MEASURING COMPLEXITY AND ECONOMIC REGIONAL RESILIENCE

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Abstract: *The concept of economic regional resilience has been stemming from ecology many years ago and got both theoretical and empirical attention in recent years. Its popularity is still increasing. In particular, slightly different approaches of regional economic resilience seem to represent different interpretations of regional ability to prosper thought out different obstacles. Starting from definition of resilience, this paper aims at highlighting advantages and disadvantages of engineering, ecological and evolutionary approach towards resilience. This is in order to offer some insights into its measurement within the resilience analysis. In this paper we will describe an empirical application, in which the resilience of the Czech regional labour market at the level NUTS 2 in the period 2000 - 2014 is going to be investigated by use of an algorithm for business cycle detection and method for complexity of time series measurement. For this reason, we employed the Hurst and Lyapunov exponent as metrics of complexity. The results show the existence of a relationship between the Largest Lyapunov Exponent and the size of Index of Regional Sensitivity on Recession.*

Keywords: *Resilience, Engineering resilience, Ecological resilience, Evolutionary resilience, Spatial economics, Complexity.*

JEL Classification*: B52, O18, R10, R11.*

Introduction

In recent years, regional resilience has been the subject of research in numerous studies, that on the basis of the impact assessment of a large spectrum of negative shock phenomena concluded on resistance (or non-resilience or vulnerability) of investigated regions. A comprehensive overview of the carried out empirical research provides post by authors Modica and Reggiani [16] and in detail acquaints the reader with differences and analogies in the concept of economic resilience. Over the years had formed three distinct conceptions of resilience, which differs in the angle of view on what is the fundamental nature of this ability, where the bearer is a territorially defined region.

Existing empirical research work with complexity mostly as with indicators applicable to quantify regional resilience in terms of "ecological" or "evolutionary" concept. Our goal is to verify the real usability of selected complexity measures in the context of economic crisis of 2008. Research hypotheses thus formulate, in other researches silently implied, existence of a relationship between the level of complexity and sensitivity of the region on the economic downturn. The result show that the success is greatly affected by the choice of the specific measure of complexity applied to the time series.

The economic resilience of the regions and its different concept

Despite the existence of a number of different definitions of economic resilience, it is possible to see the general nature of this concept in the ability to withstand the external deflection. Succinct definition of the economic resilience of the region offer, for instance, Hill et al., who defined the economic resilience as the ability of the economy of a region [8]: *"... to recover successfully from shocks to its economy that throw it substantially off its prior growth path and cause an economic downturn* ". Despite the basic consensus on the nature of the resilience, there are different concepts of this term, which may be seen as grasping the same from a different perspective.

A fundamental concept of the regional resilience is the so called “technical” concept, which is based on the ideas of the static balance sway with some outer event. An essential characteristic of this approach is to assess the ability of the region to “go back” to its original balance[1]. Through a large set of the latest empirical studies using this approach (mainly due to its easy comprehensibility), the application of this concept also met with considerable criticism, which gradually led to the development of the other two concepts. The first of these is the resistance observed from the environmental perspective, for which the author is considered Canadian environmentalist Holling [9]. The essence of this approach is the emphasis on the region's ability to resist external interference due to the existence of multiple equilibrium states, among which the region gradually changes.

Another approach, which is, in some studies regarded as just an extend analogy of the “ecological” concept, is referred to as “adaptive” (sometimes also “development” or “evolutionary”) – see e.g. [14]. It was created in response to criticism by some authors (e.g. [15]), who sees in the first two concepts insufficiently covered aspects of the economy in the long term. The resilient economy of the region, according to this approach, in terms of its internal structure is constantly changing and preventively minimalize the effects of destabilizing phenomena. An adaptive approach to resilience is derived from the theory of “complex adaptive systems”, which is the basic paradigm of “ecological” and “adaptive” approach. It is therefore not surprising that the appropriate tool for the measurement of resilience (with regard to these two concepts) in some empirical studies is the measure of complexity.

Methodology of research

The aim of the research described in this text is to provide verification of the real applicability of the selected complexity measures on time series for the purposes of the quantification of regional resilience in the context of the economic crisis of 2008. For the fulfilment of the objectives were laid down the following two hypotheses:

H1: A measure of the complexity of time series of regional employment in the phase of expansion before the onset of the economic crisis of 2008, measured by the largest Lyapunov exponent exhibits a stochastic dependency with the index of the region's sensitivity to the economic downturn.

H2: A measure of the complexity of time series of regional employment in the phase of expansion before the onset of the economic crisis of 2008, measured by the Hurst exponent exhibits stochastic dependency with the index of the region's sensitivity to the economic downturn.

For the purposes of the validation of presented hypothesis, we used quarterly data of regional employment in the NUTS 2 regions of the Czech Republic in the period 2000-

[1] For instance, it may be a return of the growth rate of employment in the region to an appropriate value before the crisis [14].

2014 (the data was obtained from a sample survey of the labour force [4]). The choice of the research period was motivated by the need of the research, i.e. the need to verify the formulated hypotheses. In order to ensure a meaningful analysis of the quarterly data, the data were first treated with an X 12-ARIMA filter that removes seasonal fluctuations.

With regard to the formulation of hypotheses, the next step of the analysis is to build the necessary indexes based on the dating of the tipping points. Methods of dating tipping points are used to identify alternating stages of growth (recovery, expansion) and decline (the recession). The detection of these checkpoints is a necessary prerequisite for determining the values of indicators C_{emp}, LLE, H (see below) from the time series based on knowledge of the business cycle (dated in the case of our time-series studies on the regional employment).

For these purposes, the Organisation for economic cooperation and development (OECD) compiled recommendations for the creation of indicators. The document [5] contains the recommended procedure for the identification of the economic cycle by Bry-Boschan algorithm [3] or its modified version for the quarterly data (BBQ algorithm). The purpose of the algorithm is to identify local minima and maxima on the Hodrick-Prescott smoothed series filter. In our study, with a view to the formulation of hypotheses, it was used for the detection of two phases (for regional employment growth stage prior to the start of the economic crisis of 2008 and the first phase of the regional employment decline due to the crisis).

The BBQ algorithm allows detecting the beginning and end of the phases of growth and decline.[2] The advantage of this automated processing is a fast and reliable detection of turning points in the analysis of several time series at the same time. The OECD document, however, warns against the identification of short intervals that divide a time series into too many sections, which can complicate the subsequent construction of the indicators. Therefore, it is recommended to check and optionally partially modify the results with regard to the construction of meaningful indicators.

In the following is presented the methodology for the determination of the magnitude of the region’s sensitivity to the economic downturn. The index of the region's sensitivity to the economic contraction ($\boldsymbol{C_{emp}}$), based on previous research (e.g., see [14]), is characterized by the size of the impact of the negative economic shock to the labour market of a given region to the same change measured, however, at the national level. For each region, the calculation is made according to the formula (1):

$$C_{emp} = \frac{(Z_{R(p1)} - Z_{R(t1)})/Z_{R(p1)}}{(Z_{N(p1)} - Z_{N(t1)})/Z_{N(p1)}}, \text{ where} \qquad (1)$$

C_{emp} = The index of the region’s sensitivity to the economic contraction (a dimensionless number)

$Z_{R(t)}$ = The level of employment in the region at time t (the number of persons in thousands)

$Z_{N(t)}$ = Level of employment at the national level in time t (the number of persons in thousands)

[2] BBQ algorithm that was implemented within the framework of our research in the environment of R studio using BCDating library that, by default, operates with a minimum length of the cycle (15 months) and a minimum length of stages of growth or decline (5 months). Due to the use of quarterly data, the minimum cycle length was set at 5 quarters, and the minimum length of the phase at 2 quarters.

p1 = Time of the beginning of the downturn determined with BBQ algorithm (quarter)

t1 = End time of the downturn determined with BBQ algorithm (quarter)

The values of C_{emp} greater than one indicate a significant sensitivity to the region's economic shock (on the contrary, values less than one indicate less sensitivity and resistance of the region to economic shock compared to national levels).

It was also necessary to quantify the value of complexity of an examined time series. The choice of the appropriate methods for measuring the complexity was based on a lot of similar empirical studies (e.g. [16]). On the basis of research, for potentially suitable methods measuring the complexity was elected the greatest Lyapunov exponent and Hurst exponent. Both are related to the basic properties of complex systems (which include, for instance, self-similarity or non-linearity).

Hurst exponent (H) is used for the analysis of time series with long-term memory. Hurst exponent has been historically associated with Harold Hurst, who carried out an analysis of the level of the river Nile, more accurately, determine the optimum size of the dam based on historical data of precipitation and drought [10]. In the field of fractal mathematics, the Hurst exponent was generalized by Benoît Mandelbrot [12], which created a direct relationship to the fractal dimension (D). Generalized Hurst exponent measured behavioural randomness of time series [13].

The values of the Hurst exponent are from the interval $< 0; 1 >$, more specifically the values from the interval $< 0; 0.5 >$ evoke a time series with long-term positive autocorrelation, and the value from the interval $< 0.5; 1 >$ evoke a time series, in which values change regularly (oscillate between high and low values). The value of the Hurst exponent equal to 0.5 represents the non-correlated time series. Generalized Hurst exponent is defined as H(q), and it can identify the solution (e.g. using logarithm) of the following equation (2):

$$\frac{\langle |x(t+\tau)-x(t)|^{q}\rangle}{\langle |x(t)|^{q}\rangle} \sim \tau^{qH(q)}, \tag{2}$$

Where τ represents a time delay, t represents time and $x(t)$ individual values of time series. For the purposes of the quantification of this indicator is used the library "pracma" [2] in the R environment.

Another popular tool for analysis of complexity is the largest Lyapunov exponent (LLE), which is widely used in the analysis of non-linear time series. If the value of this indicator is positive, it indicates a situation where the time series shows signs of chaos. To calculate the largest Lyapunov exponent there are a number of methods, for example. [11] or [18]. For the purposes of this contribution, the largest Lyapunov exponent was quantified using Kanz method implementations of libraries "tseriesChaos" in the R environment [1].

Results of the analysis

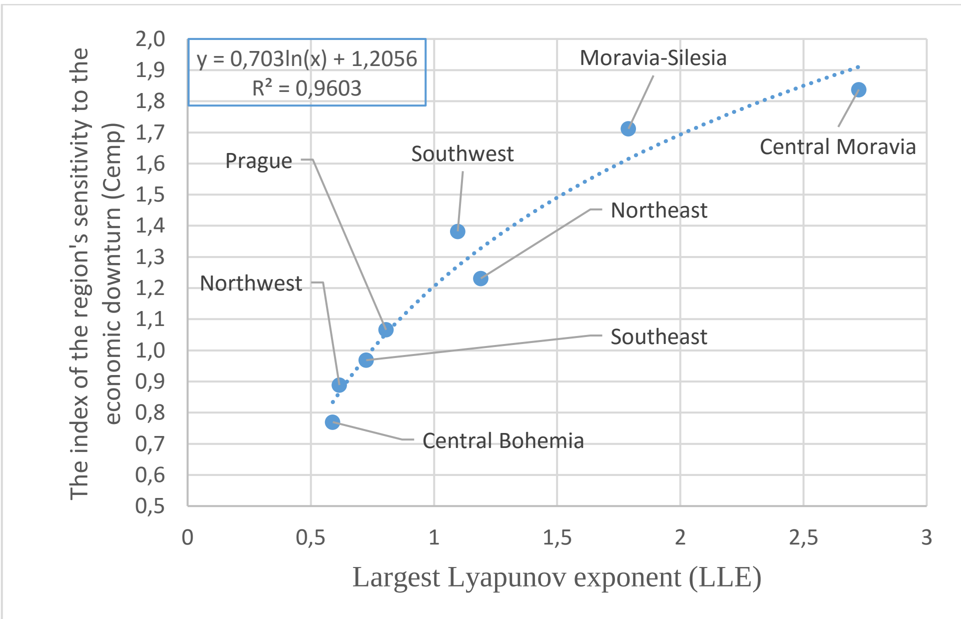
The following table (see Tab. 1) contains the tipping points detected by BBQ algorithm. Because of the length of the time series needed for the calculation of the LLE and H, it was necessary to find such period of growth immediately preceding the recession of 2008 and also was not broken with the period of decline for than two quarters.[3] The table contains, in addition to the period of detected phase, also index value C_{emp} for investigated regions.

Tab. 1: Tipping points and the values of the C_{emp} index for NUTS 2 regions.

The name of the region	**The period of growth**	**The period of downturn**	C_{emp}
Prague	2004Q3 to 2009Q2	2009Q2 to 20011Q3	1,066
Central Bohemia	2003Q4 to 2009Q1	2009Q1 to 20010Q1	0,770
Southwest	2004Q1 to 2008Q2	2008Q2 to 20010Q2	1,382
Northwest	2003Q2 to 2008Q3	2008Q3 to 20010Q1	0,889
Northeast	2004Q1 to 2008Q3	2008Q3 to 20010Q1	1,231
Southeast	2002Q4 to 2008Q4	2008Q4 to 20010Q1	0,968
Central Moravia	2004Q4 to 2008Q4	2008Q4 to 20010Q3	1,838
Moravia-Silesia	2004Q1 to 2008Q4	2008Q4 to 20011Q1	1,711

Source: Custom processing on the basis of a labour force sample survey [4]

Fig. 1: Relationship between degree of complexity (LLE) and C_{emp}



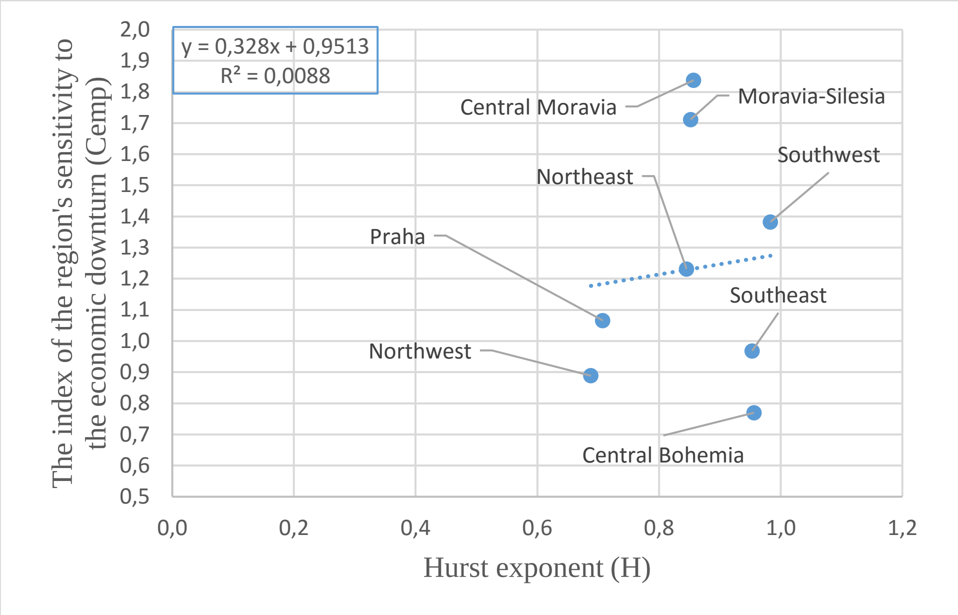
Source: Custom processing on the basis of a labour force sample survey [4

Fig. 1 shows the relationship between the values of LLE and the size of the index C_{emp}. Distribution of points around the logarithmic curve and its index of determination determine evidence of the stochastic dependencies between the largest Lyapunov exponent and the index of region's sensitivity to the economic downturn. Based on these results, it is possible to consider, that between these two indicator exist strong non-linear

[3] Insignificant decrease in phase (two quarters long), which divided the several years of pre-crisis growth phase on the two shorter phases, were based on the recommendations of the OECD document ignored. It worked in the case of the regions of the Southwest, Northwest and Northeast, when in the years of growth (2004-2007) was identified a six-month phase of the decline in employment. By abstracting from this minor downturn, it was possible to achieve a sufficiently long time series needed for the calculation of the LLE and H and also especially the comparability of the indicators between regions.

relationship. Hypothesis H1 is therefore not possible to reject and therefore it is possible to consider its acceptance.

Fig. 2: Relationship between degree of complexity (H) and C_{emp}



Source: Custom processing on the basis of a labour force sample survey [4]

The Fig. 2 illustrates the relationship between the size of Hurst exponent and $\boldsymbol{C_{emp}}$ index. Distribution points around the regression line or the index of determination do not show to the existence of a stochastic dependencies between the indicators. Therefore, hypothesis H2, based on these data, cannot be confirmed.

Discussion

The verification of the real usability of the selected measures of complexity for the purposes of the quantification of regional resilience in the context of the economic crisis of 2008 was the main objective of this study. The current studies mostly assume the relationship between complexity measures and economic resilience without adequate empirical validation. The results of our research verify the existence of a stochastic dependence between the LLE and C_{emp}, which is consistent with the results from other studies (e.g. [17]). The distribution of points in Fig. 1 shows the logarithmic relationship between indicators (in addition, the index of determinacy also shows relatively strong dependence). This finding leads to the conclusion that, in the case of LLE, it is possible to consider the complexity measure as an appropriate tool for the evolution of the economic resilience of the regions. Found non-linear relationship provide a who new perspective on the issue of regional resistance measurement (and not just with regard to empirical studies, which do not consider to test the stochastic dependency).

Furthermore, the reliability of the implementation of the BBQ algorithm was verified in the R language. With the exception of the above three NUTS 2 regions, where it has been necessary to abstract from the minor regional employment declines, that due to the construction of indicators H and LLE must be ignored, the chosen approach seems effective primarily for a more extensive set of data.

The presented results are also interesting with regard to the relationship between the complexity of the economy and the size of GDP growth (see [7]). In that study, the proposed indicator ECI represents another of the alternative approaches to the measurement of complexity, i.e. it has an unusually strong positive correlation with an indicator of economic growth (even in comparison with a number of other indicators – see [6]). In the case of the LLE, it is also possible to consider this complexity measure to be a useful predictor of region's sensitivity on the economic downturn.

Conclusion

The text of the contribution focuses on the issue of three different concepts of the economic resilience of the regions. Builds on the previous empirical research based on the "ecological" or "adaptive" concept of regional resilience. The purpose of the research was to verify the assumption of the existence of stochastic dependencies between selected measures of complexity and sensitivity of the regions to the economic downturn. The results showed the existence of a relation between the values of the largest Lyapunov exponent (LLE), and an index of sensitivity to the region's economic downturn (C_{emp}). On the other hand, the relationship between the values of the Hurst exponent indicator (H) and C_{emp} has not been confirmed. The results show that the success of the quantification of regional resilience through complexity measure is highly subject to the choice of methods that are applied for measurement of complexity on time series.

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