, zero growth in both employment and turnover in the same year indicate that data were simply adopted from the past year, probably due to the lack of updated information. In total, half of the zero growth events are identified as extrapolations.

recessions. Better performing regions are expected to be more able to reconcile turbulent processes at the level of firms. Likewise to all subsequent variables based on employees, data is retrieved from the German Institute of Employment Research (IAB).

The innovation conditions might directly measure a region's "ability to replace declining or uncompetitive activities with new, dynamic and competitive ones" (FINGLETON et al. 2012). Innovativeness is measured by the university third party research funding (*ResFunding*). Here data is obtained from destatis. Alternative measures, like universities' budget, patents or employees in R&D-related occupations, were tested beforehand but showed an inferior fit compared to *ResFunding*. Due to multicollinearity issues, they are omitted from further analysis.

Among researchers (e.g., CHAPPLE & LESTER 2010, MARTIN 2012 and HILL & ATKINS 2012) it is widely acknowledged that the region's workforce skills are a key factor for shock resistance and regional resilience: "human capital and urban reinvention" are strongly connected, making skills "particularly valuable in places that are hit with adverse shocks" (GLAESER et al. 2011: 4). The regional qualification level is measured by the number of employees with university degree (*EmplUniv*).

Finally, the recent macroeconomic recession revealed that the region's industrial structure matters (e.g., CHAPPLE & LESTER 2010, HILL & ATKINS 2012): different industries were affected differently (GROOT et al. 2011, DAVIES 2012). Two variables control for the share of observations which are associated to the *Manufacturing* and *Construction* industries. The region's share of manufacturing is also a proxy for export orientation (CHAPPLE & LESTER 2010), and hence measures the exposure to global markets. During times of recession, especially the construction industry is targeted by fiscal policy. However, it is not only the concentration of such industries that is expected to matter, but also how the economic activities are distributed across industries, and their technological relatedness. A high degree of related variety means the existence of many inter-industry technological linkages and interdependencies (BOSCHMA & IAMMARINO 2009). GILBERT (2012: 736) supposes that in regions, where strong industrial clusters have been established, the "ability to transition to new technological forms" might be constrained. This argument is even punctuated for regions which are generally less diversified and show a high concentration of very similar industries. In contrast hereto, unrelated variety, reflecting the presence of very different activities, increases the number of potential sources for technological breakthroughs (CASTALDI et al. 2013). Thus, it enhances the region's long term ability to renew its growth path.[3]

The following measures are adopted from FRENKEN et al. (2007), BOSCHMA & IAMMARINO (2009) and ERIKSSON (2011), who also provide a more detailed discussion. Regional similarity is constructed by inverting the entropy at the four-digit industry level, with p_k^{IV} the regional share of employment within four-digit industry *k* and N^{IV} the number of different four-digit industry classes:

$$Similarity = 1/\sum_{k=1}^{N^{IV}} p_k^{IV} log_2(\frac{1}{p_k^{IV}}) \tag{1}$$

The higher the similarity measure, the higher is the concentration of similar industries within the region. Assuming a hierarchical understanding of relatedness, related variety is defined as the

[3] The portfolio-effect of unrelated variety, which is often discussed in the literature (e.g., FRENKEN et al. 2007), is primarily a matter of variance, not of fat tails. However, empirical studies show that fat tails are mostly negatively related with the variance. This paper focuses on the tails of the distributions, yet the complex interplay of fat tails and variance and its meanings for macro-dynamics deserves further attention in future research.

weighted sum of the entropy measure at the four-digit level within each two-digit class, with $p_l^{II} = \sum_{k \in S_l^{II}} p_k^{IV}$ the respective regional share of employment within two-digit industry *l* and N^{II} the number of different two-digit industry classes S_l^{II}, which nest the respective four-digit industries *k:*

$$RelVar = \sum_{l=1}^{N^{II}} p_l^{II} \cdot (\sum_{k \in S_l^{II}} \frac{p_k^{IV}}{p_l^{II}} log_2(\frac{1}{p_k^{IV}/p_l^{II}})) \tag{2}$$

The higher the related variety measure, the more technological complementarities in the activities exist within the region. Finally, unrelated variety is measured as the entropy at the one-digit level, with p_j^I the regional share of employment within one-digit industry j and N^I the number of different one-digit industry classes:

$$UnrelVar = \sum_{j=1}^{N^I} p_j^I log_2(\frac{1}{p_j^I}) \tag{3}$$

The higher the unrelated variety measure, the more the region is diversified into technologically different activities.

All region-specific variables are calculated for the base year of 2007. The highly asymmetric distributed variables of *EmplUniv* and *ResFunding* are first normalized by division through their mean value and then made symmetric by the transformation $\tilde{x} = (x-1)/(x+1)$.

4. METHODOLOGY

Growth rates are calculated by taking the difference of the natural logarithms of the firm size *S* between two successive time periods *t*:

$$g_{i,m,t} = \log(S_{i,m,t+1}) - \log(S_{i,m,t}) \tag{4}$$

where the subscript *i* indicates the respective firm and *m* the region in which the firm is located. The growth rates are then rescaled to control for the inverse relationship between their size and variance, a universal feature of the growth of complex economic organisations (AMARAL et al. 2001). Here, a similar rescaling procedure is used as in BOTTAZZI et al. (2012), which takes into account that the functional form of the relationship might be non-linear, as recently observed in the firm growth literature (BOTTAZZI et al. 2011). Because the scaling relationship might differ across regions, this step is performed for each region separately. Only after rescaling, growth rates can be interpreted as different realizations of the same underlying stochastic process, which to specify by a distributional model is the aim of this paper.

4.1. AEP density

In search for a more general and flexible distributional model that describes the empirical distribution of (rescaled) growth rates, the exponential power (EP) distribution family was introduced into economics by BOTTAZZI et al. (2002), which density *f(x)* reads

$$f_{EP}(\tilde{g}; b, a, m) = \frac{1}{2ab^{\frac{1}{b}}\Gamma(1+\frac{1}{b})} \exp\left(-\frac{1}{b}\left|\frac{g-m}{a}\right|^{b}\right) \tag{5}$$

with $\Gamma(.)$ standing for the gamma function. Three parameters define the distribution: the location parameter *m*, which indicates the general trend in the data, the scale parameter *a*, which determines the spread or dispersion of the distribution, and the shape parameter *b*. Both the normal (b = 2) and Laplace (b = 1) are particular cases of the EP family of probability densities. It allows for a continuous variation from non-normality to normality, with a smaller shape parameter *b* representing fatter tails of the corresponding density. Furthermore, it can be extended to a five-parameter family of distributions, which is able to cope with asymmetries in the data. In addition to *m*, the asymmetric exponential power (AEP) distribution possesses two scale parameters a_l and a_r for the values below and above *m* and two shape parameters b_l and b_r describing the tail behaviour on the left and right side of the distribution:

$$f_{AEP}(g;\ b_l, b_r, a_l, a_r, m) = \frac{1}{\mathrm{C}} \exp\left(-\left[\frac{1}{b_l}\left|\frac{g-m}{a_l}\right|^{b_l} \theta(m-g) + \frac{1}{b_r}\left|\frac{g-m}{a_r}\right|^{b_r} \theta(g-m) \right] \right) \tag{6}$$

where $\theta(g)$ is the Heaviside theta function and $\mathrm{C} = a_l {b_l}^{1/b_l - 1}\Gamma(1/b_l) + a_r {b_r}^{1/b_r - 1}\Gamma(1/b_r)$ a normalization constant. This new class of AEP and related ML inference problems are discussed in details in BOTTAZZI & SECCHI (2011). By applying numerical simulations, they show that the bias of ML estimators can be safely ignored if $N > 100$, except for *m*, which in case of asymmetry, that means $b_l \neq b_r$, results to be biased, even for very large samples ($N > 5000$). For the study at hand this implies that regions with less than 100 firms' growth events are dropped, leaving 100 labour market regions out of to the initial 150. Besides, the potentially biased estimates for *m* are ignored, which anyway are not the focal point, unlike the tails of the distribution.

4.2. Contemporaneous left and right tail estimation

HILL (1975) has shown that in some cases it can be useful to make inference about certain parts of the distribution, in his case the tail, without assuming any global form of the distribution function. By exploiting properties of spacings of exponential order statistics, BOTTAZZI (2012) generalizes HILL's analysis to any continuous distribution. In the present paper, the AEP distribution is estimated blinding out the central part, which is delimited by the lower and upper threshold values $\underline{d}$ and $\overline{d}$. Based upon the empirical data, these values are set to -0.006 and 0.006, respectively, in order to maximize the gap around zero, while guaranteeing that all non-zero growth events x_u are still included. Ordering the empirical observations of the sample by increasing size, only the *k* smallest (with $x_u < \underline{d}$) and *h* largest realizations (with $x_u > \overline{d}$) are considered. Conditioned on these threshold values, the likelihood function for estimating contemporaneously the upper and lower tails reads

$$L^{Tails} = \frac{N!}{(N-h-k)!}(F_{AEP}(\overline{d}) - F_{AEP}(\underline{d}))^{N-h-k} * \prod_u f_{AEP}(x_u) \tag{7}$$

where the AEP probability function F_{AEP} is integrable from the density f_{AEP} (Bottazzi & Secchi 2011). The log-likelihood function can be deduced:

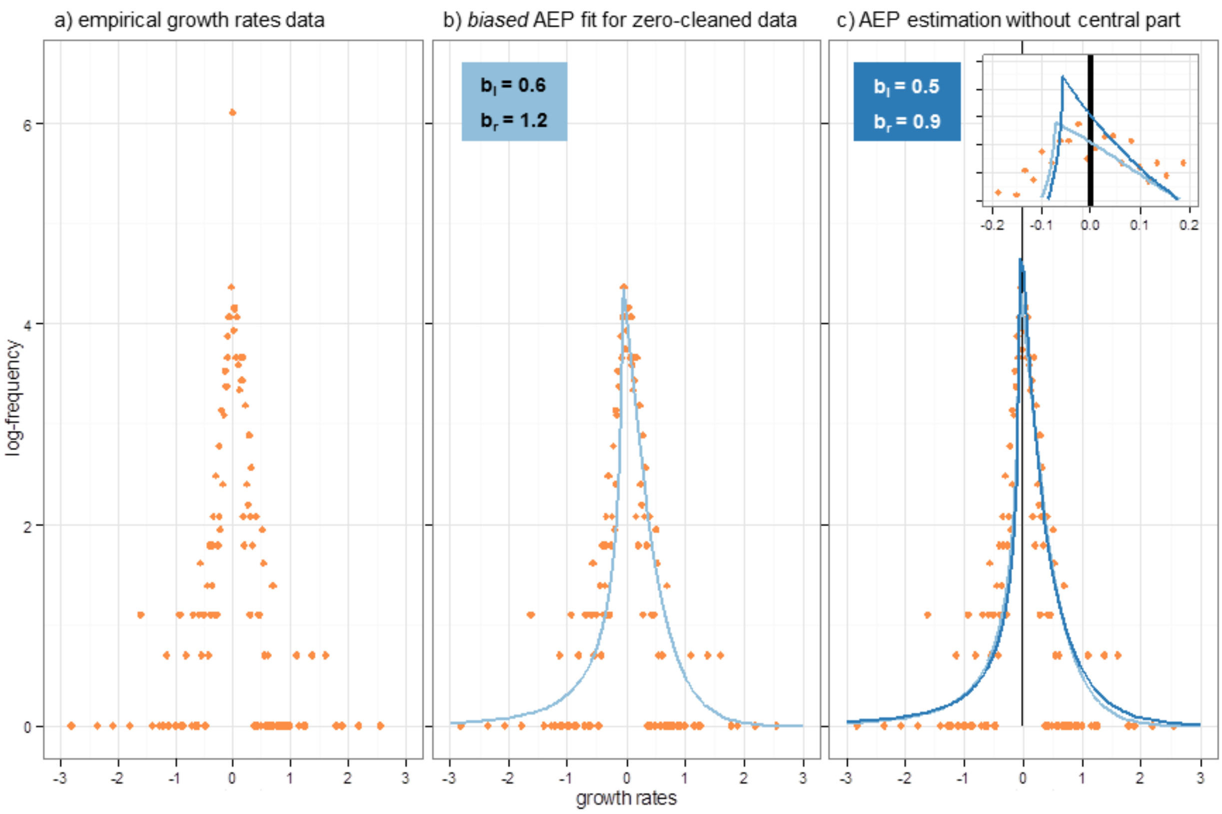
$$LL^{Tails} = \log\left(\frac{N!}{(N-h-k)!}\right) + (N-h-k)log\left(F_{AEP}(\overline{d}) - F_{AEP}(\underline{d})\right) + \sum_u log * f_{AEP}(x_u) \tag{8}$$

To account for those firms which prefer to grow but are not able to grow due to the discreteness of employees, N (here, $N := p * N$) is additionally endogenized. Finally, expression (8) is to be minimized:[4]

$$\{b_l, b_r, a_l, a_r, m, N\} = argmin_{b_l,b_r,a_l,a_r,m,N}(LL^{Tails}) \tag{9}$$

Endogenizing N not remains without any consequences. Obviously, it reduces an estimation bias stemming from the discrete nature of changes in the number of employees. It does so by raising the competition of the countervailing forces of scale and shape parameter, which both simultaneously try to account for (extreme) positive and negative events. Leaving out the central part, the flexibility regarding asymmetry increases, hence implying that higher peaks might be reached and distributional mass shifted from the variance to the tails. Based on empirical data from one arbitrarily chosen region, Fig 1 displays the main aspects and implications of this refined estimation procedure: in a) the empirical firm growth rate distribution is plotted, showing that zero-growth events are dramatically over-represented (note the log-scale on the y-axis). In b) data is zero-cleaned. However, the fitted parameters of the AEP distribution are biased, because some zero-growth events result from firms that prefer to grow, but are not able to grow due to the discrete nature of employees. To reduce this bias, the distribution is estimated in c) by leaving out the part around zero, which is coloured in black, and by making the number of observations lying within this part endogenous. This endogenization increases the number of actually growing firms h and k by around 4%.

Fig 1 Comparison of estimation procedures



[4] This formula is optimized using DEoptim in the R environment. Global optimization by differential evolution is especially "useful in situations in which the objective function is stochastic, noisy or difficult to differentiate" (MULLEN et al. 2011).

4.3. Regression model

In a next step, the distributional parameters, which are estimated for each region *m*, are related to regional factors in a simple OLS regression model. Turbulences arise through both positive and negative extreme growth events. Instead of explaining the fatness of the tails for both sides of the distribution separately, we rotate the two-dimensional space of the shape parameters, and explain the sum of b_r and b_l. This sum represents overall turbulences that are expected to accompany processes like adaptation and structural re-orientation: the smaller its value, the more likely extreme events are to occur in a regional economic system. The other dimension in the rotated space, b_r minus b_l, measures the asymmetry of the distribution and should indicate a kind of vulnerability: this value is positive for $b_r > b_l$, implying that extreme negative growth events are more likely to occur than positive ones, vice versa. Controlling for the respective opposite dimension and the number of firms in the sample, as fat tails might be sensitive to extreme events in the case of just a handful of observations, two models result:

Model 1: *resilience*

$$(b_{r,m} + b_{l,m}) = \alpha + \beta_1(b_{r,m} - b_{l,m}) + \beta_2 N_{firms} + \sum_u \beta_u x_u + \varepsilon_m \qquad (10)$$

Model 2: *vulnerability*

$$(b_{r,m} - b_{l,m}) = \alpha + \beta_1(b_{r,m} + b_{l,m}) + \beta_2 N_{firms} + \sum_u \beta_u x_u + \varepsilon_m \qquad (11)$$

with α and β representing the coefficients to be estimated, *u* counting the various regional factors *x*, and ε_m standing for a normal distributed error term.

5. RESULTS

5.1. Inter-regional heterogeneity in the firm growth rate distributions

Summary statistics of the estimated AEP parameters are reported in Tab 1. In average, the tails are to a considerable degree fatter compared to the normal and even Laplace distribution, accompanied by a significant asymmetric shape towards the left: extreme negative growth events are much more likely to occur than their corresponding positive ones. These findings confirm the recent literature on firm growth rate distributions within national economies (see section 2.2). However, the high variances of both shape parameters b_l and b_r points to a high inter-regional heterogeneity.

Tab 1 Summary statistics for estimated AEP parameters

Estimation technique	$N_{regions}$		b_l	b_r	a_l	a_r	m
Without central part	**100**	**mean**	**0.601**	**0.791**	**0.111**	**0.117**	**-0.007**
		sd	**0.213**	**0.347**	**0.025**	**0.038**	**0.059**
Without zero data	100	mean	0.734	0.932	0.131	0.132	-0.001
		sd	0.277	0.391	0.026	0.042	0.067

Furthermore, this table compares the estimates resulting from the extended estimation technique, which leaves out the central part around zero, with the ones from the conventional approach of optimizing the log-likelihood of f_{AEP}. For the latter, all zero growth events are excluded. The new technique makes the distributional mass shifting from the center to the tails: in average, both b_l and b_r become smaller as compared to the conventional technique without zero data. Simultaneously, the variance decreases. Despite one additional degree of freedom, asymmetry is reduced by the new technique. The absolute difference between b_l and b_r slightly decreases, in average, from 0.493 to 0.415 and in the case of a_l and a_r from 0.042 to 0.029.

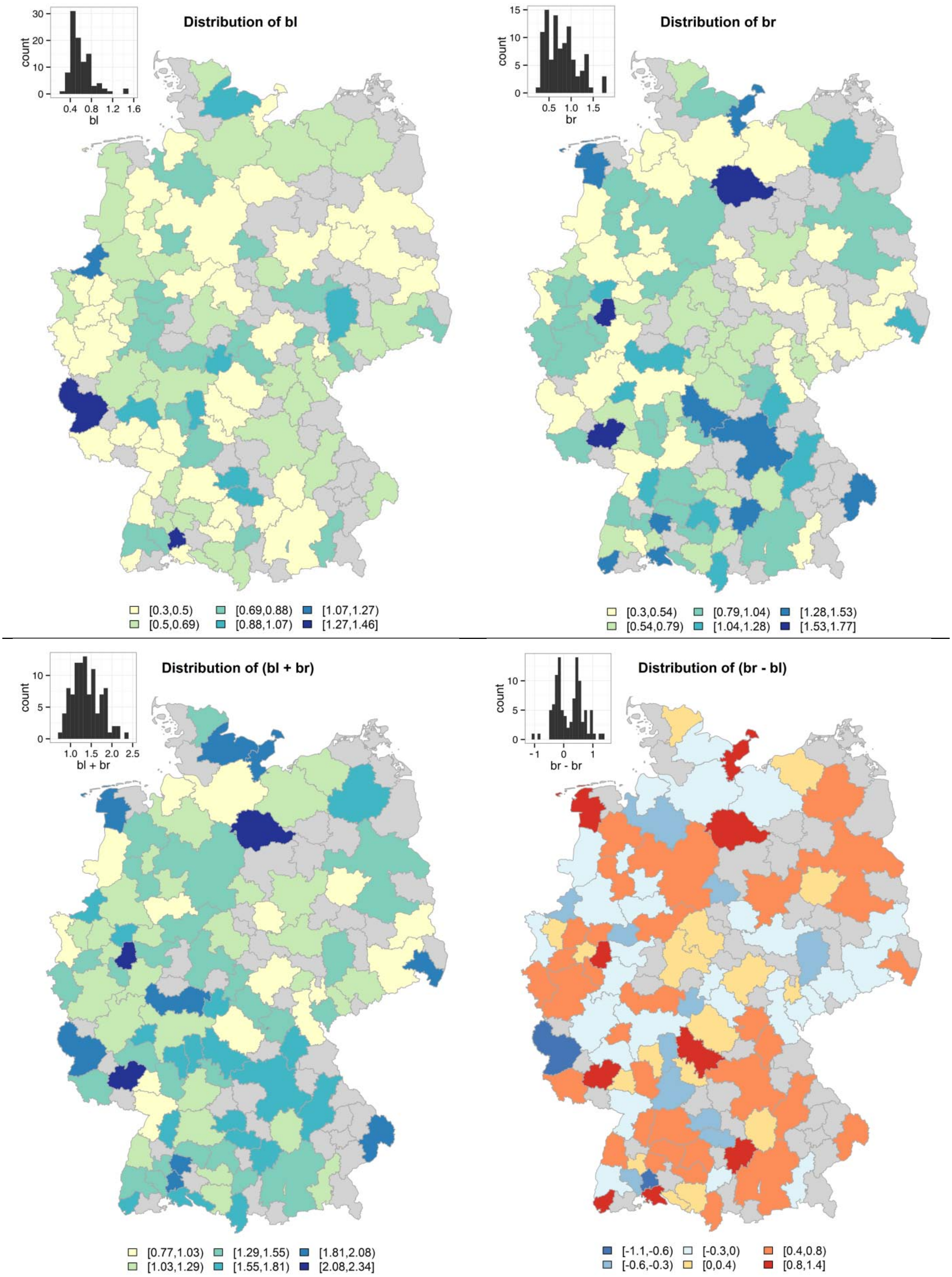
5.2. Regional factors accounting for the fat tails

The spatial distribution of the values for b_l and b_r as well as their sum $(b_l + b_r)$ and their difference $(b_r - b_l)$ are depicted in Fig 2. The high regional heterogeneity of firm growth rate distributions already suggests that they might reveal more about the underlying dynamics of regional economies. This paper argues that turbulences at the level of firms allow for a first assessment of a region's long-term ability to adapt its structure and to re-invent itself, key aspects of evolutionary regional resilience, especially so but not exclusively during times of economic crises. This leads to the question which region-specific factors are related to a higher potential for regional resilience. Results from the regression models are summarized in Tab 2.

The two base models solely control for the number of observations and the perpendicular dimension. The models 1 to 4 include further regional variables. For each independent variable two models are devised, as the variables of similarity and related variety are strongly correlated to unrelated variety, which to some extent resemble two different sides of the same coin. Regression diagnostics do not reveal any problems regarding normality of the residuals, multicollinearity or spatial autocorrelation.[5] Only the null hypothesis of the Breusch-Pagan tests is rejected, that is why White's heteroskedasticity consistent standard errors are reported.

[5] The Moran's I test statistics is also robust to different weight matrix specifications.

Fig 2 Spatial distribution of the values for b_l and b_r



Tab 2: Regression results from OLS

	$(b_l + b_r)$			$(b_r - b_l)$		
	base model	*model 1*	*model 2*	*base model*	*model 3*	*model 4*
$(b_r - b_l)$ / $(b_r + b_l)$	-0.352 0.000 ***	-0.300 0.000 ***	-0.310 0.000 ***	0.702 0.000 ***	0.737 0.000 ***	0.742 0.000 ***
N_{firms}	-0.000 0.000 ***	0.000 0.849	-0.000 0.759	-0.000 0.004 **	0.000 0.492	0.000 0.318
PopDensity		-0.000 0.681	-0.000 0. 693		0.000 0.019 *	0.001 0.009 **
UnemplRate		-0.355 0.540	-0.558 0.520		0.397 0.590	-0.313 0.833
RegGrowth		-2.766 0.003 **	-2.312 0.007 **		1.840 0.139	1.696 0.150
ResFunding		0.277 0.006 **	0.290 0.004 **		-0.010 0.475	-0.076 0.559
EmplUniv		-0.536 0.027 *	-0.487 0.042 *		-0.203 0.498	-0.263 0.408
Manufacturing		-0.746 0.039 *	-1.154 0.014 *		-0.191 0.642	-0.213 0.777
Construction		-0.616 0.560	-0.826 0.448		-0.500 0.768	-0.260 0.882
Similarity		28.143 0.042 *			-11.188 0.724	
RelVariety		0.755 0.095 ‘			-0.286 0.695	
UnrelVariety			-0.559 0.032 *			0.409 0.554
Adj. R^2	**0.269**	**0.390**	**0.386**	**0.233**	**0.212**	**0.227**
BP-test (*p-value*)	0.002	0.012	0.046	0.001	0.005	0.013
KS-test (*p-value*)	0.677	0.828	0.799	0.103	0.349	0.343
Moran’s I (*p-value*)	0.438	0.944	0.921	0.688	0.747	0.719
vif	1.001	3.758	4.510	1.052	3.965	4.718

By relating the tail measure $(b_l + b_r)$ to various regional variables, the explained variance (R^2) of model 1 and 2 increases compared to the base model from 27% to almost 40%. Regarding the general socio-economic conditions, neither *PopDensity* nor *UnemplRate* turn out to correlate with the tails' fatness, meaning that no evidence is found that the stochastic properties of firm growth rate distributions differ along the urban-rural as well as east-west or north-south divides. However, *RegGrowth* is highly relevant. The better the aggregate regional growth performance, the lower are the shape parameters and hence, the fatter the tails. This result is interesting as it shows that firm-level turbulences are predominantly a phenomenon of better performing regions.

The regions' innovation conditions, approximated by *ResFunding*, reduce significantly the occurrence of turbulences at the level of firms. Thus, regions with a strong (basic research oriented) science base are not necessarily those regions where firms are able to economically take off. In contrast hereto, *EmplUniv*, the qualification level of the region's workforce, is strongly correlated with the fatness of the tails: the more employees with a university degree, the higher the likelihood of extreme growth events. This clearly confirms the literature, which attributes the region's workforce skills an important role in its resilience and transformative capacity in general (e.g., CHAPPLE & LESTER 2010, GLAESER et al. 2011).

Finally, the industrial structure matters. Regions with a higher share of firms belonging to *Manufacturing* are more exposed to extreme events. This result is reasonable, as the manufacturing industry was stronger affected by disturbances of the macroeconomic recession (e.g., GROOT et al. 2011, DAVIES 2011). Firms from *Construction* do not show different stochastic properties in their growth dynamics. Besides the type of activity, also the way how these activities are distributed across a region's industrial portfolio matters. Particularly, a higher degree of similarity increases $(b_l + b_r)$, resulting in thinner tails. The same effect is observed for related variety, however only significant at the 10% level. Only in the case of variety of technologically unrelated activities, the sign of its effect on the tails changes – a less coherent and less interrelated technological base makes extreme growth events more likely. Thus, diversity and variety in the region's industrial structure seems to increase the likelihood that new technological trajectories unfold and old ones decline (CASTALDI et al. 2013). Put differently, specialized regions, where activities of the same or similar type concentrate, either constrain the necessary competition leading to such turbulent processes, probably due to a higher inertia of its actors and institutions, or simply provide less potential sources for path-breaking technological solutions, which "can be taken from one industry and used to create innovations that solve problems in other fields" (GILBERT 2012: 738).

Besides the explanation of the tails' fatness, which here is conceptualized as an indicator for regional resilience from an evolutionary perspective, also the asymmetry of the distribution, measured by $(b_r - b_l)$ and representing a kind of vulnerability, can be analysed. However, the inclusion of further regional variables in model 3 and 4 do not increase the explanatory power, which remains at around 20% compared to the base model. With *PopDensity* only one variable shows a significant influence: the higher the population density, the more likely extreme negative growth events are to occur relatively to positive ones. This result might be explained by the recession, as urban regions turned out to be affected more adversely.

6. CONCLUSIONS

This paper studies turbulent processes at the level of firms within regions. Turbulences are an indicator for processes like structural adaptation and technological re-orientation. Regional economies that provide a competitive environment, which facilitates that outmoded activities are substituted by new innovations and technologies, are assumed to be resilient in the long run from an evolutionary perspective. Such turbulences, otherwise hidden by aggregation, are revealed in the employment dynamics of firms. Here, the secret lies in the tails of the distribution of firm growth rates, i.e. in the extreme events, which tend to have a higher potential transformative impact on the regional economy. Therefore, this paper is a first attempt to assess the meaning of fat tails for the systems they correspond to, and the factors which make them particularly pronounced. Above all, this analysis shows that firm-level turbulences are more likely in regions with a higher aggregate growth performance. Although the direction of causality is still unknown, this finding underlines the positive nuance of fat tails throughout the paper. In this vein, especially a diversified and heterogeneous industrial structure as well as the presence of a qualified workforce seems to make regional economies more resilient. In contrast, a strong science base surprisingly attenuates the tails.

However, this empirical perspective on regional resilience, based on firm growth rate distributions, is not without any limitations. Firstly, firms that enter and exit are omitted from the analysis, because they are qualitatively different from growth processes of existing and surviving firms. Growth rates become infinite when the size changes towards zero. However, entry and exit at the firm level, which are known to show different regional dynamics and determinants (COMBES et al. 2004), are an important aspect regarding all dimensions of regional resilience, but cannot be tackled within the framework of growth rate distributions. Yet the author beliefs that a huge bulk of the processes of adaptation and re-orientation occurs within existing firms and are thus revealed by their growth performance. This is confirmed by studies like BERGEK et al. (2013), arguing that the ability of new entrants to destroy and disrupt established industries is often overestimated, while the ability of incumbents to absorb and integrate new technologies with their existing capabilities is often underestimated. Secondly, instead of being a longitudinal approach, a cross-sectional snapshot of growth rates is analysed. Here, the data stems from the years of macroeconomic recession. No systematic comparison is made to pre- or post-crisis growth processes. However, from an evolutionary perspective, regional resilience is not bound to describe the immediate reaction to shocks, but it is understood as an on-going process of adaptation and structural re-orientation. This relates to the third point, as short term approaches do not allow for a direct analysis of the evolutionary dimension of regional resilience (DAVIES 2011). However, SIMMIE & MARTIN (2010: 34) argue that resilience "depends both on longer term, region-wide processes and on shorter term microscale processes and on how these interact". The latter can have permanent effects on the potential long term output (CROSS et al. 2010). By focusing on yearly growth rates, at least a first assessment of the potential for long-term adaptability and structural re-orientation can be provided.

Taking these concerns seriously, future research is advised to explicitly link the stochastic properties of firm growth rates to long-term regional growth paths. Changing patterns before, during and after recessionary shocks could additionally shed light on the evolving ability of a region to adapt and re-invent itself. Finally, Germany has shown a particular response to the recent crisis in the European context (DAVIES 2011). Expanding this analysis to other European and non-European countries would enable to assess whether results survive in different national contexts.

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