
Are Eco-Innovations a Key Element for Green Growth?

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Abstract:

Purpose: In the recent decade, the so-called green growth (GG) concept has made a significant contribution to many-years' debate on sustainable development (SD). One of its key pillars is eco-innovation (EI), however little information is available on whether and to what extent eco-innovation can be actually perceived as a significant factor for implementing green growth. For this reason, the aim of this paper is to clarify and synthesise findings at the intersection of these two fields: eco-innovation and the green growth processes.

Design/Methodology/Approach: The paper provides a special insight into the relationship between EI and GG incorporating the spatial dimension into analysis. The empirical part is based on the sample of 21 European countries.

Findings: The rests of spatial panel models show that there exist positive effects of investing in eco-innovations on green growth. However, these results involve strong nonlinearities and threshold effects. The obtained results shed a new light on the uncovering relevant aspects and complexities of eco-innovations and green growth.

Practical Implications: These results suggest that the policy-makers should mainly focus on stimulating the companies to introduce eco-innovations aiming at a reduction of material input and energy per unit output as well as an improvement of eco-management practices. Government incentives for green technology and organizational solutions may include a combination of subsidies and tax incentives.

Originality/Value: This study is the first one which includes different measures of eco-innovations and relates them to the green growth process. These measures allow us portray the countries' eco-innovation efforts from input, process, and output perspectives.

Keywords: Eco-innovation, green growth, sustainable development, spatial effects.

JEL Codes: O40, O44, Q55.

Paper Type: Research article.

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1. Introduction

Many scientific studies emphasize that traditional growth models in less than 40 years can have a disastrous effect on the natural environment, society and economy. The proposed panacea is the need for sanctioning a new paradigm of economic growth and development which will allow us to state unambiguously that in the process of building prosperous global economy, 'environment' and 'growth' will not be seen as opposite ends (OECD, 2009c; 2012b; Huhtanen, 2010; Satbyul, Ho and Yeora, 2014).

The green growth concept meets such expectations. For the first time, the term was used during a public debate in the Ministerial Declaration on Environment and Development for Asia-Pacific adopted in 2005 in Seoul (UNESCAP, 2005). At that time, it was concluded that there was a need for leaving behind the previous 'growing first, cleaning up later' approach and adopting the green growth concept (environmentally sustainable economic growth).

In consequence of the recent financial crisis, the interest in green growth has increased among politicians and scientists. The term that was rarely used before 2008 has now become a leading discussion point for many international organisations and institutions (OECD, World Bank, UNEP) (World Bank, 2012; UNEP, 2010). The Organisation for Economic Co-operation and Development prepared the Green Growth Strategy (GGS), hence becoming a leader in promoting, implementing and monitoring progress in the implementation of green growth (OECD, 2009a; 2009b; 2010a; 2010b; 2011a; 2011d-f; 2012a; 2013a; 2013b; 2014; 2017; The World Bank and UN, 2012).

Over the past decade, an increase in the number of publications on green growth could be observed. A number of fundamental research interest areas can be identified. These mainly include issues related to the essence and origin of the concept such as: links to the idea of green economy and sustainable development (Trica and Papuc, 2013; Van de Ploeg and Withagen, 2013; Vazquez-Brust *et al.*, 2014; Kasztelan, 2017a), factors conditioning the implementation of the green growth concept (OECD, 2011e; 2011f; Stoknes and Rockström, 2018), planning and green growth strategies and policies at different levels of management (OECD, 2010b; 2011d; 2013b; Ates, 2015; Choi, 2015; Guo *et al.*, 2018), and ratios for monitoring of progress in implementing the premises of green growth (Satbyul *et al.*, 2014; Narloch *et al.*, 2016; OECD, 2017; Kasztelan, 2017b; Guo *et al.*, 2018; Lyytimäki, 2018).

To the present day, the public and political debate has not succeeded in developing a standard definition of green growth. A review of literature makes it possible to order the existing proposals within a certain framework, that is, from the so-called narrow perception of this concept as intended reconciliation between reduced emissions of pollutants and economic growth to a more comprehensive plan of improving

resources effectiveness and ensuring environmental balance within the existing system (Kasztelan, 2015). According to the definition formulated by the OECD, green growth means ‘taking measures conducive to growth and economic development, while ensuring that natural assets continue to provide the resources and environmental services which contribute to the country’s prosperity’... (OECD, 2011f, p. 9). It is indicated that conventional production technologies and consumer behaviours tend to reach the limit beyond which the depletion of natural capital will have a negative impact on the general development level. Green growth can provide a solution to economic and ecological problems and create new sources of growth through eco-innovation (environmental innovation, green innovation).

So far many studies have emphasized the key role of eco-innovation (green innovation, ecological innovation) in sustainable development, building the foundations of green economy, or recently – the so-called circular economy (Speck and Zoboli, 2017; Varadarajan, 2017; De Jesus *et al.*, 2018; Feng and Chen, 2018). At the same time, few publications discuss the role of eco-innovation in implementing the premises of green growth concept. In addition, in most cases such considerations are purely theoretical (Machiba, 2010; Padilla-Pérez and Gaudin, 2014; Wang and Lian, 2016). With regard to the fact that eco-innovation is supposed to be a key element of another technical and economic revolution, a question emerges whether and to what extent it contributes/will contribute to the transition to green growth.

Based on a critical literature review and the authors’ research results, the fundamental objective of this study is to examine the role of eco-innovation in implementing the premises of green growth. The three main objectives of this paper are thus to: 1) derive literature-based working definitions and characteristics of EI and GG; 2) review and assess the relationship between EI and GG, and; 3) based on empirical analysis to find some practical implications for policy-makers. The research results show that there exist positive effects of investing in eco-innovations on green growth, however, these results involve strong nonlinearities and threshold effects. What’s more, there is also a correlation between neighbouring countries in terms of eco-innovation levels, and thus the degree of ‘greening’ economic growth.

The paper is organized as follows. In Section 2, the GG concept has been presented, taking into account the genesis, essence and scope, as well as the role of eco-innovation in implementing the concept has been characterized. Section 3 introduces the methodology, while Section 4 analyses the results stemming from the research and the findings of this study are discussed. Finally, section 5 concludes by examining avenues for further research.

2. Eco-Innovation and Green Growth – What do we Know so far?

Choi (2015) states that green growth is the fourth social and economic revolution in the history of the world (following agricultural, industrial and high technology (IT)

revolutions). It is based on practical and feasible policies of the governments and strategies of the private sector. Green growth is an idea that has still not been given one universal definition. Of course, some elements characteristic of sustainable development or sustainability referring to intergenerational responsibility and environmental balance determine the definition of green growth and the scope of the concept. Literature most often quotes the definition proposed by the Organisation for Economic Co-operation and Development (OECD, 2011f) being an institution which was involved in promoting this concept throughout the world to the greatest extent.

According to the OECD strategy, one of the underlying components of the conceptual framework for green growth is innovation, and in particular eco-innovation. It plays a key role in mitigating negative effects of the choices that arise between investing in the (shrinking) natural capital and growing consumption and investments in other forms of capital. Thanks to eco-innovation, the limit of possible choices is moved further, which is a significant contribution to 'greening' growth. Moreover, eco-innovation is perceived as a factor creating new sources of economic growth and an effective tool for solving environmental problems (OECD, 2011d).

The eco-innovation concept emerged in the 1990s. The term was coined and incorporated in the nomenclature of environmental economics by Fussler and James (1996). The authors defined ecological innovation alternatively using the term 'sustainable innovation', as new products and processes creating value for enterprises and their customers and reducing (negative) environmental impacts. A similar definition was proposed by Kemp and Pearson (2008) who accepted that "*eco-innovation is the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*". In turn, European Commission (EC) defines eco-innovation as "*any innovation resulting in significant progress towards the goal of sustainable development, by reducing the impacts of our production modes on the environment, enhancing nature's resilience to environmental pressures, or achieving a more efficient and responsible use of natural resources*" (European Commission, 2018).

The first definition of EI has undergone minor or major modifications (Diaz-Garcia *et al.*, 2015). This resulted in the emergence of numerous related terms that nowadays are deemed synonymous with the original term, i.e., environmental innovation (Huber, 2008; Forsman, 2013; Triguero *et al.*, 2017), environmentally sustainable innovation (Hellström, 2007; Bossink, 2011; De Medeiros *et al.*, 2014) or green innovation (Chen *et al.*, 2006; Chang, 2011; Range and Sandberg, 2016; Huang *et al.*, 2017; Song and Yu, 2018). Currently available literature on EI is quite elaborate. It mainly covers the following research areas: conceptualization of the phenomenon (Fussler and James, 1996; Rennings, 2000; OECD, 2011; Vallet *et al.*, 2016; Veugelers, 2016) identification of factors and barriers to eco-innovation

(Kemp and Pearson, 2008; Huang *et al.*, 2017; Bendell, 2017; Cai and Li, 2018), methods of measurement and assessment of eco-innovation levels (Kemp and Pearson, 2008; Kobryń and Prystrom, 2017; García-Granero, 2018), and effects of eco-innovation processes, including impact on competitiveness at different levels of management (Kasztelan and Kijek, 2015; Range and Sandberg, 2016; Braungardt *et al.*, 2016).

Eco-innovation can be measured directly and indirectly (OECD, 2011f). Kemp and Pearson (2008) classified measurements into four types to quantify technological changes, considering the process of eco-innovation: input measures, intermediate output measures, direct output measures and indirect impact measures. Input measures include research and development (R&D) expenditures, R&D personnel and innovation expenditures. Intermediate output measures consist of patents, scientific publication and citations. Direct output measures include data on new product sales, based on product and trade information databases. Indirect impact measures are derived from aggregate data, including resource efficiency and productivity. Indirect impact can be measured with company information about innovation and eco-innovation performance, obtained from the specially designed surveys. Several indicators which measure environmental performance have been developed, including Eco-Innovation Scoreboard-Eco-IS. The Eco-innovation Observatory developed the Eco-IS in 2010 as a tool to assess and illustrate eco-innovation performance across the EU member states.

In a Schumpeterian model, Aghion and Howitt (2009) showed that sustained growth in the presence of exhaustible resources is achievable if the R&D labour share is sufficiently large to overcome the environmental drag. Additionally, in a comparison of different endogenous growth models, Elbasha and Roe (1995) confirm that the potential to combat environmental externalities seems to exist mainly in the models allowing for innovative activity as a driver for growth. These results accentuate the critical role of eco-innovation in this third perspective to balance the growth-environment trade-off by countervailing the diminishing returns to capital and the previously discussed environmental drag through enhanced productivity.

In scientific discussion, an increasing number of studies address the role of technological innovation in stimulating green growth. Tellis *et al.* (2008) emphasize that innovation plays an essential role in sustainable development of present-day economies. Padilla-Pérez and Gaudin (2014) prove the existence of a relationship between science, technology and innovation and inclusive and sustainable economic growth in the countries of Middle America. Studies by Wang *et al.* (2016) confirmed, on the other hand, that green innovation efficiency had a considerable positive effect on green growth performance. In turn, studies by Zhou *et al.* (2017) showed that the main drive for green growth was innovation oriented at pollution control, and thus green innovation had a positive impact on green growth of economies. Unfortunately, all of the mentioned studies provide anecdotal evidence

about the positive effects of eco-innovation. They suffer from the lack of the methodological regime of eco-innovation and green growth measurement.

In 2008, the OECD launched the Green Growth and Eco-innovation Project to improve the understanding how innovation can lead to new technological and system solutions in the face of global challenges and to provide the industry with relevant means to improve its contribution to green growth and sustainable development. In its publications, the OECD clearly indicates the key role of eco-innovation in green growth, which contributes to decoupling economic growth from the consumption of natural capital and to creating new jobs (Rutkowska-Podołowska *et al.*, 2016; Michalski *et al.*, 2017; Sulich and Rutkowska-Podołowska, 2017; Sulich and Zema, 2018).

However, whether and to what extent eco-innovation is actually a significant factor for implementing green growth has not been discussed in many studies so far. Despite the fact that elaborate literature on eco-innovation does exist and the number of studies exploring green growth mechanisms has been increasing, a comprehensive study of the relations between the two concepts has not been developed yet. In order to fill this gap in the literature we decided to find the link between eco-innovation and green growth applying a mulita dimensional framework. Contrary to previous empirical studies on the economic effects of eco-innovation, we employ the input-output approach to measuring eco-innovation.

Moreover, we take into account additional measures that refer to eco-innovation activities of enterprises. Such approach allows us to open the black box of eco-innovation, since it covers all elements of an eco-innovation process. As regards green growth we follow the OECD recommendation. OECD identifies environmentally adjusted multifactor productivity (EAMFP) as a green growth headline indicator. It measures a country's ability to generate income from a given set of inputs, while accounting for the consumption of natural resources and production of undesirable environmental outputs. The EAMFP has the potential to complement the traditional measure of productivity – multifactor productivity (MFP) – widely used by economic and finance policy makers, and thus fosters greater consideration of environmental concerns in economic policy decisions. We do believe that our study is able to provide a robust answer to a question if eco-innovations lead to higher green growth performance of countries?

3. Materials and Methods

This study uses the data published by OECD, Eurostat, and European Commission. Due to missing data the real problem was to ensure their comparability. For this reason we have selected years 2010-2013 as research period. Our sample consists of 21 European countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg,

Netherlands, Poland, Sweden, Slovenia, Slovak Republic, Spain, United Kingdom. The data set has panel structure with 21 units and 4 periods.

As a measure of green growth we use the environmentally adjusted multifactor productivity (EAMFP) developed by OECD (Cardenas *et al.*, 2018). The approach presented by OECD builds on the model developed by Brandt *et al.* (2014). EAMFP makes adjustments for natural capital inputs and for undesirable outputs, i.e., negative by-products of the production process. It increases when GDP increases or when pollution decreases, for a given growth of input employment. The EAMFP growth is the residual, i.e., the share of pollution-adjusted GDP growth that cannot be explained by growth in the use of factor inputs (including labour, produced capital and natural capital). As such, the EAMFP explicitly connects “green” and “growth” to produce a measure of environmental and economic performance. Therefore, the EAMFP growth can be defined as:

$$\frac{\partial \ln EAMFP}{\partial t} \equiv \frac{\partial \ln Y}{\partial t} - \varepsilon_{YR} \frac{\partial \ln R}{\partial t} - \varepsilon_{YL} \frac{\partial \ln L}{\partial t} - \varepsilon_{YK} \frac{\partial \ln K}{\partial t} - \varepsilon_{YS} \frac{\partial \ln S}{\partial t} \quad (1)$$

where L, K, and S represent labour, produced capital, and natural capital (14 types of subsoil assets, including fossil fuels, i.e., hard coal, soft coal, gas, oil, and minerals, i.e., bauxite, copper, gold, iron ore, lead, nickel, phosphate, silver, tin and zinc), Y denotes the desirable output (GDP), R is the undesirable output/pollution (CO₂, NO_x, SO_x, PM₁₀, CH₄, CO, NMVOC, N₂O), and the terms ε_{YR} , ε_{YL} , ε_{YK} , ε_{YS} are the elasticities of Y with respect to R, L, K, and S, respectively.

Within the EAMFP framework environmental inputs and outputs are valued from the producer’s perspective. Similarly, a shadow price of undesirable output is estimated as the producer’s marginal cost of abating one unit of pollution.

In our study we apply four measures of eco-innovation. Three of them relate to the components of eco-innovation index which presents eco-innovation performance across the EU Member States. The first one denotes eco-innovation inputs that consist of financial and human resources investments directing to stimulate eco-innovation activities. The indicators within the eco-innovation inputs include total value of green early stage investments (USD/capita), governments environmental and energy R&D appropriations and outlays (% of GDP), and total R&D researchers and personnel (% of total employment).

The second component illustrates eco-innovation activities undertaken by companies. The indicators in this component include firms declaring to have implemented innovation activities aiming at a reduction of material input per unit output (% of total firms), firms declaring to have implemented innovation activities aiming at a reduction of energy input per unit output (% of total firms), and ISO 14001 registered organisations (per mln population). The last component includes

eco-innovation outputs describing the extent to which knowledge outputs generated by businesses and researchers contribute to eco-innovation. The indicators within this component include eco-innovation related media coverage (per numbers of electronic media), eco-innovation related academic publications (per mln population), and eco-innovation related patents (per mln population). We decided to focus on these three dimensions of the eco-innovation index, since they allow for measuring eco-innovation in the entire chain of eco-innovation efforts. The fourth measure of eco-innovation is an index reflecting the relative advantage in environment-related technology. This index is calculated as the ratio of the share of environment-related patents on all patents (in all technologies) at a given country and the share of environment-related patents on all patents (in all technologies) in the world. The index above 1 shows a relative technological advantage in environment-related technologies compared to the world value.

To fulfil the aim of the article, we employ a spatial panel data model. The spatial models allow researchers to study the relationships between variables taking into account different spatial patterns. A general form of linear spatial panel models is given by the following set of equations (Anselin, 1988; Baltagi *et al.*, 2003):

$$y_{it} = \lambda W y_{it} + X_{it} \beta_{(1)} + W X_{it} \beta_{(2)} + \mu_i + u_{it} \quad (2)$$

$$u_{it} = \rho W u_{it} + \varepsilon_{it} \quad (3)$$

The model consists of two equations. The first one considers spatially lagged dependent variable y as one of the regressors and may also contain spatially lagged variables of some or all of the exogenous variables (the term WX). It also includes panel-level effects μ_i , which may be fixed or random. The second equation describes a spatial model for the stochastic disturbances. In principle, there is no need for the three weight matrices in Equations (2) and (3) are to be the same.

Another option of spatial panel model with random effects is slightly different than previous one (Kapoor *et al.*, 2007):

$$y_{it} = \lambda W y_{it} + X_{it} \beta_{(1)} + W X_{it} \beta_{(2)} + u_{it} \quad (4)$$

$$u_{it} = \rho W u_{it} + \mu_i + \varepsilon_{it} \quad (5)$$

In this variant the panel-level effects μ_i are placed in the error equation and have the same autoregressive form as the time-level errors ε_{it} .

Our model is used to describe the environmentally adjusted multifactor productivity growth (EAG). The eco-innovation inputs (EcoInp), the eco-innovation activities (EcoAct), the eco-innovation outputs (EcoOut), and the relative advantage in environment-related technology (AET) are applied as independent variables. We

also test the non-linear relationship between eco-innovation and green growth. To do this, we include EcoInp, EcoAct, EcoOut, AET and their squares in Equations (2) and (4). The U-shaped (inverted U-shaped) relationship implies that the squares of EcoInp, EcoAct, EcoOut, and AET are expected to have positive (negative) coefficients.

Maximum likelihood method is applied to estimate parameters of spatial panel models. We consider different model specification, including the fixed-effects model, the random-effects model and the random-effects model with autoregressive panel effects. We impose various restrictions on parameters λ , β , and ρ . The choice of appropriate model specification is based on Akaike's and Bayesian information criteria, and parameters significance. In our study we use four types of spatial weights matrices which reflect the intensity of the geographic relationship between countries. They are based on the distances between countries and the lengths of shared border. The spatial weights are calculated as follow:

1. inverse of centroid distances between countries;
2. inverse of centroid distances between countries with threshold distance beyond which there is no direct spatial influence;
3. first order neighbours;
4. first order and second order neighbours.

The matrices are row-standardized. In consequence, the spatially lagged variables are the mean values of them in neighbour regions. The application of these matrices allows us to choose these ones that ensure better model adaptation.

4. Results and Discussion

Table 1 presents the descriptive statistics and correlation coefficients among explanatory variables. It is important to stress that pairwise correlations don't exceed a commonly used threshold (0.7). So, we may state that the collinearity is not a problem in our analyses.

Table 1. Descriptive statistics and correlation coefficients between explanatory variables

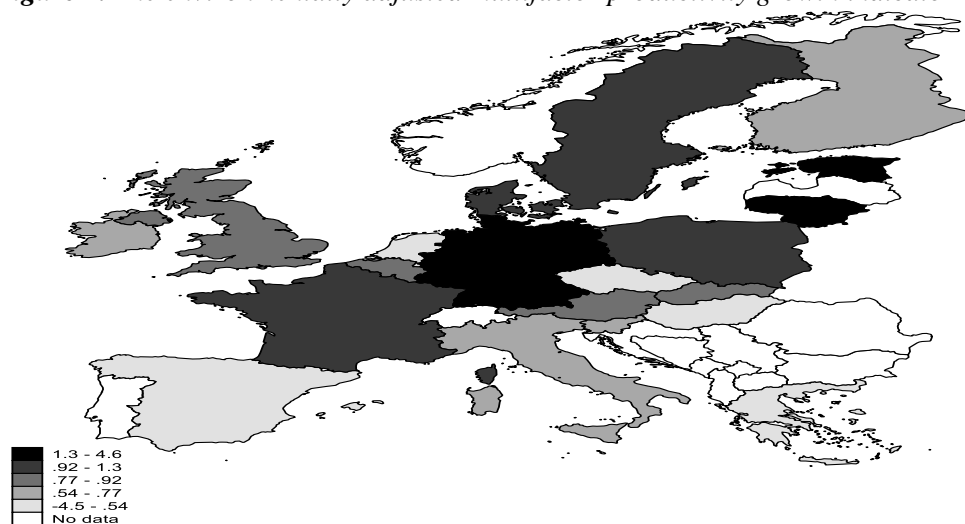
Variables	Mean	Std. Dev.	Median	Min	Max	EcoInp	EcoAct	EcoOut	AET
EcoInp	103.2	58.8	95	12	287	1			
EcoAct	96.4	50.6	89.5	7	246	0.4401	1		
EcoOut	105.2	67.5	92.5	4	258	0.5601	0.2573	1	
AET	1.121	0.36	1.1	0.42	2.2	0.1322	0.0758	0.1406	1

Source: Own calculations.

The average values of the environmentally adjusted multifactor productivity growth for 21 European countries in years 2010-2013 is presented in Figure 1. Most EU

economies have achieved a positive productivity (EAMFP) growth over the analysed period, on average. Some of the high-ranking countries with favourable green growth rates have mostly relied on opportunities for the adoption of innovation in cleaner technologies while decreasing the use of factor inputs (e.g., Ireland) and keeping constant (on the marginal level) the extraction of their natural resources (e.g., Germany). In the case of other top-ranking countries they have faced with substantial economic changes, often complemented by a wide adoption of cleaner technologies (e.g., Estonia, Lithuania). At the bottom of the ranking with a low or negative EAMFP growth there are mostly countries with economic difficulties (e.g., Spain). These economies have confronted with the decreasing productivity growth along with the shrinking contribution of factor inputs.

Figure 1. *The environmentally adjusted multifactor productivity growth indicator*



Source: Map generated using STATA 15.

The results of the estimation of the models for the environmentally adjusted multifactor productivity growth are shown in Table 2. The model contains only significant variables at 0.1 level. As a consequence, the EcoInp and EcoOut variables were removed from the model. It is worth noting that the environmentally adjusted multifactor productivity growth is better explained when spatial relations are measured on the basis of neighbourhood between countries. As suggested by LeSage and Pace (2009), the interpretation of the parameter estimates in spatial autoregressive models may result in erroneous conclusions. This can be explained by the non-linear character of these models that include a spatial lag in the input and output variable.

Table 2. *Estimates of model parameters*

Variable	EAG
EcoAct	0.0448***
EcoAct2	-0.0002***
AET	-4.0182*
AET2	1.6994**
Year	
2011	-0.2724
2012	-2.104***
2013	-1.7851***
CONST	0.8638
spatial matrix	W
EcoAct	-0.015**
AET	2.4587***
Pseudo R2	0.492
Wald test of spatial terms	7.19
(p-value)	(0.0274)

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, W – spatial matrix based on first-order and second-order neighbourhood.

Source: Own calculations.

In order to analyze the consequences of changes in the explanatory variables on the EAG, we present the direct effects, the indirect effects, and the total effects in Table 3. The direct effect is the effect of the change in the explanatory variable within the country, ignoring spillover effects. In turn, the indirect effect is the across countries spillover effect. The total effect is the sum of the direct and indirect effects.

Table 3. *Average marginal effects of EcoAct and AET on EAG*

Independent variable	Kind of effect	EAG
EcoAct	Direct	0.0089*
	Indirect	-0.0135**
	Total	-0.0046
AET	Direct	-0.2083*
	Indirect	2.2245***
	Total	2.0163*

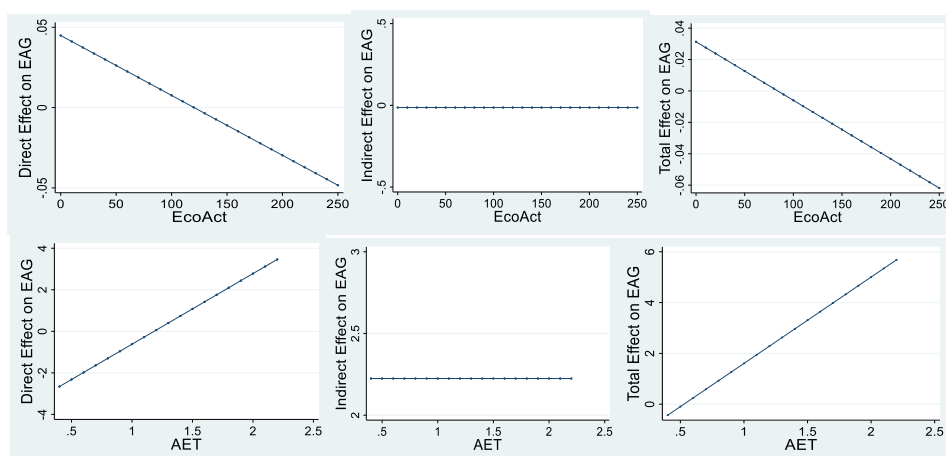
Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Source: Own calculations.

Since we included the squared terms of the independent variables in our model, we could check if the direct, indirect, and total effects are different over the specified range of EcoAct and AET (Figure 2). Our analyses show that the direct effect of EcoAct on the environmentally adjusted multifactor productivity growth is non-linear. As shown in the Figure 2, it is positive for countries with the relatively low level of eco-innovation activities and after reaching a threshold (i.e., EcoAct=120,3) it becomes negative. This situation may result from a few reasons. First of all, there

may be a strong later-comer advantage with respect to introducing eco-innovations. According to the leapfrog theory, countries less developed in terms of eco-innovation activities can take full advantage of global knowledge on green innovation and hence experience cost savings and green productivity improvements (Angang, 2014). On the other hand, countries that are very activate in implementing eco-innovations may face with a crowding out effect of environmental innovations at the expenses of other (possibly more productive) innovations, which can result in the decrease of the environmentally adjusted multifactor productivity. In line with our results some authors give evidence in support of the presence of crowding out effect of eco-innovations and its negative impact on the productivity growth (Martin, 2014).

Figure 2. Average marginal effects of EcoAct and AET on EAG



Source: Map generated using STATA 15.

As regards the direct effect of AET on the environmentally adjusted multifactor productivity growth, we reveal that investments in patent applications in the environment-related technologies make a negative contribution to green growth at the beginning. Then, after reaching a threshold (at the index value equal to 1.182), this relationship becomes positive. This optimal point is achieved by the countries which have the relative technological advantage in environment-related technologies compared to the world value.

This result is consistent with the well-known S-curve theory (Foster, 1986) and the technological uncertainty theory (Oriani and Sobrero, 2008). The former shows the four phases of technology life-cycle. The first phase of technology life-cycle, which is called the "bleeding edge", is characterized by negative gains from new technology and the relatively high prospects of failure. It is worth noting the process of commercialization of green inventions is a very complex task, which takes place

in technological uncertainty settings. Enterprises faced with market uncertainty may hold an option to wait and delay the commercialization process of inventions. Technological uncertainty depends on exogenous factors, such as the legal and institutional factors.

According to the Porter Hypothesis (PH) properly designed environmental standards can trigger invention/innovation that may partially or more than fully offset the cost of complying with them (Porter and Van der Linde, 1995). As suggested by Costantini and Mazzanti (2012), the strong version of PH assumes that environmental regulations enhance economic performance and competitiveness of complying firms, and eventually, of the whole economy. In this vein, regulations are regarded as a shock that stimulates firms to seek new opportunities and stimulates eco-innovation. The weaker version of PH states that additional eco-innovation stimulated by regulations generates both opportunity costs and, possibly higher, gross benefits. Eventually, the narrowly strong PH expects that environmental protection might affect only the green part of the economy.

We also find that there are positive spillovers of knowledge embedded in green patents (the indirect effect of AET). According to Grossman and Helpman (1994) and Jones (2002), when knowledge enters the public domain, it becomes immediately available to all market agents and leads to increasing returns. A seminal study by Coe and Helpman (1995) shows that a country's productivity level not only depends on internal R&D capital stock but also on external R&D of foreign trade partners. On the other hand, the fact that knowledge spillover has spatial dimension is non-controversial. For example, Kwon (2003) studies the role of R&D on total factor productivity during the period 1987-1996, incorporating the spatial dimension of the countries. The main finding of this study is that the rate of the rate of return to R&D spillovers in Korea is less than advanced economies.

In the case of green innovation, Acemoglu *et al.* (2018) appeal to complementarities between green technologies in developed and in less developed countries. In similar vein, Aghion and Aravel (2015) argue for supporting knowledge spillovers from the developed green innovation countries to the developing green imitation countries. As suggested by Dechezlepretre *et al.* (2017) technologies in the green domains differ from technologies in other fields in their ability to generate knowledge spillovers. They find that knowledge spillovers induced by patents from four green technology fields (lighting, automobiles, fuel, and energy production) are much larger than those generated by patents relating to the four substitute brown technologies. Moreover, knowledge spillovers from green patents are greater in magnitude than the ones from such fields as robotics, 3D printing, and nanotechnology.

What is important, our models show that the indirect effect of EcoAct is relative low and negative. This may suggest that there is competition and strategic interaction between eco-innovative firms from different countries. Contrary to Feng and Chen (2018) who report that green product innovation is beneficial to the industrial green

development performance of the province and neighbouring provinces, our findings don't suggest "win-win" situation, where green productivity benefits can be obtained by all agents investing in development and production of environment saving new products and processes. In the case of eco-innovation, global competition between many different product designs and technological solutions during a proliferation period may lead to the market domination by the most efficient and desirable solutions (OECD, 2011b).

5. Conclusions

This paper proposes a unique approach for modelling the relationship between eco-innovation and green growth. Since a significant portion of the literature in this field has a theoretical character, we have tried to find if eco-innovations lead to higher green growth performance in the sample of the EU countries. The article provides relevant insights, both from a theoretical and methodological perspective. We first show that discussion on the role of eco-innovation in implementing the premises of green growth concept is, so far, purely theoretical.

Despite the fact that elaborate literature on eco-innovation does exist and the number of studies exploring green growth mechanisms has been increasing, a comprehensive empirical study of the relations between the two concepts has not been developed yet. To our knowledge, this study is the first one which includes different measures of eco-innovations and relates them to the green growth process. These measures allow us portray the countries' eco-innovation efforts from input, process, and output perspectives.

What is important, we employ the environmentally adjusted multifactor productivity which is complementary to the traditional measure of productivity by including the consumption of natural resources and production of undesirable environmental outputs. Concerning the non-linear relationship between eco-innovations and green growth in our spatial model, many relevant results have been explored. These results involve nonlinearities and spatial effects that cannot be uncovered using standard linear formulations.

The empirical approach adopted in the paper shares a few relevant drawbacks with other similar works in the same stream of literature. First, it relies on the eco-innovation index components and the relative advantage in environment-related technology as measures of eco-innovations. Although they give a holistic view of countries' eco-innovation performance, they suffer from the aggregation problem. Second, the models include the geographical proximity and do not explicitly assess the role of alternative non-spatial proximities.

On the one hand these limitations should be considered when interpreting the empirical results. On the other hand, they may be the starting point for further analyses. In our opinion, it would be interesting to consider the impact of particular

indicators constituting the eco-innovation index components on green growth. As regards the relative advantage in environment-related technology, the exploration of green productivity improvements for different patent domains is needed. Finally, an institutional proximity in the terms of environmental standards and requirements may be used in the spatial model describing the link between eco-innovation and green growth.

Keeping in mind the limitations presented above, the empirical analysis also produces a number of policy implications. Perhaps the clearest result concerns the existence of positive effects of investing in eco-innovations on green growth. However, the positive effect is only reported for eco-innovation activities and the relative advantage in environment-related technology. The impact of eco-innovation inputs and eco-innovation outputs turns out to be insignificant.

These results suggest that the policy-makers should mainly focus on stimulating the companies to introduce eco-innovations aiming at a reduction of material input and energy per unit output as well as an improvement of eco-management practices. Government incentives for green technology and organizational solutions may include a combination of subsidies and tax incentives. It should be noted that our findings suggest the possibility of overinvesting in eco-innovation activities, which may result from a crowding out effect of environmental innovations at the expenses of other (possibly more productive) innovations.

Indirectly, these results may support the narrowly strong the Porter Hypothesis, which assumes that eco-innovation might affect only the green part of the economy and their net benefits may be negative. The direct negative effects of overinvesting in eco-innovation activities may be reinforced by the indirect effect of eco-innovation activities. The latter can be involved with the competition between eco-innovative firms from different countries, which may ultimately lead to the crowding out effect. In this situation, there is a need for more flexible approach to environmental regulations and smart eco-innovation policy incentives that reduce the crowding out effect.

As regards the effects of eco-invention on the green growth, we reveal that there is a minimal level of knowledge embedded in patents that must be reached to gain benefits from commercialization of these inventions by enterprises. On the other hand, we show that there are the positive spillovers of knowledge embedded in green patents. This supports a need for an increase in the policy emphasis on the socio-institutional frameworks that support the absorptive capacities of lagging countries. Finally, the important role of the geographical proximity in explaining the green growth trajectory in the sample countries makes clear that environmental regulations ought to be tailored to specific conditions which are similar for closely located countries.

References:

- Acemoglu, D., Akcigit, U., Bloom, N., Kerr, W. 2018. Innovation, Reallocation, and Growth. *American Economic Review*, 108(11), 3450-3491.
- Aghion, P., Howitt, P. 2009. *The Economics of Growth*. MIT Press, Cambridge.
- Aghion, P., Jaravel, X. 2015. Knowledge spillovers, innovation and growth. *The Economic Journal*, 125, 533-573.
- Angang, H. 2014. *China: innovative green development*. Springer, Heidelberg.
- Anselin, L. 1988. *Spatial econometrics: methods and models*. Kluwer Academic, Dordrecht, The Netherlands.
- Ates, S.A. 2015. Development planning in twenty-first century: the case of green growth strategy in South Korea. In: Yülek, M. (Ed.). *Economic Planning and Industrial Policy in the Globalizing Economy*. Public Administration, Governance and Globalization 13. Springer International Publishing, Switzerland, 345-354.
- Baltagi, B., Song, S.H., Koh, W. 2003. Testing panel data regression models with spatial error correlation. *Journal of Econometrics*, 117, 123-150.
- Bendell, B.L. 2017. I don't want to be green: prosocial motivation effects on firm environmental innovation rejection decisions. *Journal of Business Ethics*, 143, 277-288.
- Bossink, B. 2011. *Managing environmentally sustainable innovation. Insights from the construction industry*. Routledge, New York, USA.
- Brandt, N., Schreyer, P., Zipperer, V. 2014. Productivity measurement with natural capital and bad outputs. *OECD Economics Department Working Papers*, No. 1154, OECD Publishing, Paris.
- Braungardt, S., Elsland, R., Eichhammer, W. 2016. The environmental impact of eco-innovations: the case of EU residential electricity use. *Environmental Economics and Policy Studies*, 18, 213-228.
- Cai, W., Li, G. 2018. The drivers of Eco-innovation and its impact on performance: evidence from China. *Journal of Cleaner Production*, 176, 110-118.
- Cardenas, R.M., Hascic, I., Souchier, M. 2018. Environmentally Adjusted Multifactor Productivity: methodology and empirical results for OECD and G20 countries. *OECD Green Growth Papers*, No. 2018-02. Paris, OECD Publishing.
- Chang, C.H. 2011. The influence of corporate environmental ethics on competitive advantage: The mediation role of green innovation. *Journal of Business Ethics*, 104, 361-370.
- Chen, Y.S., Lai, S.B., Wen, C.T. 2006. The influence of green innovation performance on corporate advantage in Taiwan. *Journal of Business Ethics*, 67, 331-339.
- Choi, Y. 2015. Intermediary propositions for green growth with sustainable governance. *Sustainability*, 7, 14785-14801.
- Coe, D.T., Helpman, E. 1995. International R&D spillovers. *European Economic Review*, 39(5), 859-887.
- Costantini V., Mazzanti, M. 2012. On the green and innovative side of trade competitiveness? The impact of environmental policies and innovation on EU exports. *Research Policy*, 41(1), 132-153.
- Dechezlepretre, A., Martin, R., Mohnen, M. 2017. Knowledge spillovers from clean and dirty technologies: A patent citation analysis. *Grantham Research Institute on Climate Change and the Environment Working Paper*, No. 135.

- De Jesus, A., Antunes, P., Santos, R., Mendonça, S. 2018. Eco-innovation in the transition to a circular economy: An analytical literature review. *Journal of Cleaner Production*, 172, 2999-3018.
- De Medeiros, J.F., Ribeiro, J.L.D., Cortimiglia, M.N. 2014. Success factors for environmentally sustainable product innovation: A systematic literature review. *Journal of Cleaner Production*, 65, 76-86.
- Díaz-García, C., González-Moreno, A., Sáez-Martínez, F.J. 2015 Eco-innovation: insights from a literature review. *Innovation: Management, Policy and Practice*, 17(1), 6-23.
- Elbasha, E., Roe, T. 1995. Environment in three classes of endogenous growth models. *Economic Development Center Bulletin*, No. 95(6).
- European Commission. 2018. Eco-innovation the key to Europe's future competitiveness. Retrieved from <http://ec.europa.eu/environment/pubs/pdf/factsheets/eecoinnovation/en.pdf>.
- Federal Statistical Office. 2013. Test of the OECD set of green growth indicators in Germany 2012. Statistisches Bundesamt, Wiesbaden, Germany.
- Feng, Z., Chen, W. 2018. Environmental regulation, green innovation, and industrial green development: an empirical analysis based on the spatial Durbin model. *Sustainability*, 10, 223.
- Forsman, H. 2013. Environmental innovations as a source of competitive advantage or vice versa? *Business Strategy and the Environment*, 22, 306-320.
- Foster, R. 1986. *Innovation: the attacker's advantage*. Summit Books. New York.
- Fussler, C., James, P. 1996. *Driving Eco-Innovation: A Breakthrough Discipline for Innovation and Sustainability*. Pitman Publishing, London, Great Britain.
- García-Granero, E.M., Piedra-Muñoz, L., Galdeano-Gómez, E. 2018. Eco-innovation measurement: a review of firm performance indicators. *Journal of Cleaner Production*, 191, 304-317.
- Grossman, G., Helpman, E. 1994. Endogenous innovation in the theory of growth. *Journal of Economic Perspectives*, 8, 23-44.
- Guo, L., Qu, Y., Wu, Ch., Gui, S. 2018. Evaluating green growth practices: empirical evidence from China. *Sustainable Development*, 26(3), 302-319.
- Guo, L., Qu, Y., Wu, Ch., Wang, X. 2018. Identifying a pathway towards green growth of Chinese industrial regions based on a system dynamics approach. *Resources, Conservation and Recycling*, 128, 143-154.
- Hellström, T. 2007. Dimensions of environmentally sustainable innovation: The structure of Eco-innovation concepts. *Development*, 15, 148-159.
- Huang, Y.C., Tu, J.C., Lin, T.W. 2017. Key success factors of green innovation for transforming traditional Industries. In M. Matsumoto, K. Masui, S. Fukushige, and S. Kondoh, (Eds.). *Sustainability Through Innovation in Product Life Cycle Design, EcoProduction*. Springer, Singapore, Japan, 779-795.
- Huber, J. 2008. Technological environmental innovations (TEIs) in a chain-analytical and life-cycle-analytical perspective. *Journal of Cleaner Production*, 16(18), 1980-1986.
- Huhtanen, T. 2010. Europe and Green Growth: the key to recovery? In *State of the Union 2010*. Schuman Report on Europe. Springer-Verlag, Paris, France.
- Jones, C.I. 2002. Population and ideas: a theory of endogenous growth. In P. Aghion, R. Frydman, J. Stiglitz, M. Woodford, (Eds.), *Knowledge, information, and expectations in modern macroeconomics*. In honor of Edmund S. Phelps. Princeton University Press, Princeton.
- Kapoor, M., Kelejian, H.H., Prucha, I.R. 2007. Panel data models with spatially correlated error components. *Journal of Econometrics*, 140, 97-130.

- Kasztelan, A. 2015. Green growth as a response to increasing environmental threats (in Polish). *Studia Ekonomiczne*, No 2, LXXXV, 185-208.
- Kasztelan, A. 2017a. Green growth, green economy and sustainable development – terminological and relational discourse. *Prague Economic Papers*, 26(4), 487-499.
- Kasztelan, A. 2017b. Is growth in the European Countries green? Proceedings of the 30th International Business Information Management Association Conference, Vision 2020 Sustainable Economic Development, Innovation Management, and Global Growth. Madrid, Spain. K.S. Soliman (Ed.), IBIMA, 1593-1603.
- Kasztelan, A., Kijek, T. 2015. Eco-innovation as a driver of regional smart specialization: the case of Lubelskie province. *Economic and Environmental Studies*, 15, 4(36), 397-413.
- Kemp, R., Pearson, P. 2008. Measuring eco-innovation. Brussels, European Commission.
- Kobryń, A., Prystrom, J. 2017. Multi-criteria evaluation of the Eco-innovation level in the European Union countries. *Problemy Ekorozwoju – Problems of Sustainable Development*, 12(2), 15-26.
- Kwon, H.U. 2003. Measuring the rate of return to R&D. Interindustry R&D spillovers in Korean manufacturing industries. *Hitotsubashi Journal of Economics*, 44(1), 49-57.
- LeSage, J., Pace, R.K. 2009. Introduction to spatial econometrics. Taylor and Francis, Boca Raton, FL.
- Lyytimäki, J., Antikainen, R., Hokkanen, J., Koskela, S., Kurppa, S., Känkänen, R., Seppälä, J. 2018. Developing key indicators of green growth. *Sustainable Development*, 26, 51-64.
- Machiba, T. 2017. Eco-innovation for enabling resource efficiency and green growth: development of an analytical framework and preliminary analysis of industry and policy practices. *International Economics and Economic Policy*, 7, 357-370.
- Martin, G. 2014. Do Eco-innovations harm productivity growth through crowding out? Results of an extended CDM model for Italy. *Research Policy*, 43(2), 301-317.
- Michalski, G., Rutkowska-Podołowska, M., Sulich, A., Rothe, R. 2017. The green jobs and the Industry 4.0. In Proceedings of the Conference Enterprises and Economies in the Face of Contemporary Challenges. Management-Restructuring-Innovation. Krynica, Poland.
- Narloch, U., Kozluk, T., Lloyd, A. 2016. Measuring inclusive green growth at the country level. GGKP Working Paper 02. GGKP Research Committee on Measurement and Indicators.
- OECD. 2009a. Declaration on green growth. Meeting of the Council at Ministerial Level. 24-25 June 2009. C/MIN(2009)5/ADD1/FINAL.
- OECD. 2009b. From grim to green. OECD messages on green growth. Retrieved from <http://www.oecd.org/greengrowth/47411244.pdf>.
- OECD. 2009c. OECD and green growth. Retrieved from <http://www.oecd.org/greengrowth/44273385.pdf>.
- OECD. 2010a. Eco-innovation in industry: enabling green growth. OECD Publishing, Paris, France.
- OECD. 2010b. Interim report of the green growth strategy: implementing our commitment for a sustainable future. Meeting of the OECD Council at Ministerial Level, 27-28, May 2010. C/MIN(2010).
- OECD. 2011a. Fostering innovation for green growth. OECD Green Growth Studies. OECD, Paris, France.
- OECD. 2011b. OECD studies on Environmental innovation better policies to support Eco-innovation. OECD, Paris, France.

- OECD. 2011c. Sustainable manufacturing and Eco-innovation. Framework, practices and measurement. Synthesis Report. OECD, Paris, France.
- OECD. 2011d. The green growth strategy. Reshaping the OECD's Work Agenda for the Years to Come. OECD, Paris, France.
- OECD. 2011e. Tools for delivering on green growth. OECD, Paris, France.
- OECD. 2011f. Towards green growth. OECD, Paris, France.
- OECD. 2012a. Inclusive green growth: for the future we want. OECD, Paris, France.
- OECD. 2012b. OECD environmental outlook to 2050. The Consequences of Inaction. OECD, Paris, France.
- OECD. 2013a. Putting green growth at the heart of development. Summary for Policymakers. OECD, Paris, France.
- OECD. 2013b. What have we learned from attempts to introduce green-growth policies? OECD Green Growth Papers. OECD, Paris, France.
- OECD. 2014. Green growth indicators 2014. OECD Green Growth Studies. OECD, Paris, France.
- OECD. 2017. Green growth indicators 2017. OECD Green Growth Studies. OECD Publishing, Paris, France.
- OECD, World Bank, UN. 2012. Incorporating green growth and sustainable development policies into structural reform agendas. The G20 Summit, Los Cabos, Mexico, 18–19 June 2012.
- Oriani, R., Sobrero, M. 2008. Uncertainty and the market valuation of R&D within a real options logic. *Strategic Management Journal*, 29, 343-361.
- Padilla-Pérez, R., Gaudin, Y. 2014. Science, technology and innovation policies in small and developing economies: the case of Central America. *Research Policy*, 43, 749-759.
- Porter, M.E., Van der Linde, C. 1995. Green and competitive: ending the stalemate. *Harvard Business Review*, 73, 120-134.
- Range, M., Sandberg, M. 2016. Windfall gains or Eco-innovation? 'Green' evolution in the Swedish innovation system. *Environmental Economics and Policy Studies*, 18, 2, 229-246.
- Rennings, K. 2000. Redefining innovation – Eco-innovation research and the contribution from ecological economics. *Ecological Economics*, 32, 319-332.
- Rutkowska-Podołowska, M., Sulich, A., Szczygieł, N. 2016. Green jobs. Proceedings of the 3rd International Conference on European Integration 2016. In E. Kovářová, L. Melecký, M. Staničková (Eds.). Ostrava, VŠB – Technical University of Ostrava. 415-424.
- Satbyul, K.E., Ho, K., Yeora, C. 2014. A new approach to measuring green growth: application to the OECD and Korea. *Futures*, 63, 37-48.
- Song, W., Yu, H. 2018. Green innovation strategy and green innovation: the roles of green creativity and green organizational identity. *Corporate Social Responsibility and Environmental Management*, 25(2), 135-150.
- Speck, S., Zoboli, R. 2017. The green economy in Europe. In: S. Shmelev (Ed.). *Green economy reader. Studies in Ecological Economics 6*. Switzerland, Springer International Publishing.
- Stoknes, P.E., Rockström, J. 2018. Redefining green growth within planetary boundaries. *Energy Research & Social Science*, 44, 41-49.
- Sulich, A., Rutkowska-Podołowska, M. 2017. Green jobs and changes in modern economy on the labour market. In R. Borowiecki, J. Kaczmarek (Eds.). *The propensity to changes in the competitive and innovative economic environment*. Cracow, Cracow University of Economics, 87-94.

- Sulich, A., Zema, T. 2018. Green jobs, a new measure of public management and sustainable development. *European Journal of Environmental Sciences*, 8(1), 69-75.
- Tellis, G.J., Eisingerich, A.B., Chandy, R.K., Prabhu, J.C. 2008. Competing for the future: patterns in the global location of R&D centers by the world's largest firms. ISBM Report. State College, PA, USA, The Pennsylvania State University.
- Trica, C.L., Papuc, M. 2013. Green economic growth premise for sustainable development. *Theoretical and Applied Economics*, XX, 1(578), 131-140.
- Triguero, Á., Cuerva, M.C., Álvarez-Aledo, C. 2017. Environmental innovation and employment: drivers and synergies. *Sustainability*, 9, 20-57.
- UNEP. 2010. Seizing the green opportunity. Annual Report 2009. Nairobi.
- UNESCO. 2005. Report on the outcomes of the Fifth Ministerial Conference on Environment and Development in Asia and the Pacific. E/ESCAP/1337, 4 May 2005; Sixty-first session, 12-18 May, Bangkok. Retrieved from https://digitallibrary.un.org/record/552295/files/E_ESCAP_1337-EN.pdf.
- UNESCAP. 2005. State of Environment Asia and the Pacific. Bangkok. Retrieved from <https://www.unescap.org/resources/state-environment-asia-and-pacific-2005>.
- Vallet, F., Tyl, B., Cluzel, F., Leroy, Y. 2016. Research directions in Eco-innovation: a French perspective. *International Journal on Interactive Design and Manufacturing*, 10(3), 309-318.
- Van der Ploeg, R., Withagen, C. 2013. Green growth, green paradox and the global economic crisis. *Environmental Innovation and Societal Transitions*, 6, 116-119.
- Varadarajan, R. 2017. Innovating for sustainability: a framework for sustainable innovations and a model of sustainable innovations orientation. *Journal of the Academy of Marketing Science*, 45, 14-36.
- Vazquez-Brust, D., Smith, A.M., Sarkis, J. 2014. Managing the transition to critical green growth: The 'green growth' state. *Futures*, 64, 38-50.
- Veugelers, R. 2016. Empowering the green innovation machine. *Intereconomics*, 4, 205-208.
- Wang, H.L., Lian, X.Y., Lin, D.M. 2016. Empirical analysis on the impact of green technological innovation efficiency on regional green growth performance. (In Chinese). *Science of Science and Management of S & T*, 6, 80-87.
- World Bank. 2012. Inclusive green growth: the pathway to sustainable development. Washington, DC: World Bank. Retrieved from http://siteresources.worldbank.org/EXTSDNET/Resources/Inclusive_Green_Growth_May_2012.pdf.
- Zhou, J.M., Zhao, Y.Z., Xiao, G.R., Wu, C.Y. 2017. Research on the mechanism of the influence of guiding technology innovation on green growth under pollution control. (In Chinese). *Science of Research and Management*, 3, 38-51.