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Evidence from the European Union

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Dissertation presented as partial requirement for obtaining the Master's degree in Information Management

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Dissertation presented as the partial requirement for obtaining a Master's degree in Information Management, Specialization in Knowledge Management and Business Intelligence

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DEDICATION

I dedicate this work to the great teachers I found along my path. Your wisdom, guidance and patience woke in me the joy of pursuing knowledge and the desire to be intellectually rigorous in doing so. I also am deeply thankful for the outstanding people in my life that love me and whom I love. To my parents, my sister and my friends, without you, all my achievements would be meaningless.

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ABSTRACT

The circular economy has gotten increasingly popular as strategy to balance economic prosperity and environmental sustainability. Using data covering the years from 2011 to 2017 of the 28 EU countries at that time we present a methodology to measure circularity levels at the country level, unveiling two main circularity dimensions, environmental degradation and resource efficiency. These dimensions were used as dependent variables for two dynamic panel models. Our study shows that innovation and investment are both relevant to reduce environmental degradation and that the latter is also significant in promoting resource efficiency. Additionally, our study suggests that circularity levels have an inter-annual dependence, thus the level of a given time period depends on that of the previous period.

KEYWORDS

Circular economy; Investment; Innovation; Human capital

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LIST OF ABBREVIATIONS AND ACRONYMS

CE	Circular economy
DEA	Data envelopment analysis
EC	European Commission
ESCC	Environmental-oriented supply chain cooperation
EU	European Union
EKC	Environmental Kuznets curve
GDP	Gross domestic product
GhG	Greenhouse gas emissions
GMM	Generalized method of moments
LCA	Life cycle assessment
MFA	Material flow analysis
OECD	Organisation for Economic Co-operation and Development
PPS	Purchasing power standard
R&D	Research and development
SMEs	Small and medium-sized enterprises

1. INTRODUCTION

In recent years, pressing challenges such as natural resource depletion, rising commodity prices, environmental pollution and climate change, have led many economies to embark on a quest for strategies to balance growth and sustainability (United Nations Environment Programme, 2019). For instance, the European Union (EU) has launched several policy initiatives built around resource efficiency. In this context, the term circular economy (CE) has received increased attention. In particular, in 2015, the European Commission (EC) introduced the CE Action Plan (European Commission, 2015) and later, the respective monitoring framework (European Commission, 2018). Furthermore, circularity is set to continue as a pillar of the Cohesion Policy for the 2021-2027 period and is also a priority for the European Regional Development Fund and Cohesion Fund (European Commission, 2019).

As these developments suggest, we are now at a point at which the CE is “an irreversible, global megatrend" (European Commission, 2019) and the EU is trying to establish itself as a circular front-runner. Policy efforts need to be accompanied by adequate monitoring and analysis of outcomes to succeed. Research about the CE has increased sharply in recent years (Merli, Preziosi, & Acampora, 2018). Academics have attempted to measure circularity levels (see, e.g., Bassi & Dias, 2019; Halkos & Petrou, 2019; Mavi & Mavi, 2019; Mayer et al., 2018), or find drivers of CE adoption (see, e.g., de Jesus & Mendonça, 2018; Gusmerotti, Testa, Corsini, Pretner, & Iraldo, 2019). However, there is a lack of quantitative studies analyzing the CE across countries and over time. This study tries to bridge this gap by systematizing relevant information about the CE in the EU and thus providing policymakers with important insights in order to develop the CE further. In this paper, we propose to conduct a comprehensive study on the development of the CE in the European Union based on evidence pertaining to the years between 2011 and 2017. Besides the current 27 member states of the EU, the United Kingdom is also included in the analysis as it was under EU CE policies until January 31st 2020, i.e., during the entire period of our data. Hence, as far as CE is concerned, as a (former) EU country, there is no difference whatsoever to the current (27) member states. This study aims to determine the main dimensions of the CE, understand if CE levels are built over past levels and estimating the effects of investment, innovation, and human capital as potential CE drivers.

The remainder of this work is organized as follows. Section 2 consists of a literature review of the CE after which we define hypotheses about its development over time and relationship with investment, innovation and human capital. In Section 3, we propose a theoretical framework for measuring CE levels. Section 4 holds the econometric analysis in which we test the previously defined hypotheses and analyse the results of the models. Section 5 presents the conclusions and suggestions for further research.

2. LITERATURE REVIEW AND HYPOTHESES

2.1. THE CONCEPT OF CIRCULAR ECONOMY

There is no consensus regarding the origin of the CE. There are some claims that the notion of an economic system that functions like a closed-loop was originated in China (Liu, Li, Zuo, Zhang, & Wang, 2009; Yuan, Bi, & Moriguichi, 2006). Contrarily, Pearce and Turner (1990) argue that the term appeared for the first time in western literature in the 1980s, referring to a closed system of interactions between the economy and the environment. According to Murray et al. (2017), the idea of the closed-loop economy emerged within the field of Industrial Ecology, being introduced by Boulding (1966) and further developed by Stahel and Reday-Mulvey (1981).

In the same sense, as there is no clarity regarding its origin, the concept itself has yet to be clearly defined (Kirchherr et al., 2018). In recent years, the term has gained momentum in politics and business, which on its hand has contributed to increase the interest of academics further and thus lead to the development of the concept (Merli et al., 2018). However, there are different interpretations of its definition, depending on the underlying perspective, and so the CE can be understood as an umbrella concept (Blomsma & Brennan, 2017). Often, the term is put in contrast to the linear economy (Murray et al., 2017) which describes an economy based on a one-way system comprising the conversion of natural resources into waste as a result from production and subsequent consumption. Different definitions of the CE have different scopes, some only being focused on the technological cycle of materials. For example, the European Commission (2015, p. 2) defines the CE as a system "where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized". Other definitions, like the one given by Murray et al. (2017, p. 25) adopt a broader perspective, including aspects of sustainability, profiling the CE as "an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being". As observable in Table 1, different definitions comprehend different dimensions of the CE.

Authors	EP	ES	H	RC	RD	RE	RW	E	RU
de Jesus, Antunes, Santos & Mendonça (2019)	X	X	X	X	X		X	X	X
European Commission (2015)	X	X		X		X	X	X	X
Geissdoerfer, Savaget, Bocken & Hultink (2017)				X	X	X	X	X	X
Murray et al. (2017)		X	X						
Suárez-Eiroa, Fernández, Méndez-Martínez & Soto-Oñate (2019)		X		X	X	X	X		X
Kirchherr, Reike & Hekkert (2017)	X	X	X	X	X				X
Ellen MacArthur Foundation (2012)				X		X	X		X
Burger, Stavropoulos, Ramkumar, Dufourmont & van Oort (2019)				X	X			X	X
Liu et al. (2009)	X	X		X	X		X	X	X
Fang, Côté, & Qin (2007, p. 316)	X	X	X	X				X	
Elia, Gnoni & Tornese (2017)	X			X	X	X	X		X

Note: EP - Economic prosperity; ES - Environmental sustainability; H - Human well-being; RC- Recycle, RD - Reduce; RE - Reduce emissions; RW - Reduce waste; E - Resource / Energy efficiency; RU - Reuse.

Table 1 - Dimensions comprised in different CE definitions.

The above-mentioned lack of a universally accepted CE definition leads us to provide a comprehensive definition of the concept on which our remaining work will draw on. Based on the interpretation of our extensive literature review, we propose the following definition:

A circular economy is an economic system that steers economic growth towards sustainability by redesigning production and consumption patterns in order to promote resource and energy efficiency while preventing environmental degradation.

2.2. CE MEASURES AND DRIVERS

The CE as a research stream has been gaining growing interest by researchers and policymakers (Merli et al., 2018). Some are focused on exploring the concept and its applications by reviewing existing literature (Merli et al., 2018; Murray et al., 2017) or using theoretical discourse (Geng, Fu, Sarkis, & Xue, 2012), while others carry out empirical analyses of CE levels and drivers at the micro, meso and macro level, as exemplified in the next paragraphs. To measure circularity, a plethora of indicators exist (Saidani, Yannou, Leroy, Cluzel, & Kendall, 2019) and studies apply either ad hoc developed methods or known metrics. Authors like Elia et al. (2017) gathered some of them to propose a taxonomy of index-based methodologies for measuring CE adoption. Besides the existence of many indicators that can be used to measure the CE, ranging from multiple indicator methods like material flow analysis (MFA) and life cycle assessment (LCA) to single indicator methods like the carbon footprint, the authors conclude that all of them have some shortcomings. The main critiques are that single indicators have a too narrow scope and composite indicators lack accuracy, while usually requiring large amounts of data and time. Other authors, like Moraga et al. (2019), also developed a framework to categorise indicators and in doing so concluded that to measure the CE level a set of indicators is a better choice than a single indicator because the concept of CE comprises several dimensions that are difficult to capture at once.

Considering the macro level, one example of a study that assesses circularity is that of Halkos & Petrou (2019) in which the authors use several variables, such as municipal solid waste generation and greenhouse gas emissions (GhG) from the waste sector, to assess the 28 EU member states' environmental efficiency levels for every other year between 2008 and 2012 recurring to data envelopment analysis (DEA). These authors found that, in general, more environmentally efficient countries, such as Germany, also reveal higher recycling rates. Another example is the analysis of Mavi & Mavi (2019) that tries to understand how the member countries of the Organisation for Economic Co-operation and Development (OECD) performed in terms of energy and environmental efficiency between 2012 and 2015, resorting to the Malmquist productivity index method based on DEA with a common set of weights. Their findings for the different countries indicate that there is a strong relationship between energy use and GhG emissions, which leads them to recommend policymakers to place more importance on input variables such as energy use instead of focusing on output variables such as GhG emissions.

There are also studies at the industry level, like the one from Zhu et al. (2010) which assesses whether the implementation of CE practices and CE-targeted performance is positively related to environmental-oriented supply chain cooperation (ESCC) practices. Firstly, the authors found the underlying factors of ESCC practises and then clustered the manufacturers resorting to their ESCC practices factor scorings. Lastly, they tested if different ESCC practices were reflected in variations in CE practices or performance using a MANOVA model, being that both hypotheses were supported by their analysis.

There is also a growing number of studies focused on the micro-level, such as the one presented by Ormazabal et al. (2018), which studied Spanish small and medium-sized enterprises (SMEs). Using a factor analysis, they found that SMEs tend to have lower CE adoption levels than other companies, being the most frequently identified opportunity related to cost savings. In contrast, the most mentioned constraint is the limited support from public authorities. Having the same focus of analysis, Bassi and Dias (2019) assessed which firm factors influence CE practices in all sectors of the European economy, using multilevel ordinal probit models. The authors not only corroborate that there is a low adoption rate of CE in European SMEs but also revealed that there are severe asymmetries across EU countries. Moreover, the firm size and the resources devoted to research and development (R&D) seem to have a considerable impact in CE adoption. Gusmerotti et al. (2019), for example, evaluated which factors incentivize firms to shift towards more circular business models. For this, they firstly grouped 821 Italian firms into clusters according to the level of CE practices. Afterwards, the authors performed a factor analysis to group the main variables into four dimensions and applied a logit regression to identify the ones that make firms shift from low-level CE clusters to high-level ones. One result of the analysis is that the driver related to economic factors is the most important one and that regulatory pressures seem to have minimal impact. Contrary to that, Cainelli, D'Amato & Mazzanti (2020) who used several econometric models to analyse data of EU firms regarding the drivers of resource efficiency-oriented eco-innovations, established that market drivers and public policies are both fundamental to implement a CE in the EU.

From the above, two aspects become clear: (i) the CE is still a novel and thus undefined concept, subject to different interpretations and measures; (ii) there is no consensus towards its main drivers and inhibitors at the three levels of analysis (micro, meso and macro). Our work aims to shed light on these issues, exploring the CE across the EU-28 along different years, focusing on the macro-level of adoption and using quantitative techniques.

2.3. HYPOTHESES

This subsection presents the hypotheses development for each of the explanatory variables considered as a driver of the CE.

The CE is a type of economic system, a way of conducting economic activity. Thus, it is expected that some of the drivers of economic growth in general, might be important as well to stimulate the CE when directed towards circularity. Bearing this in mind, we searched for the main drivers of economic growth in the economic literature.

One of the most widely accepted variables in economic growth models is accumulated capital stock (see, e.g., Kaldor, 1957; Romer, 1990; Solow, 1956), which results from the savings of each period and allows the maintenance and expansion of the production process. In order to produce goods and services, a certain combination of labour and fixed capital is needed, and high fixed capital formation benefits the productivity of production factors (Barro, 1991). In this sense, in order to increase the production of circular goods and services, fixed capital needs to be increased as well. For instance, the recycling sector in developed economies is relatively capital-intensive (Yusuf, Wu, & Evenett, 2000), so an increase in fixed capital in this sector will have a significant impact on its productivity.

The relation between fixed capital and production and, therefore, economic activity has been widely demonstrated in the literature. Apergis & Payne (2010), for example, identified that fixed capital formation is an important explanatory variable of economic growth. Later, He & Xu (2019) confirmed a positive relationship between equipment investment and growth. Being that the accumulated stock of fixed capital, and thus fixed capital formation, can be considered as essential for the development of economic activity, investment directed towards circular activities should leverage the CE. Hence, we hypothesise:

> **H1:** Investment, as a percentage of gross domestic product (GDP), in circular activities, is positively associated with higher levels of CE.

Related to the influence of capital accumulation on economic growth, suggested in the literature, we found that many growth theories (see, e.g., Barro & Sala-i-Martin, 2004; Romer, 1990; Solow, 1956) assume a positive relationship between the GDP of a given period and the GDP of the previous period, resulting precisely from the fact that the capital accumulation that assures a certain GDP level results from savings of the previous GDP. In the case of the CE level, the same pattern could exist.

As stated previously, the transition to a CE requires profound changes to the production process and produced goods (see, e.g., Edmondson, Kern, & Rogge, 2018; Ghisellini, Cialani, & Ulgiati, 2016; Merli et al., 2018), which require companies to explore new terrain. This exercise of exploration can lead to economies of learning, being that the novelty factor gradually decreases. At the same time, experience crystalizes the best approaches, which can already be seen in studies like the one from De los Rios & Charnley (2017). Furthermore, a CE might benefit from strong cooperation between companies in order to close production cycles (see, e.g. the concept of industrial symbiosis) and, over time, more and more synergies between companies might emerge, reinforcing the CE levels in a gradual way. Given these considerations, we formulate the following hypothesis:

> **H2:** The CE level of a given year builds over the CE level of the previous year, translating into an inter-annual dependence of the CE.

Another frequently identified driver of economic growth is technological progress (Kaldor, 1957; Romer, 1990; Solow, 1956), which is related to innovations in the production process, meaning new (better) ways of producing goods. Technological innovation aims at increasing efficiency, meaning that the same amount of output will require a lower amount of inputs (Tavassoli & Karlsson, 2015). There are also other types of innovation, such as product innovation (Schumpeter, 1934) which is often incentivised by the desire of a company to gain competitive advantage or even a temporary monopoly over that particular product type (Tavassoli & Karlsson, 2015). We argue that in the context of the CE, innovation (technological or not) is even more relevant than in the linear one. In order to achieve increasingly higher levels of circularity, an economic system needs to maximize efficiency as well as redesign its products to facilitate recycling, and increase durability, among others (Ellen MacArthur Foundation, 2015). Hence, a circular system needs to constantly incorporate state-of-the-art technologies which are not (yet) available to less innovative systems and dedicate resources to transition to progressively circular products.

In the literature, there is evidence that the CE demands innovation. For example, Pitkänen et al. (2016) find technological development and R&D to be critical factors in achieving a green economy. These findings are in line with the considerations of the European Environment Agency (2014) on innovation being a relevant factor behind resource productivity, an important circularity indicator. Given these considerations, we formulate the following hypothesis:

> **H3:** Innovation is positively associated with CE.

A third aspect frequently identified as a driver of economic growth is human capital. Human capital is essential to develop R&D activities and, ultimately, enable innovation (Romer, 1990). For example, Barro (1991) confirms the existence of a positive relationship between human capital and economic activity. Moreover, Mankiw, Romer & Weil (1992), argue that the Solow model should be augmented to include this factor given its positive impact on economic growth resulting from labour productivity gains. Human capital also has an indirect impact on economic activity by contributing to better policies (Glaeser, La Porta, Lopez-de-Silanes, & Shleifer, 2004) and improving a variety of indicators such as civic participation and environmental conditions (Sianesi & Van Reenen, 2003). Likewise, Yao, Ivanovski, Inekwe & Smyth (2019) found that human capital can have a positive impact on circularity because it leads to a reduction of aggregate energy consumption and a transition from dirty to clean energy. According to the authors, several reasons can explain this relationship. One is that human capital leads to economic growth which albeit boosting energy consumption, also creates a preference for clean energy. Additionally, human capital, by facilitating R&D, leads to more efficient processes and products that require less energy overall and privilege clean energy. In summary, the literature lists multiple ways through which human capital can nurture economic activity and shift it towards a cleaner path, leading us to hypothesise that:

> **H4:** Countries with a higher stock of human capital reach higher levels of circularity.

3. MEASURING THE CIRCULAR ECONOMY

3.1. METHODOLOGY

Because of the growing popularity of the CE, the problem of how to measure it has been gaining attention (Sassanelli, Rosa, Rocca, & Terzi, 2019). Nonetheless, measuring the circularity level of an economic system is still a task limited by several constraints. The first has to do with the lack of a standardised definition for the CE, as discussed previously in Section 2. The second arises from data availability. There is a clear trade-off between countries, timeframes, and variables one may include. That is, the more countries and timeframes (years) one wants to include the less are the countries with available data and vice-versa. Hence, if one privileges the comprehensiveness of the CE over the representativity of countries, conclusions will be affected in terms of generality.

In contrast, the opposite conclusions may hide important aspects of the CE. This limitation led to the development and use of a-priori composite indices; for example, the circular economy efficiency index developed introduced by Ma, Wen, Chen, & Wen (2014), which can summarise complex and multidimensional phenomena and are easy to interpret (OECD, 2008). However, they also entail limitations: they may (tend) to oversimplify complex phenomena as they reduce them to a single number. The original variables that comprise them may not have strong theoretical support, are not controllable, and may be subject to external influences. New aspects of the CE may take time to be considered. Finally, perhaps the most important, the weight that each (original) variable has on the index formation is defined in an a-priori subjective manner and not based on the actual data (Bruno, Esposito, Genovese, & Gwebu, 2010; Cruz-Jesus, Oliveira, & Bacao, 2012). For these reasons, in this study, we use original CE-related variables on which we perform a factor analysis which allows measuring the CE as a multidimensional phenomenon, an approach that has also been used by other authors (Yang, Chen, & Gao, 2011; Yang, Gao, & Chen, 2011). Each extracted factor is an underlying dimension of the CE, which are orthogonal to each other. Thus, one immediate advantage of this analysis is to identify the different dimensions through which the CE develops. These will be subsequentially explained through different econometric models.

3.2. CAPTURING IMPORTANT CIRCULAR ECONOMY PROPERTIES

The CE aims to maximize economic growth and, at the same time, minimize environmental degradation and waste. In other words, the CE emphasizes the ratio between input/output, i.e., productive efficiency; generated waste, i.e., undesired or useless output; and resource reuse.

Productive efficiency is addressed by the variables resource productivity and energy productivity which express, respectively, the amount of desired economic output, gross domestic product (GDP), is produced for each unit of raw materials and energy. A higher value of resource productivity indicates higher levels of circularity (European Environment Agency, 2016; Magnier, 2017; Tantau, Maassen, & Fratila, 2018). The same relationship is assumed by several studies regarding energy productivity (see, e.g., Bassi & Dias, 2019; Geng et al., 2012; Mavi & Mavi, 2019).

Undesired generated output is measured by pollution and waste. Hence, we used the amount of waste generated per GDP unit, being that a lower level of the variable is considered to reflect a higher level of circularity (see, e.g., Geng et al., 2012; Halkos & Petrou, 2019; Mavi & Mavi, 2019). To address the amount of pollution we resorted to GhG per GDP unit. Likewise, with the variable waste, lower levels indicate higher circularity (see, e.g., Halkos & Petrou, 2019; Jacobi, Haas, Wiedenhofer, & Mayer, 2018; Mavi & Mavi, 2019).

Finally, the reuse of materials is measured by two variables as well. On the one hand, we assess how much of the generated waste is fed-back into the economic system as secondary materials, including the recycling rate of municipal waste, which has been extensively used to measure the CE (see, e.g., Geng et al., 2012; Halkos & Petrou, 2019; Mavi & Mavi, 2019) with a higher recycling rate being equated to higher circularity. On the other hand, it also is essential to measure how much of the material input needs are being covered by those secondary materials instead of raw materials. For this, we added the circular material use rate, which a variety of studies consider a critical indicator of circularity (see, e.g., Gusmerotti et al., 2019; Jacobi et al., 2018; Mayer et al., 2018; Tantau et al., 2018) and the European Environment Agency (2016) includes in its list of indicators to measure circularity.

The presented variables were selected based on an extensive literature review and obtained from the Eurostat database. The respective acronym, description and theoretical support of each variable used can be seen in Table 2. Each variable exists for every other year between 2011 and 2017 for each EU-28 country.

Variable	**Description**	**Support**
Waste	Generation of waste excluding major mineral waste per GDP unit.	Geng et al. (2012); Mavi & Mavi (2019); Halkos & Petrou (2019)
Recycling	Recycling rate of municipal waste.	Tantau et al. (2018); Halkos & Petrou (2019); García-Barragán et al. (2019)
Use Rate	Circular material usage in the percentage of total material use.	Tantau et al. (2018); Jacobi et al. (2018); Mayer et al. (2018); Gusmerotti et al. (2019); European Environment Agency (2016)
GhG	This indicator shows trends in human-made emissions of the 'Kyoto basket' of GhG in the percentage of the GDP.	Halkos & Petrou (2019); Mavi & Mavi (2019); Jacobi et al. (2018)
Energy Productivity	GDP, in purchasing power standard (PPS), per unit of gross available energy for a given calendar year, in kg of oil equivalent.	Mavi & Mavi (2019); Bassi & Dias (2019); Geng et al. (2012)
Resource Productivity	GDP, in PPS, generated per unit of domestic material consumption.	Tantau et al. (2018); European Environment Agency (2016); Magnier (2017)

Table 2 - CE variables used in the factor analysis.

3.3. FACTOR ANALYSIS

The data suitability for factor analysis was assessed through the Kaiser–Mayer–Olkin measure, which returned the value of 0.58, above the threshold of 0.5 (Kaiser, 1974). The next step was to decide how many factors we would extract. According to the Kaiser, Pearson and Scree-Plot criteria, the optimal number of factors is two (see Table A.1 in Appendix A). The two factors were subsequentially interpreted using the factors' loadings, shown in table 3. Considering the correlation structure between the six original CE-related variables with the two factors, we labelled them as environmental degradation and resource efficiency.

Environmental degradation comprises the opposite of the designated purpose of a CE. This dimension is defined by indicators which signal a low level of circularity, more specifically, the level of waste generation, energy consumption and pollution, given that the modus operandi of a circular economy should envisage the reduction of material and energy consumption and thus the generation of waste while cutting emissions (European Environment Agency, 2016). Furthermore, being the level of emissions closely related to the level of energy consumption (Mavi & Mavi, 2019), it not only makes sense that energy productivity is more related to environmental degradation than to resource efficiency, but also that the relationship it has with the factor is negative, meaning that environmental degradation results from a low level of energy productivity.

Resource efficiency captures the other aspect of the core idea of the CE as defined in section 2.1, as resource productivity, circular material use rate and recycling rate convey the need of maximizing the economic value of resources. Higher levels of recycling, resource productivity and circular use rate allow to increase resource efficiency by requiring less raw material inputs for the same output in terms of GDP, or, in other words, allowing for higher outputs with the same amount of inputs.

Variables and Variance	Environmental degradation	Resource efficiency
Waste	0.87	-0.13
GhG	0.85	-0.31
Energy Productivity	-0.76	-0.01
Use Rate	0.18	0.94
Resource Productivity	-0.44	0.76
Recycling	-0.25	0.74
Variance (%)	49%	25%
Variance Total	49%	75%

Table 3 - Factor loadings.

4. SPECIFICATION AND ESTIMATION OF THE ECONOMETRIC MODEL

4.1. DATA AND VARIABLES

The explanatory variables of the two CE dimensions found in the factor analysis were gathered from the Eurostat and United Nations Human Development Database and also pertain to years between 2011 to 2017. Thus, as mentioned, two models are estimated; each one has one of the two dimensions (environmental degradation and resource efficiency) as a dependent variable. The independent variables were chosen as the best proxies/measures of the hypotheses developed in subsection 2.3.

Firstly, we included the lagged dependent variable, with a lag of one year, to measure the inter-annual dependence of CE.

To measure investment in circular activities we used the gross investment in tangible goods in the recycling, repair and reuse, rental and leasing sectors, and likewise many studies on economic growth (Barro, 1991; Moral-Benito, 2012) we considered the value as a percentage of GDP. Although we recognize that this variable does not capture all the investment that can contribute to circularity, we believe that it can serve as the best proxy given the available data.

Innovation can be accessed by several variables, such as the number of patents or the ratio of R&D over GDP (Cainelli et al., 2020). Patent data, however, presents several drawbacks. One is that not all inventions and innovations are patented, either due to their nature or the inconveniences of the patenting process. Furthermore, there might be differences among national patent offices that can lead to discrepancies between countries regarding the incentives of pursuing a patent (Archibugi, 1992). Hence, we prefer to use R&D data, specifically total government budget appropriations or outlays on R&D as a percentage of total general government expenditure. This arises from the fact that government subsidies for R&D are more often directed at projects that, despite promising high returns for the general public, present insufficient private returns to be pursued by private investors because of, for example, the dissemination of the outputs to competitors (Jaffe, Newell, & Stavins, 2005).

In order to measure the stock of human capital of each country, we considered the average years of schooling of people aged 25 and older, which is a well-established proxy of human capital (as mentioned in Teixeira & Queirós, 2016).

Lastly, after several variables that are associated with a positive effect on economic growth, we considered the impact growth itself might have on the CE, finding that the impact of growth on the environment, albeit widely explored in literature, remains divisive. On the one hand, like many academics, policymakers and practitioners recognise, the main appeal of the CE is to reconcile economic prosperity and environmental sustainability, which implies that economic growth has a negative impact on circularity. Nevertheless, there is a vast repository of literature supporting that economic growth is a crucial element of human development (Ranis, Stewart, & Ramirez, 2000). In fact, the Environmental Kuznets Curve (EKC), discovered in the 1990s (see, e.g. Grossman & Krueger, 1995) states that rises in GDP per capita increase environmental degradation up to a certain point, after which, those increases motivate a decrease later. In other words, according to the EKC, economic growth worsens environmental degradation until a certain tipping point after which it diminishes it. In this sense, we argue that in a linear system, economic growth has a negative impact on the environment, whereas in a circular system growth has no negative impact and, even further, can have a positive impact on the environment because of the way production and consumption are designed. Hence, we included the growth rate of the real GDP as a control variable.

4.2. Models' specification

In this section, we specify the models that will be used to test the hypotheses defined in section 2.3. As previously stated, we obtained two underlying dimensions to the CE. Hence two econometric models have been specified, model I and model II. Nevertheless, for the sake of credibility, we always considered the same set of covariates in both specifications. Using this method, we will be able to understand in more depth not only if the hypotheses are true but how each variable influences the CE in its various spheres, instead of just capturing the global effect. The general model specification is the following:

$$y_{i,t} = \alpha y_{i,t-1} + \beta_1 growth_{i,t-1} + \beta_2 circ\_invest_{i,t-1} + \beta_3 circ\_invest_{i,t-2} + \beta_4 gov\_rd_{i,t-1} + \beta_5 gov\_rd_{i,t-2} + \beta_6 gov\_rd_{i,t-3} + \beta_7 school\_avg_{i,t-1} + \mu_i + \varepsilon_{i,t}$$

Where for the i-th country observed in period t , $y_{i,t}$ denotes the dependent variable, env_deg_{it} (environmental degradation) for model I and res_ef_{it} (resource efficiency) for model II, $growth_{it}$ is the real GDP growth rate as annual percentual change on the previous year, $circ\_invest_{it}$ is the percentage of GDP spent on gross investment in tangible goods for circular related activities, gov_rd_{it} is the total government budget appropriations or outlays on R&D as a percentage of total general government expenditure and $school\_avg_{it}$ is the average years of schooling. The lag structure is the one deemed appropriate for each variable, being at least of one year in order to allow the detection of the causal relationship between the independent and the dependent variables, in a context of dynamic effects.1

One of our hypotheses is that CE levels are persistent over time. Given this hypothesis, and the panel data structure, consisting of observations for different countries along different years, we will resort to dynamic panel data model estimation. When considering a dynamic panel specification, the lagged value of the explained variable will be correlated with the error terms, and this will result in endogenous regressors (Nickell, 1981), meaning that neither the fixed effect nor random effect panel estimators will be consistent. As a solution, we will use the system generalized method of moments (GMM) estimation method (Blundell & Bond, 1998) which enables us to deal with the endogeneity problem while being less prone to bias and the problem of weak instruments than the GMM estimator of Arellano and Bond (1991) (AB methodology). The AB methodology is able to neutralize the individual fixed effects by resorting to the first differences of the original model. In a nutshell, the levels of the lagged variables are used as instrumental variables which are needed to derive the moment conditions (orthogonality conditions). What distinguishes the system-GMM from the AB methodology is that a system of equations is considered to explore more moment conditions: a level equation (with lagged

[1] The lag structure for $circ\_invest_{it}$ and gov_rd_{it} is based on our conviction that both need a longer time span until results are obtained. The latter, gov_rd_{it}, is potentially the slowest given that R&D projects are usually time consuming (Mansfield, Rapoport, Schnee, Wagner, & Hamburger, 1971; Wang & Hagedoorn, 2014). Investments in fixed capital might need more than one period to produce outcomes, depending on the size and complexity of the needed capital goods. For example, the construction of a new recycling plant might require over a year to be finished.

differences as instruments) is considered in addition to the differences equation (with lagged levels as instruments).

The estimation of the model can be done in one or two steps, depending on the choice of the weighting matrix (see, e.g. Baltagi, 2008). Due to our data span, a robust first step GMM estimator was considered to be adequate. Another option is whether to use fixed effects. We opt to use time fixed effects as considered relevant.

In order for the system-GMM estimation to be consistent, the disturbance term should have no autocorrelation. For lagged endogenous variables as well as weak exogenous variables to be valid as instruments, the transient disturbances in the base model should be non-serial correlated (Arellano & Bond, 1991). Hence, the differenced disturbances evolve following an AR(1) process and, by construction, exhibit first-order serial correlation. However, if the disturbances do not present second-order serial correlation, then no serial correlation exists in the original equation (Blundell & Bond, 1998). This conjecture can be tested with the Arellano–Bond test for second-order (AR(2)) serial correlation in the first-differenced residuals (Arellano & Bond, 1991).

The validity of the overidentifying moment conditions can be directly tested by Sargan test, given that we considered the optimal (robust) first step GMM. Since the null hypothesis is that additional instruments are jointly uncorrelated with the error term, if rejected, the instruments are not valid.

4.3. RESULTS

The objective of the previously defined model is to determine if the CE presents an inter-annual dependence and whether investment (measured by the gross investment in tangible goods in CE related activities, as a percentage of GDP), innovation (measured by the total government budget appropriations or outlays on R&D as a percentage of total general government expenditure) and human capital (measured by the average years of schooling of adults) have a positive or negative impact on each of the CE dimensions, allowing us to accept or reject our initial hypotheses. Furthermore, we included economic growth (measured by the annual percentual variation of the GDP) as a control variable, which the literature associates with a negative impact for the environment in the current predominantly linear system.

Variable	Lag	Environmental degradation		Resource efficiency	
env_deg	1	0.94	(0.07)		(0.01)
growth	1	0.03***	(0.01)	0.01	(1.17)
circ_invest	1	0.59	(0.88)	1.93*	(0.97)
circ_invest	2	-1.17**	(0.60)	-0.60	(0.17)
gov_rd	1	-0.08	(0.10)	-0.08	(0.13)
gov_rd	2	-0.13**	(0.05)	-0.08	(0.12)
gov_rd	3	0.07	(0.05)	-0.01	(0.01)
school_avg	1	0.01	(0.02)	0.01	(0.08)
res_ef	1			0.99***	(0.01)
Number of observations		127		127	
Number of instruments[2]		21		21	
AR(2) p-value		0.56		0.84	
Sargan p-value		0.52		0.52	

Note: Standard deviations in parentheses; ***, **, and * denote statistical significance at the 1%, 5%, a nd 10% level.

Table 4 - Dynamic panel data estimation of the relationship between the CE, investment, innovation and human capital (dependent variable of model I is environmental degradation and of model II is resource efficiency).

The dynamic panel data estimation for coefficients of each variable for both models can be seen in Table 4. We fail to reject the null hypothesis for the AR(2) for both models, so no serial correlation is detected. The Sargan test for the validity of the over-identifying moment conditions suggests the appositeness of instruments – we fail to reject their exogeneity for both models. Given these results, we can assert that we have no evidence of misspecification, namely as far as inconsistency problems due to weak instrumentation.

It is relevant now to make some comments on the model estimates. Firstly, one should note that economic growth has a positive impact on environmental degradation, and thus a negative impact on the level of circularity. In other words, an increase in economic output leads to a worsening of the environmental degradation level which is precisely the problem of the linear economy that the CE tries to tackle (Lieder & Rashid, 2016), evidencing that the current paradigm is still predominantly linear and the need for a transition towards a more sustainable approach (Merli et al., 2018).

Investment in the circular activities is the single most important variable for the CE since it is significant in both models ($p<0.1$), having a considerable effect in terms of mitigating environmental

[2] These results are obtained with a collapsed instrument matrix as in Roodman (2009).

degradation and an even higher impact in improving resource efficiency, thus having an overall positive impact on CE, confirming our first hypothesis. These results show that higher investment in the CE is likely to yield returns not only by maximizing the value of resources but also by mitigating the negative environmental impacts of economic activity. It is interesting to note that the impact on the environment takes longer to be felt (two years instead of just one, as is the case of resource efficiency). This aspect makes sense because an increase in resource efficiency might mitigate environmental degradation in the future. For example, increasing recycling rates and the material use rate can lead to a reduction in the need for energy use to produce goods as well as a reduction in GhG emissions that are linked to the disposal or transportation of certain materials (see, e.g., Yousef et al., 2020; Zhang et al., 2018).

The lagged dependent variable is significant in both models ($p<0.001$), confirming the inter-annual dependence of the CE. Moreover, the time persistence is strong, being the coefficient in both models positive and high. This dimension means that the impact of the independent variables will linger over a long time period and that the CE levels are expected to have a relatively steady development.

Government expenditure on R&D has a positive effect in terms of mitigating environmental degradation ($p<0.05$), but only after a time span of two years, while not affecting resource efficiency, having a positive impact on the overall circularity levels which confirms the second hypothesis. This result is in line with the notion that innovation is an important enabler of the CE (see, e.g., de Jesus et al., 2019; European Commission, 2015; Konietzko, Bocken, & Hultink, 2020; Prieto-Sandoval et al., 2018).

Surprisingly, human capital does not have any significant impact on environmental degradation nor resource efficiency. Hence, the third hypothesis is not confirmed. This finding goes against the idea of previous studies that find a positive link between human capital and circular practices (see, e.g., Ulucak & Bilgili, 2018; Yao et al., 2019). One possible explanation for a higher skill level of the labour force not being translated into higher circularity is that education level requirements of the CE are very heterogenous and actually do not differ much from the rest of the economy (Burger et al., 2019) which is still predominantly linear. Thus, the increase in human capital will not necessarily go into the circular sector and hence might be absorbed mainly by non-circular activities. In addition to that, the association between higher education levels and a stronger environmental consciousness is controversial, with some studies like the one of Zsóka, Szerényi, Széchy, & Kocsis (2013) pointing to a positive relationship and other like the one of Sánchez-Llorens, Agulló-Torres, Del Campo-Gomis & Martinez-Poveda (2019) pointing to a negative one.

5. CONCLUSIONS

5.1. MAIN CONTRIBUTIONS

For the CE to be a step towards a sustainable future and not fade like a fad, its objectives must be clearly defined, its mechanisms understood, and its progress measured. In this sense, our study contributes to the existing scientific literature in three ways.

First, we propose a new comprehensive definition of CE, derived from the existing practices and ideas about the concept. Our definition is useful in that it describes the concept in a way that presents its distinctive traits with enough detail without being too exhaustive.

Second, we present a framework for measuring the CE at the macro-level, that allows distinguishing between its two key areas, one related to the preservation of the environment (environmental degradation) and the other to the efficient use of resources (resource efficiency). This method provides deeper insights into the performance of countries regarding the CE than a single indicator or index could.

Third, this work highlights the importance of investment and innovation for the CE as well as its inter-annual dependence. For this, we built two econometric models, based on the obtained environmental degradation and resource efficiency values for each country and resorting to a dataset covering the EU-28 over the years from 2011 to 2017. One key finding is the pronounced relevance of investment for circularity, not only increasing resource efficiency but also, contributing to mitigating environmental degradation, thus having a considerably strong overall positive impact on the CE level. Innovation, measured by government expenditure in R&D, does not affect resource efficiency. Nevertheless, it has a positive effect on circularity by lessening environmental degradation. An additional, somehow surprising, result is the irrelevance of human capital, measured by the average years of schooling of adults, to both CE dimensions. Several studies have pointed to the positive relationship between the level of education and environmental consciousness as well as general efficiency in production, which our study failed to support. However, the skills demanded by the CE do not translate solely into educational attainments, there is a need for specific skills and on the job training, as pointed out by Burger et al. (2019). Furthermore, in order to increase environmental consciousness, a directed focus on educating about environmental issues could be required, which several studies have pointed as an important action to promote circularity (Zsóka et al., 2013).

5.2. POLICY IMPLICATIONS

Our results have important policy implications. Inter-annual dependence of the CE will cause the benefits of promoting it to hold over time, which means that policy efforts can have an important role in providing a sound foundation for the transition to a sustainable system. To do so, governments can promote CE practices, for example, by easing funding assess to support SMEs, which are particularly active in fields such as recycling, repair and innovation (European Commission, 2015). Several government agencies in EU member states have already developed programs to promote investment into circular activities, for instance, in 2017 the Czech Ministry of Industry and Trade launched the Turning Waste into Resources award, open to projects that search for a novel use of secondary raw materials (OECD, 2019). European funding has already had great importance in the advancement of circularity, namely the support for circular economy projects through the European Investment Bank which has been giving assess to financial tools for research and innovation projects under the InnovFin programme, such as the loans given to Heliatek, to produce an innovative solar energy-producing film, and Gorenje, for R&D activities to produce environmentally friendly domestic appliances (European Investment Bank, 2015). Ergo, policymakers can significantly promote the CE, in particular, the environmental sustainability aspect, as evidenced by our study, by further supporting R&D and investment into circular activities. In addition, circular investment should assume a central position in their circularization strategy since it has a considerable impact on both, mitigating environmental degradation and improving resource efficiency. Additionally, as de Jesus & Mendonça (2018) point out, providing adequate education and training could play an important role in terms of environmental awareness and skill base for the CE. However, for this, our empirical analysis suggests that a general increase in average school years is not enough.

5.3. LIMITATIONS AND PATHS FOR FUTURE RESEARCH

Our study has two main limitations. One is that we were unable to establish a relationship between human capital and the CE. The proxy we used to measure human capital, average years of schooling, could lack important information as it omits skills gained through non-formal education such as on the job training which is important for several CE activities (Burger et al., 2019) and the quality of schooling. Hence, we find that future research that aims to study the relationship between human capital and the CE should include measures that assess the specific CE-skills of the workforce and the level of environmental education. Lastly, the second CE dimension, resource efficiency, was not well explained by the model. This element could derive from the fact that we consider a relatively small timespan. Regardless, finding resource efficiency drivers in order to inform policymakers figures as an interesting and important research direction.

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7. APPENDIX

Factor	Eigenvalue	Difference	Proportion	Cumulative
1	2.95	1.43	0.49	0.49
2	1.52	0.83	0.25	0.75
3	0.69	0.17	0.11	0.86
4	0.52	0.33	0.09	0.95
5	0.19	0.06	0.03	0.98
6	0.13		0.02	1.00

Table 5 - Eigenvalues of the correlation matrix.