The Cycle of recycling and sustainable development. Evidence from the OECD Countries

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THE CYCLE OF RECYCLING AND SUSTAINABLE DEVELOPMENT. EVIDENCE FROM THE OECD COUNTRIES

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Abstract

The aim of this study is to analyse the circular linkages between recycling and economic development, where renewable energy plays an additional role in this process. We use a two-equation model, which describes a cumulative causation process with feedback effects, where recycling (among other growth inducing factors) is assumed to be important for sustainable economic development (given by the Human Development Index) and vice-versa. The system of simultaneous equations is estimated by *3sls*, both in a static form and introducing dynamics into the model, for a panel of 28 OECD countries over the period 2004-2015. The empirical evidence suggests a strong relationship between the economic development level and the recycling rate with feedback effects, supporting the idea of a circular cumulative causation process driven mostly by higher human capital skills and, to a lesser extent, by innovation. Atmospheric pollution also stimulates the recycling process.

Jel code: C51, F43, O44, Q56

Keywords: recycling, economic development, simultaneous equation system, panel data.

1 INTRODUCTION

Recycling plays an important role in modern societies from the point of view of sustainable economic development and environmental protection. Recycling the already used materials is one of the pillars of the modern economy to preserve the environment and increase the quality of standards of living worldwide (EU Commission, 2018; Grosse, 2010). However, to the best of our knowledge, there are almost no empirical studies that measure the impact of the recycling rates on economic development. The recycling determinants have also not been modelled in the empirical literature (Kalmykova, et al., 2018; Geissdoerfer, et al., 2017). The aim of this paper is to fill this gap in the literature, employing a model that describes the circular linkages between recycling and economic development (given by the Human Development Index, HDI henceforth).

Two main relations are used to describe such a process: the first, is an economic relationship representing the sustainable development levels which, along with the standard determinants like physical capital, human capital and innovation, includes the recycling rate and the renewable energy share as important factors for improving the countries' standards of living[1]; the second relation explains the main determinants of the recycling rate, which is mostly driven by human capital skills and innovation, depending also on the level of economic development and atmospheric pollution. The rationale behind these relations is that economically advanced countries realize that recycling is required for generating sustainable development. To this end, countries allocate resources to develop methods that reutilize the production means previously used in consumption goods, with the aim of reducing environmental degradation. Recycling is a new productive area with high technological content and labour skills, which will generate higher economic growth and development without harming the environment. A political wisdom is therefore needed to realize that recycling is

[1] For more details on the impacts of renewable energies on the development level, see Soukiazis et al. (2017).

among the key pillars for a sustainable economic development, strengthening the growth process, promoting innovation and higher labour skills through new production techniques.

In this paper, we employ a different approach to tackle the shortcomings in the literature: (i) we assume recycling as an important factor for higher economic development and environment protection; (ii) we implement a system of simultaneous equations which describes the important feedback linkages between economic development and recycling rate driven by innovation and higher labour skills; (iii) the important linkages between these variables are driven by the reciprocal correlation between the core variables of the system, which generates expanding and sustainable tendencies without environmental deterioration.

The outline of the paper is the following: besides the introduction, section 2 develops the structural model with the main behavioural relations that describe the circular process between recycling and economic development. Section 3 describes the variables and data used in the empirical approach, as well as statistical tendencies. Section 4 discusses the results obtained from the *3sls* estimation of the model. The final section concludes with policy recommendations

2 THE STRUCTURAL MODEL

The structural model employed in this paper consists of two main behavioural equations, which explain the important linkages between economic development and recycling rate. The first equation determines the factors that explain the development level, given by the Human Development Index (HDI), as follows:

$$HDI_{it} = \alpha_i + \alpha_1 GK_{it} + \alpha_2 HK_{it} + \alpha_3 R\&D_{it} + \alpha_4 RCR_{it} + \alpha_5 RNE_{it} + \alpha_6 POP_{it} + \varepsilon_{1,it} \qquad \text{Eq. (1)}$$

As in the conventional growth approach, capital (GK) is included as a factor to explain the country´s development path. This variable measures the growth of gross fixed capital formation which is expected to positively affect the development level (α_1>0). Additionally, and in line with the endogenous growth theory (e.g. Lucas, 1988; Barro, 2001), human capital (HK) and innovation (R&D) are important determinants, influencing positively economic growth and development, expecting therefore α_2, α_3>0. Furthermore, it is of particular interest to measure the impact of recycling rate (RCR) and renewable energy consumption (RNE) on the development level, expecting a positive and statistically significant effect in both cases (α_4, α_5>0). The growth of population (POP) is also used in the economic development function as a scale factor to check its significance. The constant term (α_i) captures country specific effects, which are invariant in time, such as the country size, natural resources, geographical location, and institutions, among others. All variables represent shares (percentages) except the capital and population which are in growth rates for the sake of normalization.

The second equation of the system explains the determinants of recycling rate, as follows:

$$RCR_{it} = \beta_i + \beta_1 HDI_{it} + \beta_2 R\&D_{it} + \beta_3 HK_{it} + \beta_4 POP_{it} + \beta_5 \ln CO2_{it} + \varepsilon_{2,it} \quad \text{Eq. (2)}$$

Equation (2) considers that the recycling rate is determined by the development level (HDI), stressing that advanced countries allocate more resources to the recycling process with the aim to reduce waste, reutilize production sources and prevent environmental degradation, expecting therefore β_1>0. Spending on research and development (R&D) is a required condition for developing new production processes linked to recycling resources and new production areas environment-friendly and, at the same time, reducing costs due to reutilization of previously used production sources. The relationship between recycling and R&D spending is thus expected to be positive (β_2>0). In addition to innovation, skilled labour is necessary to promote the recycling process, expecting that higher levels of human capital are required to be involved in these new productive areas. Furthermore, populations with higher levels of human capital better understand the importance of recycling to preserve the environment, expecting therefore β_3>0. Population growth (POP) is also used in this equation as a scale factor. Finally, CO2 emissions per capita are used to check its impact on the recycling rate. It is expected that the higher the atmospheric pollution, the higher the use of the recycling process to reduce environmental degradation and, therefore, β_5>0. The intercept β_i varies across countries capturing differences which are invariant in time.

Combining equations (1) and (2) a circular approach is established between economic development (HDI) and recycling rate (RCR) with feedback effects that will generate a production process with cumulative causation properties. Human capital skills and innovation are at the heart of this circular process. From equation (2), a moment will come that policy makers will realize that sustainable development will be reached through new growth policies environment friendly, and that recycling is one of the ways to achieve this goal. Innovation and skilled labour are necessary conditions to promote the recycling productive areas. These new sectors of production, in turn, promote higher economic growth and sustainable development (through Eq. 1).

The above two equations will be estimated by *3sls*, the most efficient estimation approach that controls for the endogeneity of regressors and takes into consideration the cross-equation error correlation.

3 VARIABLES AND DATA DESCRIPTION

Table 1 reports the variables used in the empirical analysis, and elementary descriptive statistics. The HDI index (from 0 to 1) is multiplied by 100 for the sake of data normalization. The mean value is 85.6, with 77.1 the minimum value (Romania) and 91.3 the maximum (Netherlands). RCR is the recycling rate of municipal waste with a mean value of 28.4%, varying between 7% and 63%, the lowest rate found in Malta and the highest in Germany. RNE represents the share of renewable energy in gross final energy consumption with a mean value of 15.5%, ranging from 0.1% (Malta) to 53.8% (Sweden). We use two proxies for human capital: the first HK1 is measured by the average years of schooling, representing the basic human capital skills; the second HK2 is the percentage of population with college degree, representing high human capital skills. GK indicates the growth of gross fixed capital formation, R&D is the spending on innovation activities as percentage of GDP, POP is the growth of population, and CO2 stands for the greenhouse gas emissions in the atmosphere measured in tons per capita. R&D is the variable where differences between countries are larger, with a mean value of 1.5%, the lower value found in Romania (0.3%) and the highest in Finland (3.8%). Regarding the remaining variables, differences across countries are not substantial.

Table 1. Descriptive statistics of variables, 2004 - 2015

Variable		Mean	Std. Dev.	Min	Max	Observations	
HDI	overall	85.58065	4.108007	74.5	92.6	N =	336
Human Development	between		3.961486	77.13333	91.25833	n =	28
Index	within		1.302939	81.54732	88.68065	T =	12
RCR	overall	28.37848	17.25247	0.4	66.7	N =	330
Recycling Rate	between		16.57149	7.05	63.21818	n =	28
of municipal waste	within		5.918405	14.03682	54.17848	T =	12
RNE	overall	15.50774	11.19575	0.1	53.8	N =	336
Renewable energy	between		10.9709	1.666667	47.09167	n =	28
share	within		2.989375	7.116072	24.5994	T =	12
HK1	overall	11.19792	1.222657	7	13.3	N =	336
Human Capital	between		1.168417	7.841667	12.83333	n =	28
(average years of schooling)	within		0.417756	10.12292	12.82292	T =	12
HK2	overall	22.8	7.336895	8.7	39.6	N =	336
Human Capital	between		6.775958	11.70833	31.96667	n =	28
(percentage of tertiary education)	within		3.069859	14.44167	33.54166	T =	12
GK	overall	0.013863	0.110062	-0.49176	0.460342	N =	336
	between		0.028594	-0.07072	0.060818	n =	28
Growth of gross fixed capital formation	within		0.106408	-0.51682	0.421922	T =	12
R&D	overall	1.480506	0.876414	0.34	3.75	N =	336
Research and Development	between		0.867114	0.428333	3.398333	n =	28
Spending as percentage of GDP	within		0.202245	0.889673	2.349673	T =	12
POP	overall	0.0024554	0.008492	-0.024992	0.030071	N =	336
	between		0.007329	-0.013486	0.019194	n =	28
Population growth	within		0.004491	-0.022355	0.020055	T =	12
lnCO2	overall	2.283861	0.345687	1.609438	3.424263	N =	336
Greenhouse gas emissions	between		0.337373	1.719731	3.257099	n =	28
(tons per capita)	within		0.097039	1.976391	2.488182	T =	12

4 EMPIRICAL FINDINGS

The system of simultaneous equations is estimated by *3sls* approach, both in a static form and introducing dynamics into the model, for a panel of 28 OECD countries over the period 2004-2015, where consistent data is available[2]. Table 2 reports the estimation results, with the HDI equation in the first half and the recycling rate equation in the second half of the table. Model (1) is the static estimation and models (2) to (5) represent different versions of the dynamic specification assuming two-lag order for the dependent variables. Overall, the results are satisfactory in terms of the goodness of fit and the statistical significance of coefficients. Additionally, the Hausman test indicates that the *3sls* estimation approach is as much as consistent with the *2sls* approach, but we give preference to the *3sls* as being more efficient. The static model indicates error autocorrelation problems which are solved by estimating the dynamic versions with lagged dependent variables of order two.

Concerning the first equation, evidence shows that both the recycling rate and renewable energy have a positive and statistically significant impact on the countries' development level.

[2] Since data on renewable energy starts only at 2004, we are restricted to consider a shorter period. For RCR and HDI, we used the values of 2002 and 2003 in order not to lose observations.

This result suggests that allocating resources to new productive areas environment friendly is the right policy to improve the standards of living without environmental distortions. Specifically, if we consider Model (5), where all variables are statistically significant, the results show that a one percentage point increase in the recycling rate (everything else constant) is responsible for 0.00935 point increase in the development level in the short run, and 0.033 point increase in the long-run perspective. The renewable energy variable is statistically significant at the highest 1% level in all dynamic specifications, revealing that in the short run a one percentage point increase in this variable (everything else constant) generates a 0.0336 point increase in the development level, while the long run effect is even higher suggesting a 0.1195 point increase in HDI. The highest marginal impact on the development level is attributed to the growth of capital stock (GK), followed by the contribution of human capital through the basic levels of education (HK1) and the spending on innovation (R&D), as expected. Population growth and higher human capital skills through the tertiary education are not relevant factors in explaining the levels of sustainable development. Regarding the second equation of the system, which analyses the determinants of the recycling rate of waste, evidence is also encouraging. The development level given by the HDI is always statistically significant, both in the static and dynamic specifications. Considering the results of Model (5), where all variables are statistically relevant, we predict that a one-point increase in the development level will generate 0.603 percentage point increase in the recycling rate in the short run and 3.29 percentage points increase in the long run.

Combining the evidence of the two equations of the system, a strong reciprocal relation is established between the development levels and the recycling rate with feedback effects, generating a cumulative causation process with expanding tendencies that benefits sustainable economic development. Additionally, it is shown that higher atmospheric pollution through the CO_2 emissions is a stimulus for developing recycling productive processes. Results reveal that the short run impact on the recycling rate is 0.06 percentage point increase given a 1% increase in the CO_2 emissions per capita, while the long run impact is even higher and equivalent to 0.332 point increase. Although human capital at higher level is important to

Table 2. Regression results using 3sls estimation approach, 28 OECD countries, 2004-2015.

Variables	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
			Equation (1) HDI		
RCR	0.231**	0.00737	0.00809*	0.00808*	0.00935**
	(2.52)	(1.52)	(1.81)	(1.65)	(2.07)
GK	-0.0295	0.916***	0.930***	0.866***	0.878***
	(-0.32)	(6.07)	(6.13)	(5.64)	(5.72)
HK1	1.358***	0.456***	0.445***	0.440***	0.431***
	(6.72)	(7.52)	(7.54)	(7.17)	(7.29)
HK2	-0.107	0.00550		0.00798	
	(-1.19)	(0.57)		(0.81)	
R&D	0.330	0.259***	0.246**	0.260***	0.242**
	(0.74)	(2.61)	(2.52)	(2.59)	(2.50)
POP	11.13	3.457		2.866	
	(0.85)	(0.98)		(0.81)	
RNE	0.0230	0.0309***	0.0317***	0.0317***	0.0336***
	(0.46)	(3.20)	(3.38)	(3.25)	(3.59)
HDI_{-1}		0.710***	0.720***	0.788***	0.799***
		(27.39)	(28.92)	(15.78)	(16.32)
HDI_{-2}				-0.0799*	-0.0801*
				(-1.84)	(-1.88)
cons	66.44***	19.34***	18.78***	19.58***	18.96***
	(26.49)	(10.22)	(10.24)	(10.32)	(10.38)
R^2 overall	0.9324	0.9951	0.9950	0.9950	0.9951
RMSE	1.05278	0.2832	0.2840	0.2832	0.2831
Chi^2	4825.16 [0.000]	65989.01 [0.000]	65557.28 [0.000]	64775.02 [0.000]	65989.70 [0.000]
Hausman test	0.0147 [1.000]	0.5337 [1.000]	1.0454 [1.000]	0.5520 [1.000]	1.1185 [1.000]
AR test	43.815 [0.000]				
			Equation (2) RCR		
HDI	3.722***	0.944***	0.608***	0.948***	0.603***
	(3.76)	(2.95)	(2.80)	(2.96)	(2.79)
HK1	-5.055***	-0.992		-1.019	
	(-2.99)	(-1.39)		(-1.43)	
HK2	0.537**	0.184*	0.211**	0.177*	0.218**
	(2.57)	(1.85)	(2.18)	(1.75)	(2.26)
R&D	-0.900	-0.324		-0.275	
	(-0.45)	(-0.33)		(-0.27)	
POP	-45.70	-26.94		-25.32	
	(-0.80)	(-0.76)		(-0.71)	
lnCO2	1.577	5.385**	5.952***	5.678**	6.075***
	(0.41)	(2.28)	(2.70)	(2.37)	(2.76)
RCR_{-1}		0.812***	0.818***	0.778***	0.817***
		(20.65)	(21.19)	(13.34)	(21.17)
RCR_{-2}				0.0426	
				(0.70)	
cons	-251.0***	-80.86***	-66.63***	-81.72***	-66.64***
	(-3.95)	(-3.62)	(-3.40)	(-3.66)	(-3.41)
R^2 overall	0.9330	0.9734	0.9734	0.9730	0.9734
RMSE	4.4579	2.7948	2.793	2.7989	2.7936
Chi^2	4627.55 [0.000]	11992.68 [0.000]	12000.87 [0.000]	11699.53 [0.000]	12001.29 [0.000]
Hausman test	0.000 [0.000]	3.2183 [1.000]	3.0895 [1.000]	3.5625 [1.000]	3.6153 [1.000]
AR test	75.914 [0.000]				
N	330	327	327	324	327

Endogenous variables: HDI and RCR.
Exogenous variables: GK, HK1, HK2, R&D, POP, RNE, lnCO2, the lagged variables and all dummies used in the regressions.
Notes: numbers in parentheses are z-ratios and numbers in square brackets are p-values P>|z|. Chi2 is the statistic for overall significance of coefficients. The coefficients of the specific-country dummy variables are not reported due to space limitations. The null hypothesis in the Hausman test assumes that *2sls* and *3sls* are both consistent but *3sls* is more efficient. The AR test uses the Wooldridge statistic for idiosyncratic error autocorrelation in panel data (see Wooldridge, 2002; Drukker, 2003).
***, **, * indicate that coefficients are statistically significant at the 1%, 5% and 10% significance level, respectively.

promote the recycling process, the spending on R&D reveals to be unimportant. Higher levels of skilled labour are needed to develop recycling productive processes. Furthermore, a more educated population better understands the need to recycling for the sake of the environment protection. Population growth again is not important for explaining the recycling rate for the OECD countries considered in this study.

5 CONCLUSIONS

This paper deals with the important relationship between recycling rates and economic development using a set of 28 OECD countries for the period 2004-2015. The study aims to fill the gap of the literature in this field that has not analyzed yet this relationship empirically. A simultaneous system of two equations is estimated by using the *3sls* approach to detect the strong linkages between the development levels and recycling, explained by a circular cumulative causation process. The regression results confirm robustly this relationship driven by human capital skills and, to a less extend, by innovation. Atmospheric pollution also contributes to better understand the need for adopting recycling policies.

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