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The analysis of innovative processes – a Polish case

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ABSTRACT

The paper aims at examining the properties of innovative processes with regard to Schumpeter premises on factors and drivers of the development of the economy. Due to the analysis of the changes of the characteristics of the economic entities formalised in a mathematical model, two new indexes, namely, an index of the creative destruction, as well as an innovators' competitiveness index, are defined. As a result, we get a formal relationship between a size of innovators' competitiveness and a level of innovativeness. These findings give us the tools for distinguishing the qualitative properties of economic transformations. In the consequence, we obtain a coherent and unified study of innovative processes in Polish regions.

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1. Introduction

The indexes used for ranking countries with respect to a phenomenon are defined by the use of a large number of variables (see, for instance, https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/). Not all the data collected for the countries are collected for the regions of the countries. Comparison of "A list of criteria in 2022", published on the website https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/, with the data disseminated on https://bdm.stat.gov.pl/, can serve us an example. Therefore, in some cases, there is a need to determine new indexes which could be calculated by the use of data taken for the regions of the economy and for the economy as a whole. Such index can be used in the research for the analysis of both the whole economy, and the regions thereof.

In the paper we focus, above all, on defining and analysing the indexes that would measure dissimilarity of economic structures (i.e., economies, regions, firms etc.) from two consecutive points of time, with respect to the phenomena connected with innovativeness. In the presented analysis, Schumpeter's premises on the features of economic evolution are taken into account, with the special attention paid to the role

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of the creative destruction and competitiveness. We wished that the mentioned index would measure otherness of an economic structure from its earlier forms.

Let us recall that in Schumpeter theory (Schumpeter, 1934), the main role in the processes of the economic development is assigned to innovation, creative destruction and firms' competitiveness in such a way that economic evolution is determined by innovations and innovators while competition between innovators provides incentives to introduce innovations. The creative destruction is understood as the synthesis of innovative processes and the processes of elimination of old, outdated solutions, commodities and structures etc.

Initially, in our approach, some variables connected strictly with the activities of innovators, creative destruction and competitiveness of firms such as rate of innovation, rate of innovative enterprises, enterprise death rate, enterprise birth rate, rate of sold innovations, etc. were taken into account into determining formulas for the indexes under study. After the preliminary analysis, this set of variables became reduced to the rate of innovation, rate of innovative enterprises and enterprise death rate. The concept for choosing the variables for determining the presented indexes was born by both studying Schumpeter writings and the analysis of the properties of the model of economic evolution defined by Lipieta and Lipieta (2022a).

Schumpeter (1934) argued that the competitiveness of innovators is one of the main factors of the economic development. Due to the best of our knowledge, the relationships between innovators' competitiveness and innovativeness were empirically verified with respect to some countries or regions (for instance, Ciocanel & Pavelescu, 2015; Clark & Guy, 2010). In the paper, we examine, using mathematical methods, whether, in the considered model under some additional requirement, an increase of competitiveness of innovators leads to an increase of innovativeness, as well as whether the inverse relationship is satisfied.

The formulas of the presented indexes are the results of the rigorous analysis of the characteristics of the economic entities formalised in a mathematical model of an economic system. Therefore, the indexes defined may be applied to the analysis of the creative destruction and the competitiveness of innovators in economic systems or sub-systems, in isolation from political systems, organisational conditions, social systems, competitiveness profiles of a region, etc. The new indexes are used to analyse the Polish regions against the background of the Polish economy with regard to the properties of innovative processes.

The paper consists of seven parts. The second part deals with the literature review, the third part presents a description of the model. In the fourth part the reader can find the theoretical results on measuring dissimilarity of economic structures changing in time, whereas the empirical analysis on the creative destruction and competitiveness of Polish regions is presented in the fifth part. The sixth part is devoted to discussion, the seven part deals with conclusions.

2. Literature survey

The first, who identified the key roles of innovations, innovators, creative destruction and competitiveness within the development of the economy was Schumpeter (1934, 1950, 1964).

Schumpeter also laid the foundation for the modern theory of competitiveness (Schumpeter, 1934). In the Schumpeter approach, competition can be compared with a game with firms as the players in which the winners stay on the market, while the losers, as a result of the creative destruction, are eliminated from the market. Schumpeter, among others, suggested that there was a relationship between competitiveness and innovativeness, and that idea has been still examined (see, for example, Clark & Guy, 2010; Moen et al., 2018; Dos-Santos, 2021). More contemporary findings on competitiveness, including also the analyses of various types of competitiveness, can be found, for example, in Cantwell (2015), Ciocanel and Pavelescu (2015), Nijkamp and Siedschlag (2011), Bukowski and Siek (2013), while, among others, Bartlett (2014), Stojcic and Aralica (2018), Stojcic et al. (2019) analysed the competitiveness of some regions.

Generally, it can be said that modern studies on the Schumpeterian evolution can be broken down into two groups: the studies within neo-Schumpeterian research program (Nelson & Winter, 1982; Freeman, 1982; Malerba & Orsenigo, 1995, 1997; Metcalf, 2001; Andersen, 2009; Foster, 2011; Nelson, 2016) and the research papers on Schumpeterian endogenous growth theory (Aghion & Howitt, 1992; Dosi et al., 2010, Assenza et al., 2015; Almudi et al., 2020). The papers from the first group deal with mainly qualitative features of economic processes, while the latter focus on quantitative properties of those processes. However, the representatives of both approaches agree that innovations, innovators, the creative destruction and competitiveness are essential for the evolutionary processes, economic development and economic growth.

In parallel, the theory of entrepreneurship that originated in Schumpeter's (1912, 1934) books, has been also dynamically developing (for instance, Mishra & Zachary, 2015; Martinez et al., 2011; Schwab & Zhang, 2018; Crudu, 2019; Stoica et al., 2020).

It should be noted that thanks to Schumpeter, particular importance of the creative destruction within economic evolution has also been noted. Aghion and Howitt (1992) proved that the mechanism of creative destruction, understood as producing commodities of higher quality, generated the economic growth and led to the improvement of effectiveness of the activities of the R&D sector – the source of economic development. In (Lipieta & Lipieta, 2022a, 2022b), the role played by the creative destruction in some processes leading to the equilibrium in competitive economy were demonstrated. Lipieta and Ćwięczek (2022) examined, among others, the importance of the creative destruction for clearing real and financial markets, Lipieta and Malawski (2021) demonstrated the importance of the creative destruction in processes leading to the introduction of eco-innovations.

3. Model

The model of economic evolution in the approach considered in the paper was originally defined in (Lipieta & Lipieta, 2022a). Our considerations concern the supply side of the economy, hence here we only highlight the main components of the model and focus on the variables relating to producers' activities. The definitions presented below are slight modifications of the definitions presented by Lipieta and Lipieta (2022a) as well as Lipieta and Malawski (2021).

To reflect the fact that an unknown number of economic agents can enter the market as well as many commodities can be introduced on the market in the future, the number of the market participants as well as the number of commodities are assumed to be countable. These arrangements are reflected in the idea of considering inactive agents and the future goods in the modelling of economic processes. In the model under study, only the activities of producers are taken into account, while time is a discrete variable. It is denoted:

- $A = (a_i)_{i\in\mathbb{N}}$ - a countable set of consumers,
- $B = (b_j)_{j\in\mathbb{N}}$ - a countable set of consumers,
- $t = 0, 1, 2, \ldots$ - a point of time.

Every point of time can be appointed by a change in the economic system, or it is determined by an investigator. It can be, for instance, the end of a calendar year. The number $\ell_t \in \mathbb{N}_+ \overset{\text{def}}{=} \{1, 2, \ldots\}$ means the number of the commodities, which are produced and consumed in the economy at time t or earlier. Space $\mathcal{R}^{\ell_t}$, where

$$\mathcal{R}^{\ell_t} \overset{\text{def}}{=} \mathbb{R}^{\ell_t} \times \{0\} \times \{0\} \times \cdots.$$

is the commodity-price space (see Mas-Colell et al., 1995) at time t, where every coordinate $l \in \{\ell_t + 1,\ \ell_t + 2, \ldots\}$ is interpreted as the number of a future good. Market activity of a producer b_j at time t is represented by a vector $y^{b_j}(t) \in \mathcal{R}^{\ell_t}$ called the plan of producer b_j at time t (shortly: production plan), while a vector $x^{a_i}(t) \in \mathcal{R}^{\ell_t}$, called the plan of consumer a_i at time t (shortly: consumption plan), describes market activity of consumer a_i at time t. All production plans with respect to the technologies feasible for producer b_j at time t form the so called production set $Y^{b_j}(t) \subset \mathcal{R}^{\ell_t}$, similarly, all consumption plans feasible for consumer a_i at time t form the consumption set $X^{a_i}(t) \subset \mathcal{R}^{\ell_t}$.

The consequence of the previous arrangements is the fact that, for every t, there exist numbers $m_t,\ n_t \in \{1, 2, \ldots\}$ such that, for every $j > n_t$, every producer b_j is interpreted as an inactive producer, as well as, for every $i > m_t$ every consumer a_i is interpreted as an inactive consumer, where by the definition, an inactive agent at time t is the agent whose activity is reduced to the zero plan of action at the time t, i.e.,

$$\forall j > n_t\ \ Y^{b_j}(t) \overset{\text{def}}{=} \{0\} \quad \text{and} \quad \forall i > m_t\ \ X^{a_i}(t) \overset{\text{def}}{=} \{0\}. \tag{1}$$

The set of active producers at time t is denoted by $B_t = (b_1, \ldots, b_{n_t})$, while the set of active consumers at time t are denoted by $A_t = (a_1, \ldots, a_{m_t})$. Moreover, it is assumed, that at least one production plan $y^{b_j}(t) \in Y^{b_j}(t)$, where $b_j \in B_t$, has ℓ_t-th coordinate different from zero. Under the above presented assumptions and the notion, below a production system is defined:

Definition 1. A system $P(t) = (B_t,\ \mathcal{R}^{\ell_t}; y_t, p(t))$, where $y_t : B_t \ni b \to Y^b(t) \subset \mathcal{R}^{\ell_t}$ is the correspondence of production sets, which to every producer b assigns a non-empty production set $Y^b(t)$ satisfying condition (2), is called a production system at time t.

In the similar way, a consumption sector of the economy is presented:

Definition 2. A system $C(t) = (A_t,\ \mathcal{R}^{\ell_t}, \Xi_t; \chi_t,\ \varepsilon_t,\ \epsilon_t,\ p(t))$, where

- $\Xi_t \subset \mathcal{R}^{\ell_t} \times \mathcal{R}^{\ell_t}$ is the family of all preference relations in $\mathcal{R}^{\ell_t}$,
- $\chi_t : A_t \ni a \to X^a(t) \subset \mathcal{R}^{\ell_t}$ is a correspondence of consumption sets, which to every consumer a assigns a non-empty consumption set $X^a(t)$ satisfying condition (1),
- $\epsilon_t : A_t \ni a \to \epsilon(a) = \omega^a(t) \in X^a(t)$ is an initial endowment mapping,
- $\varepsilon_t \subset A_t \times (\mathcal{R}^{\ell_t} \times \mathcal{R}^{\ell_t})$ is a correspondence, which to every consumer $a \in A_t$ assigns a preference relation $\preccurlyeq_t^a$ from set Ξ_t restricted to set $X^a(t) \times X^a(t)$,
- $p(t) \in \mathcal{R}^{\ell_t}$ is a price vector at time t,

is called a consumption system at time t.

Definition 3. A structure

$$\varepsilon(t) = \left(\mathcal{R}^{\ell_t}, p(t),\ P(t), C(t),\ \theta_t, \omega(t)\right),$$

in which:

- $\mathcal{R}^{\ell_t}$ is the commodity-price space
- $p(t) \in \mathcal{R}^{\ell_t}$ is the price vector,
- $P(t)$ is a production system,
- $C(t)$ is a consumption system,
- $\theta_t : A_t \times B_t \to [0, 1]$ is a share mapping, where:
  - for $a \in A_t$ and $b \in B_t$, number $\theta_t(a, b)$, means the share of consumer a in the profit of producer b,
  - $\forall b \in B_t\ \sum_{a \in A_t} \theta_t(a, b) = 1$,
- $\omega(t) = \sum_{a \in A_t} \omega^a(t)$

is called a private ownership economy (in short: an economy) at time t.

Economy $\varepsilon(t')$, for $t' > t$, is interpreted as a transformation of economy $\varepsilon(t)$, what further will be written, in short, as $\varepsilon(t) \subset \varepsilon(t')$. At time t' some new, with respect to time t, consumers or producers can be active on the market, which means that $B_t \subset B_{t'}$, $A_t \subset A_{t'}$ and consequently $n_{t'} \geq n_t$ and $m_{t'} \geq m_t$. We assume that, in every period t, producers in economy $\varepsilon(t)$ compete, however in contrast to the perfect rationality assumption (Simon, 1947), their aim is maximising profits or introducing innovations to maximise the profit in the future, which is coherent with Schumpeter's theory. In turn, it is assumed that, for every t, consumers in economy $\varepsilon(t)$ aim at maximising preferences on budget sets.

Definition 4. It is said that economy $\varepsilon(t')$ is an innovative transformation of the economy $\varepsilon(t)$, which is shortly denoted by $\varepsilon(t)\subset_{it}\varepsilon(t')$, if

$$\exists b_j \in B_{t'} \exists\ y^{b_j}(t') \in Y^{b_j}(t')\ \forall b \in B_t\ y^{b_j}(t') \notin Y^b(t). \tag{2}$$

In other words, the fact that economy $\varepsilon(t')$ is an innovative transformation of economy $\varepsilon(t)$ means that there exists a producer which in period t' realises a production plan satisfying condition (2). Suppose that an agent b_j satisfies condition (2). Then

- if $\ell_{t'} > \ell_t$, then every commodity $l \in \{\ell_t + 1, \ \ldots, \ell_{t'}\}$ is an innovative good introduced on the market at time t' by the use of an innovative technology; moreover, if the agent b_j is the alone producer satisfying (2), then he introduced all innovative commodities on the market,
- if $\ell_{t'} = \ell_t$, then an innovative technology is introduced on the market by the producer b_j at time t'.

If condition (2) is satisfied, then we say that there is an innovation in economy $\varepsilon(t')$ with respect to economy $\varepsilon(t)$. Producer b_j satisfying (2) is called an innovator. Any change in the activities of producers on the market, which results in the occurrence of an innovation, is called an innovative change. If a producer $b_j \in B_{t'}$ does not satisfy condition (2), i.e.,

$$\forall y^{b_j}(t') \in Y^{b_j}(t') : \ y^{b_j}(t') \in \cup_{b \in B_t} Y^b(t), \tag{3}$$

then it is called an imitator. Every plan $y^{b_j}(t')$ of the producer $b_j \in B_{t'}$ satisfying condition (3) is called an imitative production plan at time t' with respect to time t since it was realised by a producer $b \in B_t$ at time t. If every producer $b \in B_{t'}$ is an imitator, then the economy $\varepsilon(t')$ is said to be an imitative transformation of economy $\varepsilon(t)$, which shortly is denoted by $\varepsilon(t)\subset_{imt}\varepsilon(t')$. More information on different kinds of transformations of the economy in the approach presented can be found in (Lipieta & Malawski, 2021) and (Lipieta & Lipieta, 2022a).

We assume additionally that two various innovators do not introduce the same innovation. Hence it is assumed that, if in period $t' = t + 1$ an innovation appears on the market with respect to period t, then its price is determined by the innovator who introduces this innovation. In contrast, the prices of the non-innovative commodities are assumed to be determined by the market price mechanism, accordingly to the law of demand and supply. Consequently, if a commodity or a technology is innovative in the period t' with respect to period t, where $t' > t + 1$, but it was introduced in period $t'' \in \{t + 1, \ldots, \ t' - 1\}$, then we assume that its price in period t' is also determined by the market price mechanism. Due to the above we have, for every t, the law of one price (see LeRoy & Werner, 2002) satisfied in the economy $\varepsilon(t)$, for both innovative and non-innovative commodities.

4. Theoretical results – mixed methods approach

In this part of the paper we aim at defining some indexes which could be helpful in comparing economies $\varepsilon(t)$ and $\varepsilon(t')$, where $\varepsilon(t)\subset_{it}\varepsilon(t')$, with regard to innovativeness, competitiveness, and the creative destruction.

4.1. Creative destruction

Firstly we present some characteristics of vectors in space $\mathcal{R}^{\ell_{t'}}$. For vector $v \in \mathcal{R}^{\ell_{t'}}$, the norm of the vector v can be calculated by the rule

$$||v|| = \sum_{i=1}^{\ell_{t'}} |v_l|.$$

On the basis of the above, the distance between vector v and a nonempty set $Y \subset \mathcal{R}^{\ell_{t'}}$, denoted by $d(v, Y)$, is defined by the rule:

$$d(v, Y) = \inf\{||v - y|| : y \in Y\}$$

(see Cheney, 1966). Let us notice that for every $v \in \overline{Y}$, where set $\overline{Y}$ is the closure of set Y, $d(v, Y) = 0$. In the further consideration we assume that $B_{t'} = B_t$ in such meaning that if, $n_{t'} > n_t$, then $Y^{b_j}(t) = \{0\}$, for $j \in \{n_t + 1, \ldots, n_{t'}\}$. Denote by

- $B^{in}_{t'}$—the set of innovators at time t' with regard to time t, $B^{in}_{t'} \subset B_{t'}$,
- $B^{im}_{t'}$—the set of imitators at time t' with regard to time t, $B^{im}_{t'} \subset B_{t'}$,
- $B^{a}_{t'}$—the set of producers which are absent (inactive) on the market at time t' and which were active in period t,
- $B^{n}_{t'}$—the set of producers which enter the market at time t' and are new on the market,
- $Y(t) = \cup_{b\in B_t} Y^b(t)$ - the set of all production plans feasible in economy $\varepsilon(t)$,
- $\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right) \in Y(t) \times \cdots \times Y(t) \subset \left(\mathcal{R}^{\ell_t}\right)^{n_t} \subset \left(\mathcal{R}^{\ell_{t'}}\right)^{n_t}$ - the sequence of production plans realised in economy $\varepsilon(t)$,
- $\sum_{b\in B^{in}_{t'}} \sum_{l=\ell_t+1}^{\ell_{t'}} \left|y^b_l(t')\right|$ - the number of all innovative commodities introduced at time t' provided that plan $y(t')$ is realised and $\ell_{t'} > \ell_t$,
- $\sum_{b\in B_{t'}} \sum_{l=1}^{\ell_{t'}} \left|y^b_l(t')\right|$ - the total number of all commodities (outputs and inputs) at time t' provided that plan $y(t')$ is realised,
- $\sum_{b\in \tilde{B}_{t'}} \sum_{l=1}^{\ell_t} \left|y^b_l(t)\right|$ is the number of all inputs and outputs at time t of the producers from set $\tilde{B}_{t'} \subset B_{t'}$ provided that plan $y(t)$ was realised.

Let us notice that, due to the assumption that $\varepsilon(t)\subset_{it}\varepsilon(t')$, the set $B^{in}_{t'}$ is not empty. To analyse the results of a creative destruction in the spirit of Schumpeter's theory, we also assume in this part that the sets $B^{n}_{t'}$, $B^{a}_{t'}$, $B^{im}_{t'}$ are also not empty. Under the above assumptions and notation the following is true:

Proposition 1. Let, for $j \in \{1, \ldots, n_{t'}\}$, $y^{b_j}(t') \in Y^{b_j}(t')$. If

$$\exists b_j \in B_{t'} : y^{b_j}(t') \notin \overline{Y}(t),$$

then

$$d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right) \leq \sum\nolimits_{b_j \in B_t : y^{b_j}(t') \notin \overline{Y}(t)} ||y^{b_j}(t')||. \tag{4}$$

Let, for $j \in \{1, \ \ldots, n_t\}$, $y^{b_j}(t) \in Y^{b_j}(t)$. If

$$\exists b_j \in B_t : y^{b_j}(t) \notin \overline{Y}(t'),$$

then

$$d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right) \leq \sum\nolimits_{b_j \in B_t : y^{b_j}(t) \notin \overline{Y}(t')} ||y^{b_j}(t)||. \tag{5}$$

Proof. See the Appendix.

Additionally, it is clear that, if

$$\forall b_j \in B_{t'} : y^{b_j}(t') \in \overline{Y}(t), \tag{6}$$

then

$$d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), \quad Y(t) \times \cdots \times Y(t)\right) = 0$$

as well as, if

$$\forall b_j \in B_t : y^{b_j}(t) \in \overline{Y}(t'), \tag{7}$$

then

$$d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), \quad Y(t') \times \cdots \times Y(t')\right) = 0.$$

Assumptions (6) and (7) are related to the case when the technological abilities described in sequences $\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right)$ or $\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right)$ are so close to the technological abilities of the production systems in periods t and t', respectively, that the distances under study are equal to zero. As a consequence of the assumption (6), we obtain the following:

$$\left(\forall b_j \in B_{t'} : \ \ Y^{b_j}(t) \subset Y(t')\right) \Rightarrow \left(d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right) = 0\right). \tag{8}$$

Similarly, as the consequence of (7), the following is valid:

$$\left(\forall b_j \in B_t : \ \ Y^{b_j}(t') \subset Y(t)\right) \Rightarrow \left(d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_t}}(t')\right), Y(t) \times \cdots \times Y(t)\right) = 0\right). \tag{9}$$

Keeping in mind the conditions (8) and (9), we obtain the following:

Remark 1. Let the assumptions of Proposition 1 be satisfied. Then

$$d\Big(\Big(y^{b_1}(t'),\ \ldots,\ y^{b_{n_{t'}}}(t')\Big), Y(t) \times \cdots \times Y(t)\Big)$$
$$\leq \#B^{in}_{t'} \cdot \max\Big\{||y^{b_j}(t')||:\ b_j \in B^{in}_{t'} \wedge y^{b_j}(t') \notin Y(t)\Big\}. \tag{10}$$

If,

$$\forall b_j \in B_{t'} \backslash B^a_{t'}:\ \ Y^{b_j}(t) \subset Y(t') \tag{11}$$

as well as

$$\forall b \in B^a_{t'} \exists\ y^b(t) \in Y^b(t):\ \ y^b(t) \notin Y(t'), \tag{12}$$

then

$$d\big(\big(y^{b_1}(t),\ \ldots,\ y^{b_{n_t}}(t)\big), Y(t') \times \cdots \times Y(t')\big)$$
$$\leq \#B^a_{t'} \cdot \max\Big\{||y^{b_j}(t)||:\ b_j \in B^a_{t'} \wedge y^{b_j}(t) \notin Y(t')\Big\}. \tag{13}$$

Proof. See the Appendix.

Let us notice that condition (11) in Proposition 1 means that every, active at time t', producer can realise in this period his every production plan that is feasible in the period t, whereas the condition (12), concerning the producers exiting the market at time t', means that at least one production plan of every such producer, feasible in the period t, has not been realised in the economy $\varepsilon(t')$.

Below we show that in some cases the “inequalities signs” in conditions (10) and (13) can be replaced by the “equality signs”.

Example 1. Consider economy $\varepsilon(t)$ and its innovative transformation $\varepsilon(t')$, $\varepsilon(t) \subset_{it} \varepsilon(t')$, in which:

A1) $\ell_t = 2,\ \ell_{t'} = 3,$
A2) $\#B_t = 2,\ \#B_{t'} = 3,\ B^{in}_{t'} = B^n_{t'},\ \#B^{in}_{t'} = 1,\ \#B^{im}_{t'} = 1,\ \#B^a_{t'} = 1;$ for simplicity we assume that $B^a_{t'} = \{b_1\},\ B^{im}_{t'} = \{b_2\},\ B^{in}_{t'} = \{b_3\}$, consequently $B_t = \{b_1,\ b_2\}$,
A3) $Y^{b_1}(t) = Y^{b_2}(t) = \big\{(y_1, y_2, 0):\ y_1 \geq 0,\ y_2 \leq 0\big\},\ \ Y^{b_1}(t') = \{(0,0,0)\},\ Y^{b_2}(t') = \big\{(y_1, y_2, 0):\ y_1 \geq 0,\ y_2 \leq -4\big\},\ Y^{b_3}(t') = \big\{(y_1, y_2, y_3):\ y_3 \geq y_1 - y_2,\ y_2 \geq 1,\ y_1 \leq -1\big\}.$

It is easy to check that, under the above assumptions, the following is satisfied:

$$d\left(\left(y^{b_1}(t'), y^{b_2}(t'), y^{b_3}(t')\right), Y(t) \times Y(t) \times Y(t)\right) = \#B_{t'}^{in} \cdot \max\left\{||y^{b}(t')||: \ b \in B_{t'}^{in}\right\}.$$

Example 2. We consider a private ownership economy in which $Y^{b_1}(t) = \{(y_1, y_2, 0): \ y_1 \geq 0, \ y_2 \leq -1\}$, $Y^{b_1}(t') = \{(0,0,0)\}$, $Y^{b_2}(t) = Y^{b_2}(t') = \{(y_1, y_2, 0): y_1 \geq 1, \ y_2 \leq -3\}$ and the rest of characteristics is the same as in the economic system analysed in Example 1. Now condition (13) is satisfied. It is easy to check that, for $y^{b_1}(t) = (1, -1, 0)$, $y^{b_2}(t) = (1, -3, 0)$,

$$d\left(\left(y^{b_1}(t), y^{b_2}(t)\right), Y(t') \times Y(t')\right) = \#B_{t'}^{a} \cdot \max\left\{||y^{b_j}(t)||: \ b_j \in B_{t'}^{a} \wedge y^{b_j}(t) \notin Y(t')\right\}.$$

Now let us turn our attention to the following:

Remark 2. Under the assumptions of Proposition 1, the following is satisfied:

$$d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right) \leq \#B_{t'}^{in} \cdot \sum\nolimits_{b_j \in B_{t'}^{in}} ||y^{b_j}(t')||, \tag{14}$$

$$d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right) \leq \#B_{t'}^{a} \cdot \sum\nolimits_{b_j \in B_{t'}^{a}, \ y^{b_j}(t) \in y(t')} ||y^{b_j}(t)||. \tag{15}$$

Moreover, in the economies considered in Examples 1 and 2, in fact, we have for the vectors analysed the equality signs; adequately, in condition (14) and (15).

On the basis of Proposition 1 and Examples 1 and 2, we can see that, generally, the inequalities (10) and (13) are optimal in such meaning that numbers $\#B_{t'}^{in} \cdot \max\left\{||y^{b_j}(t')||: \ b_j \in B_{t'}^{in} \wedge y^{b_j}(t') \notin Y(t)\right\}$ and $\#B_{t'}^{a} \cdot \max\left\{||y^{b}(t')||: \ y^{b_j}(t) \notin Y(t') \wedge b_j \in B_{t'}^{a}\right\}$ are the least upper bound of numbers $d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right)$ and $d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right)$, respectively. However, the above mentioned upper bounds depend on the characteristics indicated with a "size" of the economy, namely the numbers of the producers at every periods (i.e., numbers $\#B_{t'}$ or $\#B_t$) and the amounts of commodities used by the producers at the every period (i.e., numbers $||\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_t}}(t')\right)||$ or $||\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right)||$). That is why we think that numbers

$$d_{t',t} = sup\left\{\frac{d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right)}{\#B_{t'}||\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_t}}(t')\right)||}: \left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right)\right.$$
$$\left. \in Y(t') \times \cdots \times Y(t') \backslash \{0\}\right\}.$$

and

$$d_{t,t'} = sup\left\{ \frac{d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right)}{\#B_{t'} \left\| \left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right) \right\|} : \left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right) \right.$$
$$\left. \in Y(t) \times \cdots \times Y(t) \backslash \{0\} \right\}.$$

better describe the "size" of changes between economies $\varepsilon(t')$ and $\varepsilon(t)$ as well as $\varepsilon(t)$ and $\varepsilon(t')$, respectively, than numbers $d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right)$ and $d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right)$. This is due to the fact that numbers $d_{t',t}$ and $d_{t,\ t'}$ are not dependent on the amounts of commodities and the number of the producers.

On the basis of the earlier consideration, the following is proposed:

Proposition 2. Assume that sets $B^n_{t'}$, $B^a_{t'}$, $B^{im}_{t'}$, $B^{in}_{t'}$ are not empty as well as conditions (11) and (12) are satisfied. Then

$$d_{t',t} \leq \frac{\#B^{in}_{t'}}{\#B_{t'}}, d_{t,t'} \leq \frac{\#B^a_{t'}}{\#B_{t'}}. \tag{16}$$

Proof. The inequalities (16) are the immediate consequence of the Proposition 1 and Remark 2. □

On the basis of the results of Propositions 1 and 2 as well as Examples 1 and 2 we determine maximal difference $D_{t,t'}$ between producers' activities from economies $\varepsilon(t)$ and $\varepsilon(t')$, where $\varepsilon(t) \subset_{it} \varepsilon(t')$, under the assumptions that the sets $B^n_{t'}$, $B^a_{t'}$, $B^{im}_{t'}$ are not empty and the conditions (11) and (12) are satisfied., by the following rule

$$D_{t,t'} = \max\left\{ \frac{\#B^{in}_{t'}}{\#B_{t'}}, \ \frac{\#B^a_{t'}}{\#B_{t'}} \right\}. \tag{17}$$

Number $D_{t,t'}$ measures relative results of the creative destruction with respect to periods t and t' and it shows how far economies $\varepsilon(t)$ and $\varepsilon(t')$ have moved from each other. Therefore it will be called a relative rate of the creative destruction with respect to periods t and t'. As we can see, number $D_{t,t'}$ is the maximum of the innovative enterprises rate (i.e., number $\frac{\#B^{in}_{t'}}{\#B_{t'}}$ - the share of the number of innovative enterprises in the period t' in the total number of enterprises in period t') and the enterprise death rate (i.e., number $\frac{\#B^a_{t'}}{\#B_{t'}}$ - the share of the number of enterprises which exited the market in period t' in the total number of enterprises in the period t'). If, in formula (17), $D_{t,t'} = \frac{\#B^{in}_{t'}}{\#B_{t'}}$, then the results of activities of innovators in the period t' outweigh negative results of collapses of firms in this period. If $D_{t,t'} = \frac{\#B^a_{t'}}{\#B_{t'}}$, then the conclusion is opposite. If $D_{t,t'} = \frac{\#B^{in}_{t'}}{\#B_{t'}} = \frac{\#B^{a}_{t'}}{\#B_{t'}}$, then the negative market effects resulting from the collapses of firms in period t' are compensated by the results of activities of innovators in this period. By the fact that $D_{t,t'} \geq \frac{\#B^{in}_{t'}}{\#B_{t'}}$ we get the following dependency: if the values of the rate $D_{t,t+1}$ decrease over time within a period, then in that period the values of the innovative enterprises rate also decrease over time. The decrease of the innovative enterprises rate means a reduction in the number of innovative processes in the economy.

4.2. Competitiveness

Now, we take a short look at the effects of innovators' competitiveness in the model under study. The competitiveness of innovators is a result of interaction between innovators and consumers and that is why it is one of the main components of economic evolution. In the approach considered, firms compete on the market, above all, in introducing innovations and selling commodities. Additionally, producers do not have any possibilities to set their own prices of offered commodities. Hence the effects of competitiveness of a group of firms in the model presented can be measured as the share of the amount of sold innovative commodities (outputs) produced by the firms from the group in the amount of all sold commodities. Below we admit the following notion:

- $O^b(t) = O^b\left(y^b(t)\right) = \left\{l \in \{1, \ldots, \ell_t\} : \; y^b_l(t) > 0\right\}$ means the set of outputs of producer b at time t provided that plan $y^b(t)$ is realised,
- $\tilde{y}^b(t)$ denotes a market modification of the plan $y^b(t)$; by definition, it is a vector in the commodity space $\mathcal{R}^{\ell_t}$ satisfying:
  $\rightarrow$ $\tilde{y}^b_l(t) = y^b_l(t)$ for $l \in \{1, \ldots, \ell_t\} \backslash O^b\left(y^b(t)\right)$,
  $\rightarrow$ number $\tilde{y}^b_l(t)$ is the amount of commodity $l \in O^b\left(y^b(t)\right)$ which was sold in period t; $0 \leq \tilde{y}^b_l(t) \leq y^b_l(t)$,
- $\sum_{b \in \tilde{B}_t} \sum_{y^b(t)} \sum_{l \in O^b\left(y^b(t)\right)} \tilde{y}^b_l(t)$ is the number of sold outputs at time t of producers from the set $\tilde{B}_t \subset B_t$.

More formally, for $b \in B_t$, a competitiveness index of producer b in economy $\varepsilon(t)$ is defined as number

$$S^b_t \stackrel{\text{def}}{=} \frac{\sum_{l \in O^b(t)} p_l \tilde{y}^b_l(t)}{\sum_{b \in B_t} \sum_{l \in O^b(t)} p_l \tilde{y}^b_l(t)}. \tag{18}$$

provided that

$$\sum_{b \in B_t} \sum_{l \in O^b(t)} p_l \tilde{y}^b_l(t) \neq 0. \tag{19}$$

Consequently, number

$$S_t^{B_t^{in}} \stackrel{\text{def}}{=} \frac{\sum_{b\in B_t^{in}} \sum_{l\in O^b(t)} p_l \tilde{y}_l^b(t)}{\sum_{b\in B_t} \sum_{l\in O^b(t)} p_l \tilde{y}_l^b(t)} \tag{20}$$

means an index of innovators' competitiveness. It is easy to see that number S_t^b is the share of the net profit of producer b from sales of his innovative products in the total profit from sales, whereas number $S_t^{B_t^{in}}$ is the share of the net profit of all innovators from sales of innovative products in the total profit from sales. The number $S_t^{B_t^{in}}$ measures the results of innovators' competitiveness in the period t; it is positive and not greater than 1.

Referring to the results presented in (Lipieta & Lipieta, 2022a), under the assumptions that $\ell_{t'} > \ell_t$ (which certainly gives the relationship $\varepsilon(t) \subset_{it} \varepsilon(t')$), we define a relative level of innovativeness of the economy $\varepsilon(t')$ with respect to economy $\varepsilon(t)$ as number

$$LI_{t,t'} = \frac{\sum_{b\in B_{t'}^{in}} \sum_{l=\ell_t+1}^{\ell_{t'}} y_l^b(t')}{\sum_{b\in B_{t'}} \sum_{l\in O^b(t')} y_l^b(t')} \tag{21}$$

under the assumption that $\sum_{b\in B_{t'}} \sum_{l\in O^b(t')} \tilde{y}_l^b(t') > 0$. Number $LI_{t,t'}$ is the share of the amounts of outputs innovative at time t' with respect to time t in the amounts of all outputs at time t'. Let us recall that commodities from set $\{\ell_t + 1, \ \ldots, \ \ell_{t'}\}$ are innovations in economy $\varepsilon(t')$, with respect to economy $\varepsilon(t)$. Assume that $p_l > 0$, for every l, in both periods t and t'. For set $\hat{B}_t \subset B_t$ and $O^{\hat{B}_t} = \cup_{b\in\hat{B}_t} O^b(\tilde{y}_l^b(t))$ we put

$$p_m(O^{\hat{B}_t}) = \min\left\{p_l : \ p_l \text{ is the price of commodity } l \in O^{\hat{B}_t}\right\},$$

$$p_M(O^{\hat{B}_t}) = \max\left\{p_l : \ p_l \text{ is the price of commodity } l \in O^{\hat{B}_t}\right\},$$

Combining formulas (20) and (21), provided that

$$\tilde{y}_l^b(t') = y_l^b(t'), \text{ for every } b \in B_{t'} \text{ and } l \in O^b(t'), \tag{22}$$

as well as the prices of commodities are not changed, we get that

$$\frac{p_m\left(O^{B_{t'}^{in}}\right)}{p_M(O^{B_{t'}})} LI_{t,t'} \le S_{t'}^{B_{t'}^{in}}. \tag{23}$$

Assumption (22) means that any amount of every output at time t' was sold. In fact assumption (22) means that the total production plan $\tilde{y}(t')$ forms with a total consumption plan a feasible allocation as well as all commodities manufactured in period t' are sold. The formulas (18)–(21) and the inequality (23) give, under the assumption (22), that an increase of innovativeness in the economy $\varepsilon(t')$ leads to the increase of the competitiveness of innovators in the economic system under study. On the other hand, under the assumption that the prices of commodities are not changed as well as condition (22) is valid, the following inequality is true:

$$S_{t'}^{\tilde{B}_{t'}^{in}} \leq \frac{p_M\left(O^{B_{t'}^{in}}\right)}{p_m\left(O^{B_{t'}}\right)} LI_{t,t'}. \tag{24}$$

Hence, in the considered economic system in which, additionally, condition (22) is satisfied, the increase of the competitiveness of innovators leads to the increase of the innovativeness.

5. Empirical results

Now we use the formulas defined in the fourth part of the paper to analyse evolutionary processes in Polish regions in years 2009–2019, on the basis of the statistical data presented at page https://bdl.stat.gov.pl/BDL.

Firstly let us notice that, for $t \in \{2010, \ldots, 2019\}$ sets B_t^n, B_t^e, B_t^{im}, B_t^{in} in Polish regions and consequently in the whole Polish economy are not empty. The details can be found at https://bdl.stat.gov.pl/BDL Hence, assuming assumptions (11) and (12) are satisfied in the real economy, we can implement formula (17) for calculating the size of the creative destruction in the Polish economy.

We calculate rates $D_{t,t'}$, according to formula (17), for $t' = t+1$ and $t \in \{2009, \ldots, 2018\}$, for Polish regions and the Polish economy as a whole. Thereby, numbers $D_{t,t+1}$ are the relative rates of the creative destruction of Polish regions or Polish economy, adequately, with respect to two consecutive years, starting in 2009 and ending in 2018. The values of rates $D_{t,t+1}$ for $t \in \{2009, \ldots, 2018\}$ are presented in Table 1.

Let us have a look at the figures in Table 1. In every year $t \in \{2009, \ldots, 2018\}$, the largest value of the rate $D_{t,t+1}$ is obtained in the region MAZOWIECKIE, the next in the region ŚLĄSKIE or in the region WIELKOPOLSKIE. The cells in which $D_{t,t+1} = \frac{\#B_{t+1}^a}{\#B_{t+1}}$, i.e., when the relative rate of the creative destruction of a structure (a region or the whole economy) with respect to years t and $t+1$ is equal to the enterprise death rate in the year $t+1$, are marked in grey. This situation concerns the three most populated Polish regions: MAZOWIECKIE, ŚLĄSKIE and WIELKOPOLSKIE. The values of $D_{t,t+1}$ in those three regions are significantly higher in each year considered than the adequate values of the rate $D_{t,t+1}$ for the Polish economy. Regions LUBUSKIE, ŚWIĘTOKRZYSKIE and WARMIŃSKO-MAZURSKIE have the least values of the rate $D_{t,t+1}$ and in those cases $\frac{\#B_{t+1}^{in}}{\#B_{t+1}} > \frac{\#B_{t+1}^a}{\#B_{t+1}}$. In every white cell in Table 1, $D_{t,t+1} = \frac{\#B_{t+1}^{in}}{\#B_{t+1}}$. The latter is valid for most Polish regions and the whole Polish economy. In case of many regions and the whole economy, except of few cases, the values of the rate $D_{t,t+1}$ in the structure maintained the same level (Table 2).

Table 1. Relative rates of the creative destruction of the Polish economy and the Polish regions.

	$D_{t,t+1}$										
NAME OF THE STRUCTURE (COUNTRY or REGION)	2009 [%]	2010 [%]	2011 [%]	2012 [%]	2013 [%]	2014 [%]	2015 [%]	2016 [%]	2017 [%]	2018 [%]	2019 [%]
POLAND	16.0	14.9	13.8	14.4	14.3	14.5	13.7	16.1	14.5	21.8	15.4
DOLNOŚLĄSKIE	16.6	14.9	12.3	16.8	16.2	16.3	14.2	13.4	14.8	22.8	17.2
KUJAWSKO-POMORSKIE	15.7	13.6	15.4	14.2	11.0	12.4	12.5	14.2	12.1	21.0	10.8
LUBELSKIE	15.6	14.6	15.2	13.6	13.0	19.4	13.5	22.9	14.1	24.9	12.1
LUBUSKIE	12.1	13.4	11.3	14.3	14.4	10.5	11.6	13.2	13.0	18.1	10.2
ŁÓDZKIE	19.9	11.9	10.5	12.6	13.0	13.5	12.5	13.0	12.7	15.9	14.8
MAŁOPOLSKIE	16.1	14.5	15.3	15.2	14.9	13.5	15.2	17.3	15.1	22.2	19.3
MAZOWIECKIE	55.8	35.1	64.6	38.9	41.5	48.1	45.2	46.7	46.4	65.8	32.8
OPOLSKIE	18.7	16.5	15.2	14.0	15.0	17.6	15.0	12.4	12.6	21.2	11.7
PODKARPACKIE	16.5	17.2	16.2	14.8	14.7	14.6	14.2	18.0	15.3	19.7	17.7
PODLASKIE	14.6	12.7	13.0	15.0	17.7	14.7	15.3	11.5	12.2	23.4	12.3
POMORSKIE	15.4	14.3	15.2	10.9	12.5	12.3	12.6	18.1	15.5	25.6	15.4
ŚLĄSKIE	35.0	24.1	41.3	26.5	27.8	31.7	29.2	29.8	28.7	30.7	23.6
ŚWIĘTOKRZYSKIE	10.8	14.0	11.6	13.3	12.1	11.1	11.5	10.4	12.2	14.3	11.5
WARMIŃSKO-MAZURSKIE	15.0	13.6	12.4	11.9	14.6	10.9	11.3	9.1	9.1	14.9	15.8
WIELKOPOLSKIE	38.6	25.0	36.0	26.4	27.3	29.6	30.3	28.6	27.2	30.1	19.0
ZACHODNIOPOMORSKIE	15.8	13.3	9.8	14.9	14.6	14.1	15.8	11.9	13.7	20.2	12.1

Authors' own work. The cells in which $D_{t,t+1} = \frac{\#B^{a}_{t+1}}{\#B_{t+1}}$ are marked in grey.
Source of data: https://bdl.stat.gov.pl/BDL Access: 12th March 2021.

Table 2. Linear correlation coefficient (LCC) between rate $D_{t,t+1}$ and dynamics of GDP per capita.

	Linear correlation coefficient (LCC) between rate $D_{t,t+1}$ and dynamics of GDP per capita										
NAME	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
LCC	0.439	0.394	0.419	0.406	0.473	0.369	0.427	0.428	0.455	0.468	0.539

Authors' own work.
Source of data: https://bdl.stat.gov.pl/BDL Access: 12th March 2021.

Summing up: in most Polish regions and the whole Polish economy in the years considered, innovative, processes determine the "size" of the creative destruction as well as the results of activities of innovators in every year outweigh negative results of collapses of firms in this year. The values of the rate $D_{t,t+1}$ are significantly different in regions. What is more interesting, the value of the linear correlation coefficient (LCC) between rate $D_{t,t+1}$ and dynamics of GDP per capita (see https://bdl.stat.gov.pl/BDL) in years 2009–2018 is equal or very close to 0.04, which means that there is moderate average dependency between the values of these variables in the structures considered in the years under study. The exact values of LCC in the Polish regions and in the Polish economy as a whole in the years 2009–2019 can be found in Table 2.

In the table below we present the values of index $S_t^{B_t^{in}}$ for Polish economy and Polish regions, where $t \in \{2009, \ \ldots, \ 2018\}$:

It should be noted that it is most probable that the law of one price (see LeRoy & Werner, 2002). is not satisfied for imitative commodities in the real economies in different innovative commodities, hence the shares of net revenues from sales of innovative products in total net revenues presented in the Table 3 may slightly differ from their theoretical values that could be calculated by formula $S_t^{B_t^{in}}$ (see (20)). As we can see, the shares of net revenues from sales of innovative products in total net revenues presented in Table 3 are the highest in the region POMORSKIE (the grey cells), however, in regions, where the highest values of the relative rate of the creative destruction can be observed, i.e., in MAZOWIECKIE, ŚLĄSKIE and WIELKOPOLSKIE, they

Table 3. Share of net revenues from sales of innovative products in total net revenues from sales.

	Share of net revenues from sales of innovative products in total net revenues from sales										
NAME OF THE STRUCTURE (COUNTRY or REGION)	2009 [%]	2010 [%]	2011 [%]	2012 [%]	2013 [%]	2014 [%]	2015 [%]	2016 [%]	2017 [%]	2018 [%]	2019 [%]
POLAND	10.56	11.34	8.93	9.22	8.65	8.78	9.50	8.12	7.08	9.1	9.4
DOLNOŚLĄSKIE	5.95	5.96	5.91	7.73	9.95	12.52	14.97	14.19	8.83	7.2	9.6
KUJAWSKO-POMORSKIE	13.45	14.67	6.35	6.50	7.12	7.80	10.57	7.12	6.70	6.3	6.8
LUBELSKIE	7.36	3.45	3.57	5.34	4.85	4.28	5.57	6.18	3.81	4.9	4.5
LUBUSKIE	6.08	4.47	3.51	4.67	6.05	5.57	4.65	5.36	4.44	12.8	12.1
ŁÓDZKIE	6.65	6.73	4.29	6.19	5.74	8.13	7.71	6.61	6.46	9.2	9.1
MAŁOPOLSKIE	10.37	10.63	7.60	6.48	6.49	7.71	9.45	9.91	9.71	12.1	10.0
MAZOWIECKIE	14.80	8.49	5.59	5.31	5.72	4.86	5.01	5.06	5.44	10.3	11.3
OPOLSKIE	5.87	5.31	5.84	7.78	7.37	6.96	5.28	8.20	4.50	8.0	10.9
PODKARPACKIE	10.96	8.54	10.49	8.75	8.49	7.34	8.32	8.85	7.88	9.0	9.1
PODLASKIE	9.84	4.97	4.41	5.30	5.08	4.09	4.27	6.02	4.17	6.5	5.4
POMORSKIE	23.38	43.40	32.07	36.27	18.15	27.21	18.34	11.94	12.63	9.8	6.9
ŚLĄSKIE	7.05	12.90	6.05	8.33	10.09	10.73	10.93	10.39	7.84	8.8	10.0
ŚWIĘTOKRZYSKIE	5.95	5.74	4.68	5.33	6.35	3.58	4.32	5.08	5.19	4.5	3.5
WARMIŃSKO-MAZURSKIE	11.43	10.67	6.69	3.10	2.43	3.06	3.60	3.08	3.87	8.9	3.2
WIELKOPOLSKIE	8.03	11.15	15.72	12.35	13.21	7.53	14.62	8.01	6.94	10.0	10.0
ZACHODNIOPOMORSKIE	5.44	2.89	4.88	3.98	4.74	6.39	5.98	5.97	5.57	3.2	3.8

Authors' own work.
The cells in which the shares of net revenues from sales of innovative products in total net revenues are maximal in a considered year are marked in grey.
Source of data: https://bdl.stat.gov.pl/BDL Access: 12th March 2021.

are also high (they are among top five most cases). However, it should be noted that over analysed period, there is no prevailing tendency for the values in Table 3 for the structures under study, what is seen in the regions POMORSKIE and DOLNOŚLĄSKIE. In the region POMORSKIE the shares of net revenues from sales of innovative products in total net revenues significantly decreased in the period analysed in contrast to the region DOLNOŚLĄSKIE for which, those values had decreased only in years 2010–2011 and 2016–2018; for regions KUJAWSKO-POMORSKIE and LUBELSKIE those shares were increasing and decreasing in many cases alternately.

6. Discussion

In the present paper we extend and generalise the theoretical studies by Lipieta and Malawski (2016, 2021) as well as Lipieta and Lipieta (2022a, 2022b). We focused on defining two indexes that measure the relative sizes of two key phenomena occurring within economic evolution, i.e., the creative destruction and innovators' competitiveness, and using them for comparing exemplary real economic systems.

On the basis of the presented set-up, from a broader perspective of economic evolution, we can see that the effects of destruction are revealed in the set of outcomes of innovative mechanisms (see Lipieta & Lipieta, 2022a): besides new commodities, technologies and organisational structures, the old, unattractive products and technologies as well as the uncompetitive in the new economic reality firms, disappearing from the market. The mechanisms which are innovative and destructive are the mechanisms of the creative destruction (see the details in Lipieta & Malawski, 2021 and Lipieta & Lipieta, 2022b). The mechanisms of the creative destruction differ not only in the economic environments and in the sets of outcomes, but also in the sets of variables that characterise or will characterise the economic entities, which is caused by adopting by economic agents the innovative changes to their routine activities (*ibidem*). Therefore the sets of outcomes of the mechanisms of the creative destruction, in facts, determines transformations of the economy (Lipieta & Malawski, 2021; Lipieta & Lipieta, 2022a, 2022b). However, the range of the maximal possible change carried by the mechanisms of the creative destruction has not been analysed so far. This range, in fact, determines the innovation potential of the transformed economic system. A value of the relative rate of the creative destruction defined in Section 4.1 informs what is the relative size of the maximal change carried by the mechanism of the creative destruction, which transformed an economic system from date t into economic system at date t'. Due to the above and the reasonings presented in Section 3, which were largely inspired by Schumpeter's (1934) writings, it is easy to see that the innovation potential of a transformed economic system can be measured by the relative rate of the creative destruction. The values of this rate calculated for Polish regions (Section 5) showed that regions MAZOWIECKIE, ŚLĄSKIE and WIELKOPOLSKIE have the strongest innovation potentials within Polish regions.

The index of innovators' competitiveness, defined in Section 4.2, measures the effects of innovators' competition. In many theoretical researches (for instance, Schumpeter, 1934; Cantner, 2016; Winter, 1984), the Authors analyse the features of Schumpeterian innovators and emphasize that the Schumpeter's entrepreneurs have natural tendency to compete within the process of introducing innovations. Therefore innovators' competitiveness is the main factor influencing on the development of the economy. On the other hand, according to the perfect rationality assumption (Simon, 1947), firms aim at increasing profits rather than at engaging in competition unless the desire to compete is the effect of their rationality of activities. Due to the above findings, comparing the values of the index of innovators' competitiveness for Polish regions supplies a piece of information on the diversity of the potential development of Polish economy. On the basis of our calculations, region POMORSKIE has the strongest potential to develop.

The choice of the variables to calculate the values of the indexes presented in the paper was optimal in such a meaning that we constructed some theoretical examples of the economic structures for which the set of variables by the use of which the creative destruction or the competitiveness was measured, could not be reduced. Due to the above we justified the selection of the solutions presented. What is more, our consideration gave the theoretical basis to analyse the creative destruction in subregions of an economy against the background of the whole economy.

Empirical results (Bartlett, 2014; Stojcic & Aralica, 2018; Stojcic et al., 2019) show that the changes of competitiveness of economic structures are connected with their economic transformations. Economic changes in the regions of Poland were originated by the transformation of the system taking place in Poland (starting from 1989) and intensified by Poland's accession to the European Union (2004). Due to that new industries and markets were risen which resulted in the growth and well-being of the Polish society. Stojcic and Aralica (2018) identified that in those countries of Central and Eastern Europe in which the competitiveness was smaller, the rise of new industries was slower. In this context monitoring of competitiveness of the regions of the economy as well as the analysis of its determinants are purposeful. An analysis the relationship between competitiveness of Polish regions and their structural changes remains under our research perspectives.

7. Conclusions

The results of this research gave us the tools for distinguishing the qualitative properties of economic transformations in such a way that they would realise the aim of economic agents in Pareto sense, namely they would improve the position of the analysed group of entities, i.e., the innovators, the imitators and new producers. On the basis of comparing the values of the adequate indexes, we justify that the increase of the competitiveness leads to the increase of the innovativeness and, consequently, to the increase of the "size" of the creative destruction.

The model presented in the paper is a theoretical market structure. In fact we study macroeconomics mechanisms which are the results of innovative activities of firms. Therefore our approach can be assigned to the mainstream of the microfoundations of macroeconomics (Weintraub, 1979). We analysed the agents activities on non-equilibrium markets on which the structure of information plays a central role. In the model presented, we assume that firms and consumers have full access to information, because in the last years economic agents had increasing access to information. Such assumption simplifies the reasoning and enables us to distinguish the variables which determine the range of the analysed occurrences. Due to the above simplification, we found the logical arguments for the existence of a relationship between innovativeness of an economic structure and innovators' competitiveness as well as explore the phenomenon of the creative destruction. However a question arises about reasonableness of using the theoretical presented results to analyse the real economic structures. In order to distinguish our findings from the results of empirical researches, which are usually conducted under a partial access to information, we say in section Discussion about "innovation potential" instead of "innovativeness", as well as about the "potential to develop" instead to the "development" with regard to the analysis of Polish regions.

Due to the above, the results of the paper do not call into question other wide known and widely applied indexes used to compare economic objects with regard to innovativeness or competitiveness as well as the introduced indexes do not aspire to the role of the best. They should be rather regarded as an attempt to adapt new concepts for exploring the existing problems in order to more fully understand the complex nature of economic evolution.

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Availability of data

We provided a detail summary of our data, its source and version, however they may be provided upon request.

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Appendix A

Proof of Proposition 1. Firstly we prove the inequality (4). It is easy to notice that, by (3), for every $b \in B_{t'}^{im}$, $Y^b(t') \subset \cup_{\tilde{b} \in B_t} Y^{\tilde{b}}(t)$. Hence:

$$\begin{aligned} d_{t',t}\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right) &\stackrel{\text{def}}{=} d\left(\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right), Y(t) \times \cdots \times Y(t)\right) \\ &= inf\left\{ \begin{array}{c} \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_1}(t') - y_l^b(t)\right| + \ldots + \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_{n_{t'}}}(t') - y_l^{\hat{b}}(t)\right| : \\ b, \ \ldots, \ \hat{b} \in B_t, \ y^b(t'), \ldots, \ y^{\hat{b}}(t') \in Y(t) \end{array} \right\} \\ &= \sum_{j=1}^{n_{t'}} inf\left\{ \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_j}(t') - y_l^b(t)\right| : b \in B_t \right\} \\ &= \sum_{b_j \in B_{t'}^{in}} inf\left\{ \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_j}(t') - y_l^b(t)\right| : b \in B_t \right\}. \end{aligned} \quad \text{(AP1)}$$

To end this part of the proof it is necessary to notice that if $\ell_{t'} > \ell_t$, then every coordinate $l \in \{\ell_t + 1, \ \ldots, \ell_{t'}\}$ in every plan $y^{\tilde{b}}(t)$ is equal to zero, which gives

$$\begin{aligned} d_{t',t}\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right) &= \sum_{l=\ell_t+1}^{\ell_{t'}} \sum_{b \in B_{t'}^{in}} \left|y_l^b(t')\right| \\ &+ \sum_{b_j \in B_{t'}^{in}} inf\left\{ \sum_{l=1}^{\ell_t} \left|y_l^{b_j}(t') - y_l^b(t)\right| : b \in B_t \right\}. \end{aligned} \quad \text{(AP2)}$$

By the facts that

$$y^{b_j}(t) = 0 \in Y^{b_j}(t) \ \text{ for } \ b_j \in B_{t'}^n \ \text{ and } \ B_{t'}^n \subset B_t,$$

we get that

$$d_{t',t}\left(y^{b_1}(t'), \ \ldots, \ y^{b_{n_{t'}}}(t')\right) \le \sum_{b_j \in B_t : y^{b_j}(t') \notin Y(t)} \|y^{b_j}(t')\|,$$

which gives inequality (4).

Now we focus on condition (5). Since every vector $y^b(t)$, for $b \in B_t$, belongs to space $\mathcal{R}^{\ell_{t'}}$, hence as above

$$\begin{aligned} d_{t,t'}\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right) &\stackrel{\text{def}}{=} d\left(\left(y^{b_1}(t), \ \ldots, \ y^{b_{n_t}}(t)\right), Y(t') \times \cdots \times Y(t')\right) \\ &= inf\left\{ \begin{array}{c} \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_1}(t) - y_l^b(t')\right| + \ldots + \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_{n_t}}(t) - y_l^{\hat{b}}(t')\right| : \\ b, \ \ldots, \ \hat{b} \in B_{t'}, \ y^b(t'), \ldots, \ y^{\hat{b}}(t') \in Y(t') \end{array} \right\} \\ &= \sum_{j=1}^{n_t} inf\left\{ \sum_{l=1}^{\ell_{t'}} \left|y_l^{b_j}(t) - y_l^b(t')\right| : b \in B_{t'} \right\}. \end{aligned} \quad \text{(AP3)}$$

Let us notice that, for $b \in B_t$, for which $y^b(t) \in Y(t')$,

$$inf\left\{ \sum_{l=1}^{\ell_{t'}} \left|y_l^b(t) - y_l^{\tilde{b}}(t')\right| : \tilde{b} \in B_{t'} \wedge \ y^{\tilde{b}}(t') \in Y^{\tilde{b}}(t') \right\} = 0.$$

Therefore

$$d_{t,t'}\left(y^{b_1}(t),\ \ldots,\ y^{b_{n_t}}(t)\right)$$
$$= \sum\nolimits_{b_j\in B_t : y^{b_j}(t)\notin \overline{Y}(t')} inf\left\{\sum\nolimits_{l=1}^{\ell_{t'}}\left|y_l^{b_j}(t) - y_l^{b}(t')\right| : b\in B_{t'} \wedge\ y^b(t')\in Y^b(t')\right\},$$

Since $y^b(t') = 0\in Y^b(t'),$ for every $b\in B_{t'}^a \subset B_{t'},$ we get inequality (5).

□

Proof of the Remark 1. Let us notice that by (AP2)

$$d_{t',t}\left(y^{b_1}(t'),\ \ldots,\ y^{b_{n_{t'}}}(t')\right) \le \sum\nolimits_{b_j\in B_{t'}^{in}} \sum\nolimits_{l=\ell_t+1}^{\ell_{t'}}\left|y_l^{b_j}(t')\right| + \sum\nolimits_{b_j\in B_{t'}^{in}} \sum\nolimits_{l=1}^{\ell_t}\left|y_l^{b}(t')\right|$$
$$= \sum\nolimits_{b_j\in B_{t'}^{in}} \sum\nolimits_{l=1}^{\ell_{t'}}\left|y_l^{b_j}(t')\right|.$$

Due to the above, inequality (10) is satisfied. In the same way we prove the condition (13). It is an immediate consequence of assumptions (11) and (12).

□