INDIRECT ESTIMATION OF THE DEVELOPMENT OF CAPITAL PRODUCTIVITY IN THE REGIONS: THE CASE OF POLAND

Pavel Zdražil[1], Ivana Kraftová[2]

[1] University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Czech Republic, ORCID: 0000-0003-0815-404X, pavel.zdrazil@upce.cz;

[2] University of Pardubice, Faculty of Economics and Administration, Institute of Economic Sciences, Czech Republic, ORCID: 0000-0003-0740-2670, ivana.kraftova@upce.cz.

Abstract: *This study introduces a new (adopted) method of indirect estimation of the development of the productivity structure in the regions, which at the same time allows estimation of the contribution resulting from changes within the capital factor. Its theoretical background is built on the principles of growth accounting. Within this framework the study employs an arguable assumption of analogy in development of multifactor productivity of industry between the national and regional level. The literature review and empirical results shows, however, that such an assumption may be correct in some cases. Therefore, the article enhances the existing productivity analysis capabilities at the regional level. Within the aim, this study verifies the potential of applicability of proposed method on the regions of Poland. It uses the measure of symmetric mean absolute percentage error (SMAPE) to evaluate the accuracy of method proposed against actual values and the results of two other frequently used methods for disaggregation of capital among the regions in a country. The results indicate that the new method should be more accurate than the methods of regional decomposition of capital-based on value added, and flows investment accumulation. In fact, it seems to be quite correct especially in the industries of wholesale & retail trade, transport & storage, real estates, health & social work, and manufacturing. On the other hand, it is likely incorrect in the industries of information & communication activities, finance & insurance, and administrative & support activities. In general, the method seems to be more accurate for larger industries and vice versa. Higher precision is also observed for industries where capital demand is clearly increasing. Similarly, the method is more accurate in industries where none of the regions are more specialized and vice versa.*

Keywords: *Capital, productivity structure, regional growth, growth accounting, regional decomposition.*

JEL Classification: O47, R11, D24.

Introduction

The dominant determinant of development, in the current economy affected by globalization, is not the quantity of resources, but especially their productivity. Although the productivity is not everything on the way towards the successful economics, as Krugman (1997) pointed out, it is almost everything in the long-run. The premise of favourable development is therefore the effective, efficient and economical use of available resources, whose appropriate structure and rational allocation is the basis for

the efficiency of the process of transforming the potential to entering real outputs. On this basis, a country or region is competing with its surroundings, as well as affecting the living conditions and quality of life of the population (Capello et al., 2011).

A quantitative approach of growth accounting is commonly used to analyse the productivity issues and assess the living standards prospects. It is based on the evolution of the volume and structure of inputs and the relationship between inputs and outputs, to isolate specific causes of growth and isolate individual components of productivity (Hulten, 2009). For the usual absence of consistent and comparable data on regional capital distribution (Derbishire et al., 2013; Mas et al., 2014), however, this approach is generally not applicable at the level of sub-national analysis. But at the same time numerous studies have led to conclusions, which show that the reference level of the regions, rather than the level of the national economy, is the decisive level, which crucially impact the growth and development patterns of any area (Cheshire & Malecki, 2004; Fischer et al., 2009). Hence there is a need to pay close attention to detailed monitoring of the use and transformation of resources in particular regions to address specific undesirable disorders, problems and uneven development with the highest efficiency.

To overcome this gap, mainstream research typically focuses on methods of regional decomposition of capital, based on disaggregation of data across national entities. This article, however, shows a new (adapted) way of tackling the problem, as it considers analogy in the size of the residual component of productivity at national and regional level. Based on this reasoning, at the level of sub-national units, the dynamics of the productivity of the capital component can be estimated in addition to the labour productivity development estimate. In other words, the value added for the regional specialized literature may be seen in idea that it is possible to decompose also the development of the structure of the indescribable parts of productivity.

In connection with the acute need for data for a detailed analysis of productivity at regional level but at the same time their usual unavailability; the aim of this study is to present a method of indirect estimation of the development of capital productivity in

the regions, and to verify the potential of its applicability on a concrete example.

To achieve this goal, the article discusses the need for a detailed productivity analysis at the regional level and presents the theoretical basis for regional decomposition of development of the productivity structure. On the example of the Polish regions, a method of indirect estimation of the development of capital productivity in the regions is applied. The error rate of the indirect estimation method against the actual values is evaluated using the measure of symmetric mean absolute percentage error (SMAPE). The patterns found in the deviations are discussed in wider contexts and specifics of particular industries. Furthermore, the error rate of this method is compared with two commonly used approaches to decomposition of capital – a disaggregation based on the regional structure of gross value added (GVA) and gross fixed capital formation (GFCF). Finally, the applicability of the presented method and recommendations for the further direction of research in this field is discussed.

1. Practical Supports for Productivity Assessment in Regions

The changes in the economic structure take place continuously, with greater or lesser intensity, with a variety of factors, the effects of which need to be systematically monitored. Maskell et al. (1998) considers one important factor to be internationalization, which brings on the one hand the process of ubiquitisation. But at the same time he is pointing out that in the last third of the 20th century, to some extent, the patterns of specialization have stabilized, both at national and regional level. The analysis of these patterns, their understanding, can then be considered as the basic premise of the optimization of processes that lead to an increase in the efficiency of economic processes, through productivity, and the quality of life of the population.

The urgency of the reflection of systematic changes is also underlined in the still discussed document "Industrie 4.0 – Smart Manufacturing for the Future" (MacDougall, 2014) which explicitly announces the advent of the fourth industrial revolution geared to the digitization of the economy and the need for its re-industrialization. Changes that have begun to show up in jobs caused by technical progress point to a reduction in the importance of labour

in the structure of productivity factors and the growing importance of capital, which absorbs relevant technological progress in its material form. The beginning of the Fourth industrial revolution is an unrepeatable moment of human history; the one who knows and is able to accept, use and multiply the supporting trends gets the most (Kraftová et al., 2018). However, an adequate quantification of ongoing processes is a prerequisite for capturing these benefits.

It is necessary to analyse the issue of productivity in detail and systematically at the level of the regions, in all its components, to understand the principles of existing development schemes and mechanisms resulting from the long-term train of events and past decisions, so-called path-dependence processes (David, 2001). With this knowledge, the effectiveness of the potential correction measures implemented through the usual regional policy instruments, or other forms of intervention, is, of course, directly related. Hence, the regional decomposition of data is becoming more important in this context as a method of allocating data for larger territorial units to smaller territorial units by means of certain keys. However, each individual indicator needs to be approached individually and, in particular, from the material point of view it is necessary to find such a key (Zeman & Vrabec, 2017).

A quantitative approach to growth accounting is used to analyse productivity issues and assess living standards prospects. This allows – based on the evolution of the volume and structure of inputs and the relationship between inputs and outputs – to track particular causes of growth and isolate individual components of productivity (Hulten, 2009). The importance of productivity analysis through growth accounting also underlines the existence of the well-known international project EU KLEMS (2018), which focuses on data collection for a detailed analysis of productivity across the EU, unfortunately for the time being only at national level.

The approach of growth accounting originally based on the idea of the neo-classical Solow-Swan model (Solow, 1956, 1957; Swan, 1956) presupposes an analysis of relatively detailed and easily accessible data on labour input but also on capital input, while the late are very difficult to measure (Mano & Castillo, 2015). Due to the different concepts of valuation at the level of accounting units and at the level of the macroeconomic aggregate, information on capital input is to a certain extent also problematic (Sixta et al., 2011). The availability of information on capital and its productivity at regional level is therefore inaccessible or, at least, very limited in the vast majority of countries. For this reason, most studies focusing on productivity issues of regional economics usually restrict themselves to a partial analysis of labour productivity (Zdražil & Applová, 2016). In fact, there is limited number of studies that attempted to estimate the regional capital, or its productivity (see above), still their results offer only a partial view in terms of time, space, economic sectors and level of disaggregation considered. Therefore, the crucial areas of capital productivity and multifactor productivity have not been systematically explored and well-described within the mainstream research.

Moreover, empirical research based on the growth accounting technique shows that during the whole period from the end of the Second World War to the early 1990s, the importance of changes in the labour component within productivity growth was only minor. In developing countries, these changes may have contributed to a 25–40% increase in overall productivity, but only in a few percentages in the developed countries of Western Europe (Easterly & Levine, 2001). Similarly, Feenstra et al. (2015) also point to the need for more comprehensive analyses, as the inclusion of indicators usable for calculating capital productivity and multifactor productivity developments into the latest (9th) version of the Penn World Table national accounts database state that these indicators open new possibilities because they finally allow for spatial analysis of the expected disparity sources in productivity and at the same time in living standards.

As Escribá-Pérez and Murgui-García (2014) point out, the non-availability of information on capital at regional level is usually dealt with by regional decomposition, with the most commonly used methods being based on value added and flows investment accumulation. Alternatively, a method based on the accumulation equation, which assumes that the economy is at the stage of neoclassical steady-state growth, can be used; still its applicability is considerably limited. Following that, the regional capital stock should be estimated using the perpetual inventory method. However, the problem of all

methods is a high degree of inaccuracy, so their results are only to be regarded as indicative.

The inadequacy of approach to productivity-based work has been well-understood by Lewis (1954) stating that a central problem in economic theory is to understand the process of accumulation of capital, knowledge and skills, because the speed of the process is the main factor of development. Capello et al. (2011) add, in this context, that capital is capable of binding knowledge and therefore the management of both inputs must be regarded as a critical factor for the successful development and innovation activity of each region. In addition, the evolution of capital productivity correlates with its accumulation associated with the allocation of jobs (Slaper, 2014). Therefore, information on capital development is also relevant in terms of analysing and predicting the labour market in the regions and shaping employment policy.

Gillula (1981), Walton (1981), or Gowdy (1982) attempted regional decomposition of selected indicators in the area of capital already at the end of the 20th century. More recent studies include Derbyshire et al. (2013), Escribá-Pérez and Murgui-García (2014) and Cambridge Econometrics (2010) geared to European regions. This problem has been long addressed on the example of Spanish regions (Mas et al., 2014), in the Netherlands (Manshanden, 2009) and in the Chinese regions (Zhang, 2008; Wu, 2016). Also, in the Czech Republic a similar problem was dealt with by Čadil and Mazuch (2012), Kraft et al. (2015) and Kramulová et al. (2016).

2. The Theoretical Basis of Regional Decomposition of the Development of the Productivity Structure

The basis of the indirect estimation of the development of the productivity structure in the regions and hence of its capital components is the standardized theoretical apparatus of growth accounting (Easterly & Levine, 2001; Hulten 2009; Caselli, 2005). This apparatus is generally based on the principles of the Cobb-Douglas production function (1), and the technological change is considered to be Hicks-neutral (i.e. the ratio of marginal product of capital to that of labour remains unchanged at constant capital labor ratio). As Artal-Tur et al. (2010) showed in their study, the assumption

of Hicks-neutral technological differences is appropriate at the level of sub-national regions.

$$Y = A \cdot C^{\alpha} \cdot L^{1-\alpha} \tag{1}$$

where Y represents the total output, A multifactor productivity, i.e. other factors that cannot be explained by changes in labour and capital inputs, e.g. changes in materials, energy, innovations, etc, but especially technology (Camus, 2007; OECD, 2001), C capital factor, L labour factor and α the production function parameter representing the share of the capital factor in total output.

Based on formula (1), any changes in total production are decomposable. It is therefore possible to estimate how these factors have contributed to these changes in the production function, which can be expressed as formula (2):

$$\Delta Y/Y = (\Delta A/A) + \alpha \cdot (\Delta C/C) + \\ + (1 - \alpha) \cdot (\Delta L/L) \tag{2}$$

This implies that changes at the output of the production process can be deduced from the additive aggregation of partial changes on the input side. But also, if changes in production volume and contributions of at least two production factors are known to these changes, it is possible indirectly to deduce changes that the third factor is involved in. These relationships can then logically be used to analyse in detail the development of productivity across the economy, to monitor the overall efficiency of labour and capital involvement, and the impact of technology levels. These relationships are usable at industrial level, but, of course, also to derive potentially appropriate corrections in the allocation of disposable resources between industries to increase total output revenues and thereby influence the level of economic development and living standards of the population.

At the level of national economy, the above-described contexts resulting from the growth accounting technique are well known and are now used by default in the analysis and subsequent formulation of strategies and industrial policies. In fact, the information on labour, capital and production volumes belong among the key indicators that statistical offices monitor and report by standard, often for individual industries.

At regional level, however, only information on the volume of labour and production is

usually available, which makes more detailed analysis of productivity much more difficult. Therefore, the logical question is whether it would be possible to overcome this obstacle, at least in some cases, and thus significantly expand the possibilities of productivity analysis at the regional level. As a possible path, in this context, there is an approximation of the evolution of unknown components of the production function, which could be based on the knowledge of the industrial structure, the relations between the national and regional levels within the industries and the industrial indicators that are reported at the level of the regions. In particular, one can infer the development of the productivity structure at regional level, based on the assumption of approximately analogous level of multifactor productivity of the industry across the regions of particular country, respectively as (3).

$$\Delta A_n^i / A_n^i \approx \Delta A_r^i / A_r^i \qquad (3)$$

where i symbolizes the industry, r region and n the state. When applying the assumption (3), in the basic growth accounting formula (2), the last unknown remains the contribution resulting from the change in the capital factor $\Delta C/C$. As Zdražil (2018) pointed out, this can now be indirectly deduced as a residual component $(\Delta C/C)'$, see (4) and quantified thanks to the knowledge of other variables. The other variables, i.e. L and Y, respectively ΔL and ΔY and α, are directly deductible from commonly reported regional statistics.

$$\left(\frac{\Delta C_r^i}{C_r^i}\right)' = \frac{\frac{\Delta Y_r^i}{Y_r^i} - \left(\frac{\Delta A_n^i}{A_n^i} + (1-\alpha)\cdot\frac{\Delta L_r^i}{L_r^i}\right)}{\alpha} \qquad (4)$$

In order to accept the assumption (3), and thus the potential applicability of the outlined use of industrial structure information to estimate the regional level of unproved productivity components, the neoclassical approach speaks strongly. It assumes that technological progress is exogenous, from which it can be deduced that technology diffusion should be equivalent in general. However, due to a number of constraints on the neoclassical approach, the assumption of equivalence does not seem too relevant.

However, conclusions of empirical research may speak for at least assuming the assumption

of analogue diffusion of technology across industries. They demonstrate that imitation, which is significantly easier, cheaper and faster than innovation, allows for a relatively rapid spread of technology and knowledge, making it a very important asset for other players (Barro & Sala-i-Martin, 2004). These authors further state that spillovers associated with technology and knowledge tend to be considered across the economy for simplification, but usually have limited scope. Therefore, it is more appropriate to consider that the benefits flowing from them are expanding just within a given industry, jurisdiction or defined territory (ibid).

Similarly, Porter (1998b) states that knowledge and new technologies are spreading relatively quickly across the industry. He points to increased rivalry, higher fluctuation rate within industry, but also direct and indirect links resulting from cooperation or sharing of supply-chain links. These factors direct the natural evolutionary process of the development of the entire industry to its common 'potential structure' (Porter, 1998a).

Harrigan (1997, 1999) has also reached conclusions supporting the applicability of the assumption (3), which, based on an empirical analysis of productivity and its structure, states that although multifactor productivity of the industry is often very different, even among areas that reach similar level of development. At the same time, these differences are attributed to the factors resulting from the status of countries in the international exchange, the developments in price levels and the differences in the legal, social and political environment (ibid). These conclusions are also supported by other studies which, in view of the differences in multifactor productivity, refer in particular to differences in working practices and to the level of market regulation, which partly determines the level of competition that domestic producers are exposed to in the global economy (Caselli, 2007).

Moreover, Beugelsdijk et al. (2018) also found that the multifactor productivity differs substantially across countries, as well as there are countries with substantial interregional variation. On the other hand, they also identified many small-sized as well as large-sized countries, where the distribution of multifactor productivity across regions is relatively condensed. In addition, their results indicate that the average within-country variance in

multifactor productivity is, as a rule, lower than that of international. At last, they highlight the importance of industrial view for further research (ibid).

It should be also noted that the application of the assumption (3) is arguable as it may be associated with certain distortive problems. Even at a regional level, there may be some discussion about the significance of some assumptions that are standardized at the level of the analysis of national economies. For example, the validity of the Balassa-Samuelson hypothesis, which implies a more pronounced spatial differentiation in productivity for those industries, whose consumption is not linked to the production site (Samuelson, 1994). Similarly, a similar phenomenon to the so-called Penn effect, based on the existence of systematic differences in price levels between more developed and less developed countries (ibid), can be considered at regional level. Certain distortions may also be expected due to the scale and use of agglomeration effects or other impacts.

Considering these constraints, it is prospectively possible to assume that the applicability of the above-mentioned principle of deriving a productivity structure in the industry at regional level will not be universal but will differ more or less in individual industries. This assumption is in one line with the findings of Marrocu et al. (2013) and Schrengell et al. (2007) who conclude that there is a large gap between the multifactor productivity processes and spillovers within the 'low-tech' and the 'knowledge-intense' industries. Hence we accept various level of accuracy for particular industries. In fact, we expect the lower accuracy within the service industries. It can also be assumed that the principle will be applicable to smaller countries with a relatively homogeneous economy and a balanced price level. Furthermore, given the assumption of Hicks's neutral technological change, the method seems likely to be appropriate rather for analysing shorter periods in which the ratio between labour input and capital does not change significantly.

In a summary, if there are natural mechanisms that act to converge multifactor productivity within the industry, and at the same time, the critical factors are not very different between the regions of a single country (e.g. legislation, access to the global market, price developments, competition in the internal market, political and social environment, etc), the assumption of a possible substitution between multifactor productivity of industrial level at national and regional level (3) seems to be justified.

Even we know the extensive list of pros and cons of the approach proposed, our ambition is not to develop any universally applicable method for all industries and regions in the world. On the other hand, we believe, that the adopted method may partially contribute to the regional specialized literature by partially fulfilling the existing niche of the regional productivity assessment. As a result, the method can be potentially usable to estimate the evolution of the productivity structure in the industry and, at the same time, the contribution resulting from the change in the capital factor (4) at regional level for some industries, at least.

These theoretical principles and assumptions related to the proposed method of indirect estimation of the development of the productivity structure in the regions, and hence its capital components, are logically necessary to undergo extensive verification. It is, at least in limited form, the aim of the following passages of this text.

3. Research Methodology

After an extensive search of data availability in all EU countries, all the necessary information on production and production factors of labour and capital at regional level was obtained only for the NUTS II regions of Poland (i.e. 16 regions), and only for the period 2009–2015. Within the EU, therefore, the Polish regions are the only sample where the change in the capital component $\Delta C/C$ can be directly quantified and then evaluate how the indirect estimates of this component $(\Delta C/C)'$ differ from this result achieved through the relationship (4). We have to point out that the NUTS II level serves only for demonstrative purposes in here, due to the data availability. In fact, the typical size and functional framework of regions at the NUTS II level widely differ among countries; hence, it should not be the best option in all cases. However, the NUTS II level of spatial aggregation is considered to be an appropriate choice for modelling and analysis purposes and also used in many other studies (Scherngell et al., 2007).

However, the data obtained are not ideal because they do not cover all 21 industries

separately in the NACE (Rev. 2) classification. Therefore, the aggregated industrial group BDE – 'mining, quarrying, energy, water supply & waste' is assessed; and on the contrary, the S (other services), T (households as employers) and U (activities of extraterritorial organisations) industries are not included in the verification. Still, due to the specificity and minority nature of this trio, it cannot be perceived as a major problem. All data used was obtained from the database of the Polish Statistical Office (Statistics Poland, 2019).

This research applies the methodology of quantification of individual components of productivity based on standard measurement methods, based on the above-mentioned growth accounting system. In this context, it uses the recommended indicators for these measurements in accordance with the OECD (2001) Manual and the UK Statistical Office Guide (Camus, 2007). Specifically, given the availability of data in the required breakdown, gross value added is used as a production indicator Y, gross value of fixed assets represents the input of capital C and the number of employed people is used as the input of labour L. Unfortunately, the more preferred indicator of labour, i.e. hours worked, is not disclosed at the NUTS II level of regions. The parameter of the function $(1 - \alpha)$ from the formula (2), respectively the weight of the production factor is derived as the ratio of the compensation of employees to the production unit. Of course, the problem of mixing the 'period of time' and 'moment in time' indicators was taken into account, so the value of the capital indicator was always recalculated as the average of the previous one (i.e. the initial state) and the end of the reference period.

Verifying the applicability of the proposed indirect estimation of capital productivity developments in the regions is based on the following steps:

1) Derivation $\Delta A_n^i / A_n^i$ from formula (2) at national level.

2) Estimation $(\Delta C_r^i / C_r^i)'$ in individual regions and industries. Performed on the basis of formula (4), applying the assumption (3).

3) Evaluation of the error rate of indirect estimates $(\Delta C_r^i / C_r^i)'$ against the values computed by the standard direct method of growth accounting (i.e. with the knowledge of production and capital and labour factors), respectively $\Delta C_r^i / C_r^i$ of formula (2) at regional level.

The evaluation of the error rate is performed by the measure of symmetric mean absolute percentage error (SMAPE) (Armstrong, 1985; Makridakis, 1993), which is a simple but yet standard and recommended method of assessing the accuracy of models (Bowerman et al., 2004; Hyndman & Koehler, 2006). As Tofallis (2015) showed in his comparative study, SMAPE is even one of the most accurate methods of error measurement.

This study uses the modified SMAPE (5), which is more comprehensible and interpretable than the original version (Armstrong, 1985; Makridakis, 1993) because it is defined at a standard interval (0–100) (Flores, 1986).

$$SMAPE = (100/p) \cdot \sum_{t=1}^{p} \frac{|R_t - F_t|}{(R_t + F_t)} \qquad (5)$$

where R_t shows the actual value – $R_t = (\Delta C/C)$; estimated value – $F_t = (\Delta C/C)'$; t is the time index and p the number of periods evaluated.

4) Comparison of indirect estimates error with the error $(\Delta C_r^i / C_r^i)'$ of traditional capital decomposition methods that are derived by means of value added and flows investment accumulation. For both modes of regional decomposition, SMAPE is used as the error rate measure from the actual value.

The approach of value added consists in the decomposition of the capital C in the industry at national level n according to the distribution of the gross value added GVA of the industry i in the regions r in the given period t which can be expressed as (6):

$$C_{r,t}^i = \frac{GVA_{r,t}^i}{\sum_i GVA_{n,t}^i} \cdot C_{n,t}^i \qquad (6)$$

The method of flows investment accumulation is then based on the ratio between investment activity in the industry at regional and national level. It uses indicator of the gross fixed capital formation $GFCF$ to express investment flows, while decomposition is based on the relationship (7). Unlike the previous one, this method of regional decomposition of capital uses the average ratio of several periods that follow after the estimated period. Moreover, with the increasing number of periods involved the accuracy of the method rise (Escribá-Pérez & Murgui-García, 2014).

$$C_{r,t=0}^i = \frac{\sum_t GFCF_{r,t}^i}{\sum_t GFCF_{n,t}^i} \cdot C_{n,t=0}^i \qquad (7)$$

By the above-mentioned procedures is therefore directly quantified the productivity structure in the individual regions, as well as contributions to its changes resulting from changes in capital. In addition, the productivity structure in the regions is indirectly estimated, and the contributions of the capital factor to the productivity changes are derived from these estimates. Subsequently, the possible impact of the capital-output ratio COR of industry (8) on the accuracy of the indirect estimation method is discussed. In this context, the potential impact of the region's specialization rate on a particular industry is being discussed, using localization quotient LQ (9).

$$COR = C/GVA \qquad (8)$$

$$LQ_r^i = COR_r^i / COR_n^i \qquad (9)$$

In the next part of the discussion are outlined the selected spatial connections of the accuracy of the indirect estimation method. At the end of the discussion, capital contributions are calculated on the basis of the values obtained by the two commonly used forms of regional decomposition of capital within the industry, indicated by formulas (6) and (7). The results of these approaches are then compared to the results of the indirect estimation method and serve as a benchmark for adopting conclusions about its accuracy.

4. Verification Results

The results of the error measurement summarized in Tab. 1 confirm that the proposed method of indirect estimation of the development of the productivity structure in the regions will not be universally applicable to all industries with a sufficient degree of reliability.

A high estimate of reliability is recorded for L (real estates). Fewer inaccurate but still reliable estimates (error rate averaging less than 2.5%) are also measured for G (wholesale & retail trade), H (transportation & storage), Q (health & social work) and C (manufacturing).

On the contrary, the relatively high error rate of the estimate (on average 5% or more) is evident especially for N (administrative & support services), K (finance & insurance) and

J (information & communication activities).

For other industries, unambiguous conclusions cannot be reached on the basis of measurements. However, for industries I (accommodation & food services), F (construction) and M (professional, scientific & technical activities), the principles of the proposed methodology may also be applicable in general terms. Significant deviations in the results of these industries are rare and not dramatically high (average error rate is 2.5–3.5%). For the remaining industries, i.e. A (agriculture, forestry & fishing), O (public administration & security), P (education) and R (arts, entertainment & recreation), and BDE (mining, quarrying, energy, water supply & waste) generally higher and/or more frequent deviations are measured (up to 4.5% on average).

It is evident that the method appears to be accurate for large or larger industries (measured by GVA share). For example, C and G shares are at the national level of about 20%, F about 8% and H and L more than 5%. On the contrary, this method appears to be less precise in the J, K, N and R industries, with shares of less than 3.5%. At the same time, it one can assume that the industries, which have a minority share in the performance of the economy, have more distinct regional specifics. These specificities are not sufficiently suppressed within the aggregation of economic activities and are therefore a significant obstacle distorting the results of the indirect estimation of the development of the productivity structure in the regions.

Besides the influence of the level of aggregation of economic activities, respectively the size of the branch, it seems that from the deviations in Tab. 1 the hints can be read of one more common pattern. That is this generally non-manifest distortion, considered on the basis of the Balassa-Samuelson hypothesis (Samuelson, 1994). As has been suggested, the hypothesis predicts greater spatial variations in productivity for those industries whose production can be relatively easily transported over longer distances (so-called 'traded sectors'). Thanks to this, their consumption is not linked to the production site or the closest neighbourhood. Although there are differences in the link binding the place of consumption to the production site, the industries in which most of the activities fall into the 'traded sectors'

Tab. 1: Error estimation for indirect measurements (SMAPE 2009/10 – 2014/15)

Industry region	A	BDE	C	F	G	H	I	J	K	L	M	N	O	P	Q	R	Average
Greater Poland	2.6	2.6	2.3	2.9	2.4	0.9	1.4	5.8	4.3	0.2	2.7	4.4	2.7	4.6	1.1	2.6	2.7
Kujawy-Pomerania	2.5	6.7	1.5	3.1	3.6	1.9	3.4	4.3	7.0	1.1	2.6	8.5	4.0	5.0	1.9	3.2	3.8
Lesser Poland	5.7	3.7	1.7	5.7	0.9	1.8	1.9	5.4	7.5	0.5	1.9	6.8	3.4	1.2	1.3	3.2	3.3
Lodz	2.6	3.6	1.5	2.2	1.8	3.2	7.5	4.8	4.4	0.6	5.3	6.4	2.6	1.5	3.4	3.2	3.4
Lower Silesia	3.1	2.6	4.5	4.2	1.7	1.0	4.3	3.8	3.1	0.7	1.7	**16**	3.7	2.7	1.2	2.2	3.5
Lublin	3.8	5.1	1.6	4.0	0.8	1.3	2.1	4.5	3.5	0.8	1.9	4.2	3.6	4.4	1.2	2.9	2.8
Lubusz	2.1	3.4	1.5	3.7	2.3	5.0	1.1	9.8	7.0	0.7	8.4	9.8	3.3	3.9	3.3	5.6	4.4
Masovia	2.7	3.2	1.8	2.1	1.2	1.1	2.9	1.6	2.7	1.5	1.4	3.9	3.0	4.5	3.0	6.9	2.7
Opole	5.8	8.8	3.2	6.1	1.8	1.5	4.1	**13**	7.4	0.8	3.0	8.3	4.7	4.9	1.8	5.4	5.0
Podlaskie	3.1	2.5	2.3	3.0	1.1	1.0	2.9	3.7	9.5	0.8	3.1	8.2	3.2	5.3	2.4	5.4	3.6
Pomerania	4.1	5.3	2.5	3.6	2.4	1.8	3.5	4.0	6.3	1.1	2.4	5.1	1.4	3.5	2.6	2.6	3.3
Silesia	5.1	5.6	1.7	1.2	1.3	2.7	1.3	5.0	3.4	1.1	1.0	4.8	3.7	1.7	1.6	3.0	2.8
Subcarpathia	8.5	3.5	1.9	5.6	1.9	2.0	4.2	4.1	4.4	0.9	4.4	**17**	2.6	5.1	2.7	5.6	4.6
Swietokryzskie	2.4	4.0	4.3	4.0	1.2	1.3	3.6	**10**	5.9	0.8	6.7	8.0	8.3	5.2	1.5	2.6	4.4
Warmia-Masuria	2.9	3.6	2.3	2.7	1.0	1.6	2.9	1.7	6.0	0.9	2.0	6.3	7.2	5.6	2.6	4.3	3.4
West Pomerania	3.7	3.8	2.3	2.1	1.9	2.9	1.1	6.8	4.4	0.9	2.9	5.0	3.7	2.8	1.3	2.9	3.0
Average	3.8	4.3	2.3	3.5	1.7	1.9	3.0	5.5	5.4	0.8	3.2	7.7	3.8	3.9	2.1	3.8	3.4
Standard error	1.7	1.6	0.9	1.3	0.7	1.0	1.6	2.9	1.9	0.3	2.0	3.7	1.7	1.4	0.8	1.4	

Source: own

Note: colored columns = estimation error 5–10%; bold figures = estimation error higher than 10%.

may be simply referred to as the primary and secondary sectors of the national economy and some services, i.e. industries A, B, C, G, H and K (Mano & Castillo, 2015; Sachs & Larrain, 2001).

The results of the estimates show that relatively low deviations are recorded for industries C, G and H, industry B can be evaluated only in aggregation with 'non-traded sectors' and industries A and K can be considered as rather smaller industries whose results may be distorted by regional specifics. Therefore, it can be assumed that the Balassa-Samuelson hypothesis has only a limited validity within the regions of a single state and does not impede the application of the proposed method.

Also, the capital intensity of the industry can play its role in assessing the contribution of capital to productivity changes. From the measurements carried out in the period 2009–2015 it can be stated that in the G, H, I, L, O, and Q industry, the growth tendencies dominated in the area of the capital intensity (COR) or the development of the amount of capital per unit of GVA respectively.

On the other hand, other industries are stagnating in this sense, or their trend with regard to developments in individual regions is ambiguous. Due to the measured deviations (see Tab. 1), it may be assumed that there may be a link between the accuracy of the indirect estimation method and the capital intensity of the industry. In particular, the accuracy of the method is generally higher in those industries where capital intensity is increasing. As a footnote, L and H industries, which exceed the Polish average COR (2.0) more than three times, are the most capital-intensive industries. On the contrary, among the least capital-intensive industries do not reach even half of this average are F, M, K and N.

Tab. 2: Statistical characteristics of LQ

Measure/industry	A	BDE	C	F	G	H	I	J
Average	1.07	1.16	1.00	0.82	0.95	1.08	0.96	0.83
Var(x)	0.22	0.23	0.12	0.37	0.12	0.31	0.26	0.20

	K	L	M	N	O	P	Q	R
Average	0.73	0.92	0.90	0.69	1.00	0.92	0.97	1.02
Var(x)	0.34	0.18	0.28	0.67	0.27	0.21	0.20	0.24

Source: own

Note: Var(x) = coefficient of variation.

The potential impact of the capital intensity on the accuracy of the indirect estimation method was further analysed by assessing the degree of regional decomposition of a particular industry. The localization quotient (LQ) values of the capital bond per unit of GVA across industries and regions are within the range of <0.03; 1.93>. In general, it can be argued that the indirect estimation method appears to be accurate in those industries where LQ values in most regions are close to 1 (i.e. proportional representation of the industry in the region) at a relatively low level of variability. As can be seen from Tab. 2, these parameters are fairly good for industries C, G, L and Q, where the average LQ is in the range of <0.92; 1.07> with a variation up to 20%. Conversely, for the N, K, F and BDE industries, both the variations from the average as well as the regional variability are generally the highest, so their representation across regions can be considered very uneven.

However, it is not apparent from the results of the capital intensity analysis of the industry that there is a direct relationship between the level of specialization of a particular region in the industry and the accuracy of the indirect estimation method for the region. For example, for industry C, where the regions are the least varied, the regions of Opole, Kujawy-Pomerania, Greater Poland (LQ > 1.15) and Pomerania and Lower Silesia (LQ < 0.85) deviate most from the proportional representation of the industry. On the other hand, in the regions of Lublin, Lodz and West Pomerania, LQ is <0.99; 1.01>. By comparing the variations captured in Tab. 1, however, does not imply that the accuracy of the indirect estimation method amongst these groups differs significantly or that it differs from other regions. Similar conclusions apply to other industries.

From the point of view of economic performance (measured as GVA), it is also to be noted that the Polish regions are highly differentiated. For example, the Masovia region, with the capital of Warsaw, as a pole of growth, exceeds the performance of the weakest region of Opole over the period under review 10 times. In terms of market share, Masovia occupies the first position in all industries. As a rule (except for industry A), it is followed by the second most powerful Polish Silesian region, which also has a significant, in this case, agglomerated, growth pole.

Industrial analysis of regional performance shows another important fact for assessing the accuracy of the indirect estimation method. Industries where the precision of the indirect estimation method is the lowest (i.e. J, K, N and BDE) are characterized by the highest variability of the regional shares in the GVA relative to their share of the GVA of the entire national economy. As a rule, in these regions can be identified a region with an extremely remote maximum value of GVA. For industries J and K, this extreme is the Masovian region, where in the J industry the maximum GVA is almost 80 times the minimum; in industry K then 40 times the minimum. For the BDE group, the delineated region of Silesia is more than 20 times the minimum; for industry N, the same conclusion applies for the Lubusz region. In addition, it is also to be noted that industry M, which shows more accuracy than the indirect estimation method, is characterized by a higher rate of variability of the regions' performance – the maximum (Masovia) is roughly 25 times the minimum (Podlaskie).

However, taking into account the spatial factor, it can be concluded that the indirect estimation method appears to be more accurate (see the column average in Tab. 1) predominantly in those regions where significant urban growth poles can be identified (e.g. Masovia – Warsaw, Pomerania – Gdansk, West Pomerania – Szczecin, Lower Silesia – Wroclaw, Greater Poland – Poznan, Silesia – Silesian agglomeration). In regions with a major urban centre, higher capital productivity is generally achieved, supported by higher labour productivity, as well as labour facilities (Statistics Poland, 2019). Regions with these characteristics are located mainly in the western part of Poland, some of them directly adjoining the more developed regions of Germany and the Czech Republic. These facts give rise to a presumption of the possible spillovers from foreign regions or the need of the adjacent

Polish regions to adapt to new technologies in order to achieve competitive multifactor productivity on a cross-border basis.

5. Comparison of Accuracy with Other Methods

The comparison of the accuracy of measurement of the proposed methodology with the accuracy of the methods using regional decomposition based on value added and flows investment accumulation can be considered very interesting. However, a more detailed regional/industrial comparison is presented only with the value added method, whose deviations from the actual values were significantly lower compared to the method of flows investment accumulation. Thus, the value added method can be considered as a stricter benchmark, with which it is appropriate to compare the indirect estimation method.

Tab. 3:	Error estimation for regional decomposition according to the value added (SMAPE 2009/10 – 2014/15)																		
Industry region	A	BDE	C	F	G	H	I	J	K	L	M	N	O	P	Q	R		Average
Greater Poland	4.5	3.7	3.0	4.5	5.2	2.1	2.8	11	6.9	0.4	5.1	6.4	3.6	4.2	2.0	5.1		4.4
Kujawy-Pomerania	5.0	9.6	2.7	6.6	7.8	4.7	4.1	5.8	8.0	2.1	5.1	11	5.0	1.4	1.9	5.8		5.4
Lesser Poland	6.9	3.9	2.6	11	2.1	3.2	3.2	8.3	14	1.2	3.0	12	6.9	0.7	1.6	4.0		5.3
Lodz	5.4	6.6	2.6	4.1	3.8	7.0	18	8.2	6.9	1.0	11	13	4.0	2.0	2.3	6.7		6.4
Lower Silesia	4.5	2.3	6.6	8.2	3.3	2.3	7.6	9.2	5.3	1.5	4.0	22	3.4	2.8	1.6	2.7		5.5
Lublin	6.3	5.3	2.0	8.3	1.5	2.9	5.4	7.3	5.2	1.5	3.3	6.6	2.2	1.1	1.5	3.9		4.0
Lubusz	2.6	5.9	1.1	7.9	4.5	11	2.1	20	8.7	1.3	15	23	4.4	1.0	3.6	10		7.7
Masovia	4.5	6.8	2.6	3.0	1.8	1.8	4.7	1.9	3.1	2.5	2.1	8.0	2.0	2.2	2.8	5.8		3.5
Opole	7.4	13	2.9	13	3.8	2.7	6.5	32	9.3	1.7	5.9	14	3.5	2.3	0.9	5.6		7.8
Podlaskie	5.9	3.7	3.2	4.6	2.3	2.1	4.5	9.2	12	1.7	5.7	11	1.9	2.5	2.3	10		5.2
Pomerania	6.3	5.8	4.4	6.9	4.8	3.0	3.1	10	12	1.8	4.9	5.5	3.0	1.8	4.8	6.2		5.3
Silesia	4.7	6.1	2.1	2.9	2.8	5.4	2.1	10	4.9	1.9	2.0	5.9	4.4	0.8	2.0	2.8		3.8
Subcarpathia	5.8	5.1	3.2	11	3.6	3.9	7.9	7.9	7.1	1.9	9.6	31	4.4	1.6	2.4	5.2		7.0
Swietokryzskie	4.4	7.0	5.6	7.2	2.6	2.5	5.7	23	8.5	1.5	14	17	4.1	1.4	1.2	4.2		6.9
Warmia-Masuria	4.1	6.3	2.1	5.8	2.0	2.8	5.1	3.9	7.0	1.7	4.6	14	3.5	1.3	2.9	6.5		4.6
West Pomerania	4.7	4.4	3.9	4.0	3.6	4.0	1.9	13	5.6	2.1	6.3	9.8	5.5	1.6	1.7	4.8		4.8
Average	5.2	6.0	3.2	6.8	3.5	3.9	5.3	11	7.8	1.6	6.3	13	3.9	1.8	2.2	5.6		5.4
Standard error	1.2	2.5	1.3	2.9	1.5	2.4	3.7	7.5	2.9	0.5	3.8	6.9	1.3	0.9	0.9	2.1		

Source: own

Note: colored columns = estimation error 5–10%; bold figures = estimation error higher than 10%.

The deviations in the estimates of the value added method are captured in Tab. 3. At first glance, it is obvious that the indirect estimation method (see the deviations in Tab. 1) is generally significantly more accurate across the economy. For Industry P only, the indirect estimation method clearly shows a higher degree of inaccuracy, with other industries dominated by the public sector – O and Q; both methods achieve practically comparable accuracy.

Except for the industries mentioned (P, O and Q), the indirect estimation method is 30–50% on average more accurate, as can be seen from both the average and standard error values. Higher accuracy of the indirect estimation method is, however, apparent also for industries where even the value added-based regional decoposition estimation does not reach the clearly poor results, such as L, G and C.

From the point of view of regional errors, there was not a single case where the estimate by the value added method would be more accurate than the indirect estimation method. Even in this comparison, the indirect estimation method appears to be significantly more accurate, on average about 25–40%.

The average error rate of the estimates in individual years across the regions is shown in Tab. 4. This table reveals that, in addition to the relatively high precision in the L, G, H, Q

Tab. 4: Comparison of accuracy of methods over the years (SMAPE)

Industry method, year	A	BDE	C	F	G	H	I	J	K	L	M	N	O	P	Q	R	Average
Indirect estimation																	
2010	7.7	5.9	3.1	5.2	1.7	1.6	3.0	**11**	5.2	1.2	7.3	**10**	5.2	4.2	2.2	3.9	4.9
2011	3.3	5.5	2.6	4.3	2.3	2.0	4.9	4.4	5.9	0.7	5.0	8.7	3.2	4.3	1.5	2.7	3.8
2012	2.7	5.1	2.3	4.2	1.8	2.1	2.3	6.4	7.3	0.8	1.6	8.0	4.5	6.5	3.8	7.6	4.2
2013	3.9	3.8	2.8	3.0	1.7	1.6	3.0	6.0	5.3	1.0	1.7	6.0	3.6	2.2	2.2	2.7	3.2
2014	2.5	3.2	1.6	2.2	1.5	2.2	2.8	1.8	4.7	0.9	1.7	6.6	4.0	3.2	1.3	2.8	2.7
2015	2.7	2.1	1.5	2.1	1.1	2.1	2.1	3.2	4.1	0.5	2.1	6.5	2.4	2.9	1.3	3.4	2.5
Value added																	
2010	8.0	7.2	4.1	9.5	3.6	2.7	5.8	**27**	7.5	2.2	**14**	**16**	4.3	2.6	2.6	5.2	7.6
2011	4.3	6.9	3.7	9.0	4.7	3.0	8.3	7.7	8.3	1.4	9.5	**17**	4.2	1.1	1.2	4.3	5.9
2012	4.3	7.0	3.2	9.3	3.5	4.3	4.3	**12**	**10**	1.7	2.9	**13**	5.2	2.2	3.9	**13**	6.3
2013	5.6	5.8	3.3	5.8	3.6	4.6	4.2	**12**	6.3	1.6	3.4	**10**	3.9	1.3	2.1	4.6	4.9
2014	4.3	4.7	2.4	3.5	3.2	4.5	5.2	3.5	6.9	1.7	3.4	**11**	2.9	1.7	1.4	3.7	4.0
2015	4.5	4.3	2.2	4.1	2.1	4.2	3.8	6.0	7.5	1.0	5.0	**12**	2.7	2.0	2.2	3.3	4.2
Flows investment accumulation																	
2010	27	32	32	41	35	36	37	42	40	29	46	43	37	17	17	15	32.8
2011	28	30	29	39	35	39	40	44	36	18	44	44	36	16	28	24	33.1
2012	31	43	32	45	24	30	48	37	37	37	35	51	43	27	33	38	36.9
2013	26	36	23	47	39	40	33	46	46	24	39	45	44	36	24	22	35.7
2014	30	35	38	49	42	39	25	51	47	20	33	61	27	36	29	32	37.0
2015	40	41	37	62	40	53	41	51	63	35	44	35	34	38	29	36	42.3

Source: own

Note: see notes below Tab. 1; visual comparison is not provided for the flows investment accumulation method, since all its estimation errors are higher than 10%.

and C industries mentioned above, the indirect estimation method is generally applicable to industries I, F and M but also to A, O, P and R. For these industries, higher deviations for the whole period are due to the unique deflection of values in 2010 and 2013 respectively for industries P and R. On the other hand, the analysis for each year confirms that for industries N, J and K, but also an industrial group BDE is the indirect estimation method rather inaccurate as higher imbalances are achieved systematically in these industries.

Even in these cases, however, the indirect estimation method seems to be more accurate than both of its alternatives. Specifically, methods based on the principle of regional decomposition of capital through value added and flows investment accumulation, the results of which are in Tab. 4 also summarized. An analogous conclusion applies to all other industries, with the exception of those already mentioned, of the public sector, for which the accuracy of the value added method is comparable with the indirect estimation method (O and Q) or even higher (P).

As noted above, for the Polish regions over the period under review, the accuracy of the method of flows investment accumulation is very low. Due to the principle of this method, we can assume increasing reliability of estimation with an extended time series of investments that can be used for regional decomposition. The validity of this assumption from Tab. 4 is quite obvious as the average accuracy of the estimates gradually decreases over time.

Therefore it can be assumed that the length of the 6-year period considered is insufficient to adequately estimate the contribution of capital to productivity changes in the regions through flows investment accumulation. However, even this conclusion can be considered as significant, as the absence of information on longer periods is still fairly common at sub-national analysis. The independence of the indirect estimation method on the retrospective range of statistics can therefore be seen as a major benefit of this approach.

In analogy to the decreasing accuracy of flows investment accumulation method, it is interesting to note that in the indirect estimation method, but also partly in the value added method, the accuracy increases in the course of time. This conclusion might seem to be linked to the development of the economic cycle. Although, as one of the few in Europe, the Polish economy did not get into a recession during the global crisis, it was also dampened when, after a significant slowdown, it reached the bottom of the cycle in 2012–2013 (Statistics Poland, 2019).

It can be assumed that in a period of general uncertainty caused by the global economic crisis, the economy is in a 'special regime'. Due to cautious reasons and the difficult availability of credit, the technological development and the need for the natural recovery of de facto or morally obsolete technologies are not fully reflected in this mode by a number of enterprises. Therefore, in the period affected by the crisis, it is logical to assume increasing disparities in the technological level of entrepreneurs, which is reflected in the variability of multifactor productivity. It is clear that due to this increased variability, the validity of the multifactor component productivity assumptions across industries (3) is weakened. Therefore, it is probably possible to establish the hypothesis that, in a period affected by the crisis, the indirect estimation method will achieve lower precision.

Conclusions

This article described the need for a detailed analysis of productivity at regional level and the theoretical basis for regional decomposition of the development of the productivity and capital structure. Consequently, it introduced a new method of indirect estimation of the development of the productivity structure in the regions, which at the same time allows estimation of the contribution resulting from changes within the capital factor. In the example of the NUTS II regions of Poland in 2009–2015, it subsequently verified the applicability potential of this method. Estimates mediated by the new method are significant given the limited possibilities of a detailed analysis of the development of all components of productivity at sub-national level.

Through the measure of symmetric mean absolute percentage error (SMAPE), the study evaluated the error rate of the indirect estimation method against actual values and also compared the error rate of this method with two commonly used approaches to the regional decomposition of capital – value added and flows investment accumulation method.

The results of the analysis confirm the

assumption that, due to existing limitations, the method is not universally applicable. However, for industries C (manufacturing), G (wholesale & retail trade), H (transport & storage), L (real estates) and Q (health & social work), it appears to be fairly accurate. With a lower confidence level, however, the indirect estimation method is also applicable for industries I (accommodation & food services), F (construction) and M (professional, scientific & technical activities), but also for A (agriculture, forestry & fishing), O (public administration & security), P (education) and R (arts, entertainment & recreation).

Based on partial analyses that have been conducted to discuss the results obtained, it can be assumed that the precision of the indirect estimation method is related to the size of the industry, the capital intensity of the industry, but also the proportionality of the industry's representation across regions. The method seems more accurate for larger industries and vice versa. Higher precision was also observed for industries where capital demand is clearly increasing. Similarly, the method is more accurate in industries where none of the regions are more specialized and vice versa.

Taking into account the spatial factor, the indirect estimation method appears to be more accurate in those regions where significant urban growth poles can be identified. In addition, there was no bias in the results, considered by the Balassa-Samuelson hypothesis. Therefore, there were no more significant spatial variations in productivity for those industries whose production can be relatively easily transported over longer distances.

In addition, as an explanatory moment for the worse reliability results, the indirect estimation of the J industry (information & communication activities), K (finance & insurance), N (administrative & support activities) and group BDE (mining, quarrying, energy, water supply & waste), is the high variability of regional shares in the GVA of industry in relation to its share of the GVA of the entire national economy appears. On the other hand, we have to point out that also other factors, which are behind the scope of this study, should matter.

Comparison with alternative approaches based on regional decomposition of value added and flows investment accumulation has shown that the indirect estimation method seems more accurate than both of these commonly used

methods. The only area where this conclusion does not apply is the specific area of public services. In the O (public administration & security) and Q (health & social work) industries, the results of the indirect estimation method are comparable to the results of the method based on regional decomposition of value added. Only for industry P (education) is the value added method even more accurate.

In summary, the new method of indirect estimation of productivity developments significantly enhances the existing productivity analysis capabilities at the regional level. As a result, a number of benefits arising from the use of the outlined principles can be considered for deeper evaluation of the implementation of development strategies and rationalization of the allocation of disposable resources within development interventions. Finally, it is possible to solve specific undesirable disturbances and inequality of development with higher efficiency and also to contribute to raising living standards and the quality of life of the population.

In conclusion, however, it should be noted that the introduced method still needs to be subjected to considerably more extensive verification than the one carried out by the study. Given the very limited availability of data, verification was piloted only on a sample of regions in one country and only for a limited period. In particular, the spatial extension of analysis to cover more countries as well as time extension to cover more periods is highly demanding to check our results. The discussion of the possible influences of various factors on the accuracy of the method also opened up new questions whose response appears to be rather acute. It is in these areas that further research is to be directed towards the examination of possible additional methods employment, which would help to remove the limitations identified. Such an extension is highly demanding before diffusion of the proposed method to the level of solving the practical problems of regional development and regional policy.

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