How recycling affects sustainable growth

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Abstract

This paper quantifies the effect of waste recycling on GDP in OECD countries from 2000 to 2012. We focus on national levels and use external instruments to control for the endogeneity between GDP and waste recycling. Specifically, we examine the influence of labour, material flow and research and development (R&D) as drivers of this relationship. While R&D is often seen as key factor for a sustainable development, labour and material trades are of a higher importance for sustaining growth through recycling. Empirical results show a positive and statistically significant effect of waste recycling on the economy. An increase of 1% of the recycled waste raises GDP by up to 0.06%. Waste management, if well planned, can be a catalyst for a stagnating economy. Furthermore, our results show that the benefits of waste recycling are given rise through labour and resource flow channels. Governments are encouraged to initiate recycling investment accordingly, as such initiatives will not only improve the environment but also generate positive social welfare and pushes the transition to a circular economy.

Keywords: waste recycle; circular economy; sustainable development; resource.

1. Introduction

Human activities generate waste, which increases mainly due to urbanization, population and industrialization (Andersen et al., 2007). The dominant part of waste generated, Municipal Solid Waste (MSW)[1], accounts for 5% of global greenhouse gas emissions (IPCC, 2014, 2007, 2006). In 2016, MSW was 2 billion tonnes and it is expected to rise to 2.2 billion tonnes by 2025, according to the World Bank (Kaza et al., 2018). One possible method for reversing this trend is through the implementation of a circular economy, where recycling is a major component. As confirmed by Lacy and Rutqvist (2016) and Mavropoulos (2010), efficient waste recycling could provide business opportunities and therefore increase Gross Domestic Product (GDP). In this paper, we study how waste[2] recycling affects economic performance in developed economies.

Our study focuses on the OECD countries because developing countries have less mature waste management policies and recycling systems, which makes them difficult to study. Although waste recycling has drawn attention in many developed economies since the 1980s, it is only recently that governments have imposed regulations for waste management. The European Union (EU) offers a circular economy package to sustain growth (European Commission, 2010, 2015; FREC, 2018), and invested over €5.5 billion from 2004 to 2020 in waste management in order to increase annual waste recycling capacity by 5.8 million tonnes (Ten Brink et al., 2018). In Japan, a law was put into effect in 2001 to promote the efficient utilization of resources. Its recycling industry contributes 7% to Japan’s GDP and employs 0.65 million workers (METI, 2001). The economic effects of waste recycling strategies, which are of importance to developed economies having implemented such policies, have

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[1] MSW accounts for all waste generated by the public. It agglomerates all domestic, streets and parks and gardens (green) waste. Business, office, institution and commercial waste similar – in term of kind and amount - to those produced by households are also assimilated to MSW.

[2] Waste hereafter in the paper refers to municipal solid waste.

rarely been investigated empirically. This paper addresses this gap by evaluating the economic benefits of recycling initiatives.

The economic literature on waste recycling mainly focuses on the production and management of the recycling industry. In the 1970s, studies mainly constructed economic models to understand the dynamics of waste accumulation and resource recycling (Smith, 1972; Schulze, 1974; Hoel, 1978; Slade, 1980), while recent studies have focused on the related policy intervention for better waste management (Sidique et al., 2010; Jenkins et al., 2003; Shinkuma, 2003; Hamilton, 2003, Kinnaman and Fullerton, 2000). Another string of the literature has tried to identify possible drivers of waste and recycling industries. Economic development increases waste generation at the macro level (Ciacci et al., 2017; Johnstone and Labonne, 2004), and household income has a positive and significant effect on waste recycling at the micro level (Jenkins et al., 2003; Sidique et al., 2010). There is a recent and growing literature on the role of household behaviours with regard to recycling (Alpízar and Gsottbauer, 2015; Abbott et al., 2017; Gilli et al., 2018). Limited research has investigated the effects of waste recycling on the environment. Waste recycling can decrease greenhouse gas emissions, and thus strengthen atmospheric quality (Acuff and Kaffine, 2013). However, there is no strong evidence of the Environmental Kuznets Curve theory on waste management (Mazzanti and Zoboli, 2009).

Although it is intuitive that waste recycling helps to save resources, empirical support for sustaining economic development by recycling has not been addressed in the literature. This paper fills this gap by quantifying the effect of waste recycling on the economic performance of developed economies. We use external instruments and apply panel econometric approach, based on data of 20 OECD countries over 13 years (2000-2012). Our results show that an increase of 1% of the recycled waste leads to an increase in GDP by up to 0.06% percent, implying that waste management, if well planned, can be a catalyst for a stagnating economy.

We further identify the underlying mechanisms that reinforce the benefits of waste recycling. While R&D is expected to be a driver, empirical results show that labour and material flow are the two main channels. The recycling industry is identified as labour-intensive: higher labour supply to the recycling sector enhances productivity (e.g. the quality of the recycled material) and leads to higher economic output at country level (D'Amato et al., 2016; Kinnaman et al., 2014). Our findings support the need for resource recovery policies and training programmes dedicated to workers in the recycling sector. Our results are robust to a rich set of sensitivity checks addressing alternative waste and raw material indicators, reverse causality, endogeneity and geopolitical considerations.

This paper contributes to the literature in a number of aspects. Firstly, the existing literature linking waste management and growth focuses on the microeconomic aspects of recycling (Mazzanti and Zoboli, 2008, 2009). Information on the macroeconomic effects of waste recycling practices is generally missing. This paper is the first to empirically estimate the impact of waste recycling on economic outputs for developed countries. In addition, we explore new mechanism through which the positive effects of waste recycling on economic output can be enforced. The new perspective highlights the need for engaging labour force into the recycling industry rather than deploying investment in R&D.

Secondly, our paper complements the literature on economic growth. Traditional growth models (Romer, 1990; Aghion and Howitt, 1992; Helpman, 1992; Barro, 1996; Bretschger et al., 2017) have highlighted that population growth, R&D and knowledge diffusion are the driving forces for sustainable growth. Di Vita (2001), Pittel et al. (2010), and Fagnart and Germain (2011) confirm, from the theoretical perspective, recycling as another driver for growth. On the one hand, our results support this argument. On the other hand, our results show no evidence of R&D as underlying mechanism but highlight labour and material as main drivers to sustain development through recycling.

Thirdly, this study addresses the co-benefit analysis of environmental policies. Environmental economists are concerned about the degradation of natural resources and ecosystems and about the impacts of climate change. However, the policies to mitigate the environmental impacts are highly costly and often represent a significant proportion of government budgets (Almer and Winkler, 2017; Burtraw et al., 2014). Managing waste through recycling should be an effective way to reduce the cost of environmental policies, as effective waste recycling lowers greenhouse gas emissions and prevents environmental degradation due to excess resource extraction and consumption (Hamilton et al., 2013; Acuff and Kaffine, 2013). Recycling can therefore be considered a global and competitive strategy for climate change mitigation.

The remainder of the paper is organized as follows. Section 2 introduces our empirical model and explains our econometric strategy. It also details the choice of our instruments and their validity. Section 3 describes the data and provides descriptive statistics, and Section 4 presents our main results. Section 5 provides a series of robustness checks by using alternative measures and different estimators. Section 6 identifies different mechanisms driving the relationship between recycling and economic outcomes. Section 7 concludes the paper and highlights potential policy implications.

2. Empirical model and econometric method

2.1. The empirical model

The model is developed following the theoretical literature on growth and recycling in developed countries. We consider a standard empirical growth model of economy-wide production with technological change (DiVita, 2001; Pittel et al., 2010, Fagnart and Germain, 2011). In our model, the aggregate output Y is produced by using labour (L), physical capital (K), human capital (H), resource flows (or material input) (M), the technology level (A) and the amount of recycled waste (W) as production inputs. Consistent with the empirical literature on cross-country growth models (Kormendi and Meguire, 1985; Acemoglu et al., 2001), with all of the variables being transformed into a log-linear specification, the model takes a simple form reflecting the relationships as follows:

$$\ln\left(Y_{i,t}\right) = \beta_W \ln\left(W_{i,t}\right) + \beta_i \boldsymbol{\mathcal{X}_{i,t}} + \varepsilon_{i,t}\ ,\#(1)$$

where $W_{i,t}$ is the measure of waste recycling, β_W is the coefficient of interest, $\boldsymbol{\mathcal{X}_{i,t}}$ is a vector of other covariates[3], β_i is the unknown parameters to be estimated, and $\varepsilon_{i,t}$ is the unobserved error term. We expect waste recycling to have a positive impact on the economic outputs. By including all the controls, the model to be estimated reads as follows:

$$ln\left(Y_{i,t}\right) = \beta_W ln\left(W_{i,t}\right) + \beta_1 ln\left(K_{i,t}\right) + \beta_2 ln\left(L_{i,t}\right) + \beta_6 ln\left(H_{i,t}\right) + \beta_5 ln\left(M_{i,t}\right) + \beta_7 ln\left(A_{i,t}\right) \\ + \varepsilon_{2i,t}. \#(2)$$

Following Verdolini and Galeotti (2011), government investment in research and development (R&D) is used as proxy for the provincial specific technological changes (*A*), which could capture technology heterogeneity. The existing theoretical literature on the effect of waste recycling on growth suggests a negative effect of technological change on recycling (Di Vita, 2001). In this sense and to consider a neutral technical change common to all countries, the function for *A* is additionally specified as a linear function of time t and t^2. To further investigate the impact of such a trend on the effect of waste recycling on economic performance, the model is revised as follows:

$$ln\left(Y_{i,t}\right) = \beta_W ln\left(W_{i,t}\right) + \beta_1 ln\left(K_{i,t}\right) + \beta_2 ln\left(L_{i,t}\right) + \beta_6 ln\left(H_{i,t}\right) + \beta_5 ln\left(M_{i,t}\right) + \beta_7 ln\left(A_{i,t}\right) \\ + \beta_3 t + \beta_4 t^2 + \varepsilon_{3i,t}. \#(3)$$

We first apply the fixed effects (FE) estimator to estimate equations (2) and (3).[4] All model specifications include country-fixed effects to capture the effects of within-country changes. The transmission channels are identified and further investigated in section 6.

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[3] The covariates are assumed to be exogenous – see results Table A 1 in the appendix A.

[4] The Hausman test shows that the fixed effects model is preferred to the random effects model, which confirms the homogeneity of the OECD data detailed in Section 3.

2.2. Instrumental variables

Our model may suffer from endogeneity issue due to potential reverse causality. To precisely estimate the impact of waste recycling on the economy, we need to address the endogeneity issues between GDP and waste recycled. We use a two-stage least squares method (2SLS) with external instrumental variables (IVs) as proxy for recycled waste. Therefore, it is necessary to estimate the following equations, where equations (5) and (6) represent the first and second stages of this approach, respectively:

$$\ln\left(W_{i,t}\right) = \alpha_{IV}\ln\left(IV_{i,t}\right) + \alpha_i\boldsymbol{\mathcal{X}}_{\boldsymbol{i,t}} + \nu_{i,t}\#(4)$$

$$\ln\left(W_{i,t}\right) = \alpha_{2_{IV}}\ln\left(IV_{i,t}\right) + \nu_{2_{i,t}}\#(5)$$

$$\ln\left(Y_{i,t}\right) = \beta_{IV}\ln\left(IV_{i,t}\right) + \beta_{2_i}\boldsymbol{\mathcal{X}}_{\boldsymbol{i,t}} + \varepsilon_{IV_{i,t}},\#(6)$$

where *IV* represents the measure used as instrument variable (IV), α_{IV} and $\alpha_{2_{IV}}$ are the coefficients of the *IV* to be estimated, and ν and ν_2 represent the error terms.

Our estimation uses two external IVs for recycled waste (*W)*: environmental policy stringency (EPS) and the number of people connected to a water sewage grid (Water). This identification requires that *IV* is not correlated with the error term. In what follows, we show that this assumption is validated for our instrument choices.

The environmental policy stringency variable refers to the Environmental Policy Stringency Index, which is a country-specific and internationally comparable measure of the stringency of the environmental policy. The index ranges from 0 (not stringent) to 6 (highest degree of stringency). The level of stringency is based on the degree of stringency of 14 environmental policy instruments.

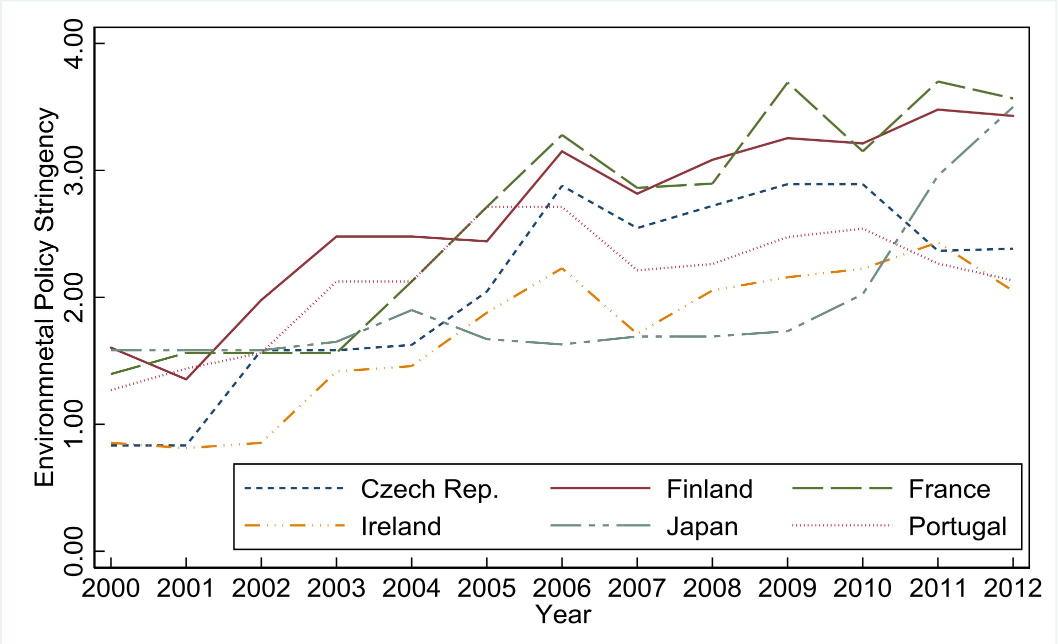

Figure 1 - Environmental Stringency Index of selected countries between 2000 and 2012

Source: Botta and Kozluk (2014)

The rationale behind the correlation between EPS and waste can be explained as follows. Waste recycling is considered as one of the best choices for governments to improve their environmental policy stringency. This is because regulations on waste management are easier to implement and less costly to set than other environmental policies such as emission reduction (Hamilton et al., 2013; Acuff and Kaffine, 2013). Recycling policies are also rapid to set and implement. On the other hand, recycling-related environmental policy has direct and immediate effect on quantity of recycled waste, while other policies that regulate human impacts on the environment may take more than one year to be implemented and even longer to demonstrate a significant impact on economic performance. It is likely to take years from such policy design to increased environmental technology research, before the final utilization of such innovation on managing waste. Therefore, EPS in general is less correlated with GDP over the period in this study. As confirmed by Albrizio et al. (2017), there is not any strong relation between economic growth and EPS at the national level,which supports our rationale for using EPS as an instrument for waste recycling.

The second instrument is waste water treatment (Water). The indicator “waste water treatment”[5] represents the percentage of the population connected to a waste water treatment plant through a public sewage network. It does not take into account independent private facilities that are used when public systems are not economical. Studies have shown that waste and water are two resources similarly managed and very much interconnected (Hamilton et al., 2013; Kellenberg, 2012; Harford, 1976). As “water supply” is often used as an instrument for waste, similarly, waste water treated could be used as an instrument for waste recycled. Moreover, no study provides a direct nexus between water effluent management specification and economic growth. In OECD countries, sludge is historically managed by regional public institutions. Also, many towns have no networks and households own independent private sludge systems. In France, more than 5 million households are not connected to any urban network. In the European Union, networks have only been compulsory since 1991 and for population centres with over 2000 inhabitants. The time period studied comes after this regulation was introduced. Figure 2 shows that even though Ireland, Portugal and the Czech Republic are part of the European Union, they have experienced different variations in the period studied. Waste water treatment data are uncorrelated with the error term.

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[5] Water hereafter in the paper refers to waste water treatment.

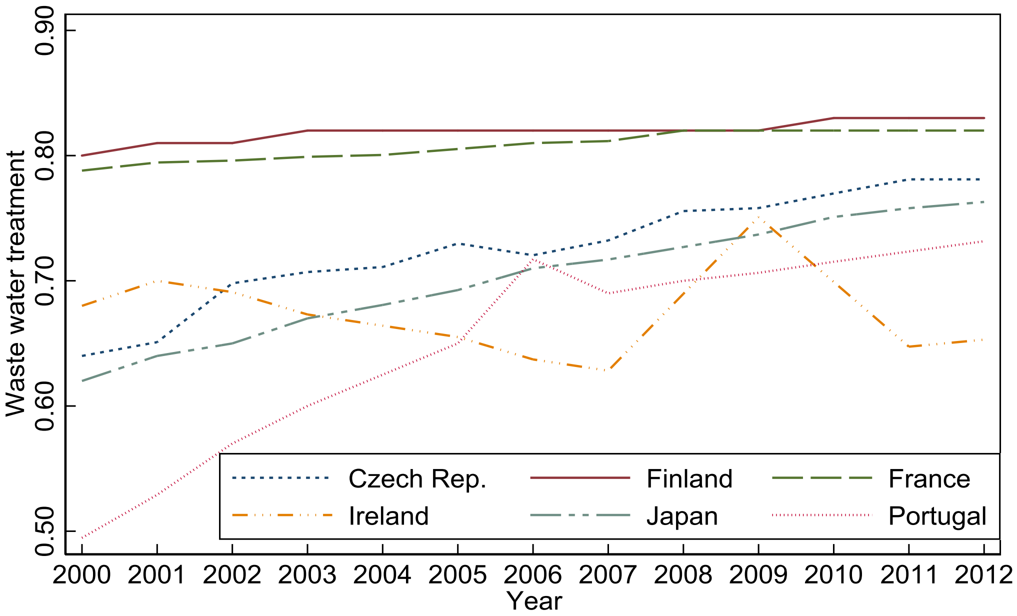

Figure 2 - Waste water treatment of selected countries between 2000 and 2012 Source: OECD (2018e)

In addition, we perform a series of statistical tests where EPS, Water or both are used as instruments to ascertain the extent to which our IVs are valid in controlling for the endogeneity. In the first stage regressions, the Kleibergen–Paap Wald F-tests are conducted to see if the IVs are jointly significant for the endogenous variable, *W*. All the results of the first stage of the 2SLS are summarized in Table A *3* in the appendix A. In the first stage regressions, all F statistics are bigger than 10, confirming the strength of our IVs to instrument *W*. The Kleibergen–Paap Lagrange multiplier test (LM) rejects the null hypothesis of under-identification at 1% significance[6]. The Cragg-Donald Wald F statistics are greater than the Stock and Yogo (2005) at the 10% level. Comparison of the Kleibergen–Paap Wald test with the critical values for the Cragg–Donald statistic in the second stage (Bazzi and Clemens, 2013) validates the strength of the chosen IVs. The Hansen J statistic, which is used

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[6] This diagnosis assesses the identification of the equation and allows us to reject the null hypothesis of the equation being under-identified. The 2SLS with IV approach is appropriate and valid for all models.

to check for overidentification of the instruments, shows that *IVs* are significantly correlated with *W*, but not with disturbances.

The results from the above diagnostics support the use of these instruments jointly to control for the endogeneity of *W* in the regressions.

Table 1 – Statistical test results of the 2SLS approach

	Water&EPS		*EPS*		*Water*	
	No time trend	*Time trend*	*No time trend*	*Time trend*	*No time trend*	*Time trend*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
ln$W$	0.0536***	0.0425***	0.2524*	0.1845	0.0327	0.0422**
	(0.0203)	*(0.0185)*	*(0.1678)*	*(0.3975)*	*(0.0205)*	*(0.0185)*
Endogeneity test	0.224	0.53	8.715	0.431	0.297	0.075
Prob > chi^2	0.6357	0.8183	0.0032	0.5116	0.5857	0.7836
KP LM stat. (under id)	18.092***	18.549***	1.657	0.218	17.754***	17.999***
KP Wald F stat. (weak id)	13.126	15.288	1.71	0.211	24.573	29.272
	19.93(10%)	19.93(10%)	16.38(10%)	16.38(10%)	16.38(10%)	16.38(10%)
CD Wald F stat. (weak id)	11.59(15%)	11.59(15%)	5.53(25%)	5.53(25%)	5.53(25%)	5.53(25%)
Hansen J statistic (over id)	8.651	0.406	-	-	-	-
Prob > chi^2	0.033	0.5241	-	-	-	-

Note: The results are estimated with 2SLS. The dependant variable is ln*GDP*. Country and year fixed effects are included. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. KP holds for the Kleibergen and Paap (2006) tests. They account for underestimation and weak identification instruments (Bazzi and Clemens, 2013). CD refers to the Cragg-Donald test. The columns with odd index are for regressions that do not include any "time trend" while those with even index for regressions do include a time trend. * $p<0.10$, **$p<0.05$, ***$p<0.01$. Standard errors are reported in brackets.

Furthermore, the Wooldridge and regression-based tests are performed to check the endogeneity of *W*. The Wooldridge and regression-based tests allow for heteroskedastic and autocorrelated errors. The endogeneity test in Table 1 rejects the hypothesis that *W* is exogenous. All the results from the above diagnostics confirm the relevance and strength of the external IVs.

3. Data

The data used in this analysis are combined from various sources to construct a unique balanced country-level panel dataset on the development of 20 OECD[7] countries from 2000 to 2012. The OECD countries are chosen for their similarity in environmental policies. As depicted by Figure 3, the selection offers different geographical characteristics in the developed world.

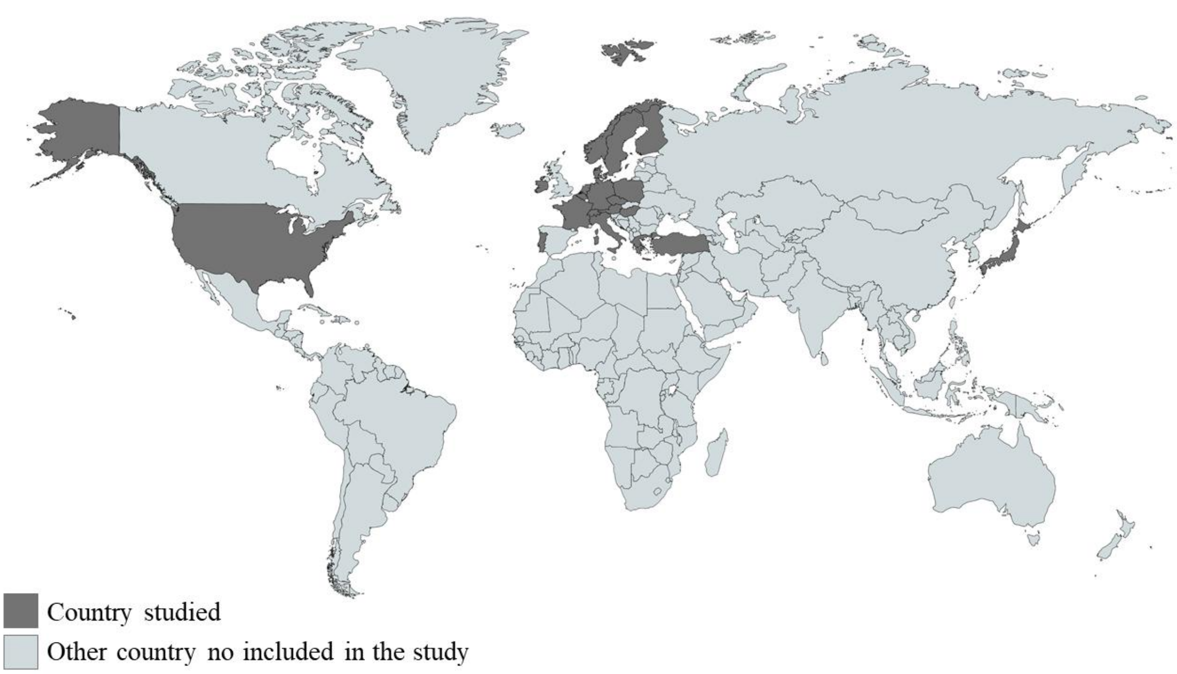

Figure 3 - Countries included in this study

While most of the proxy for the main variables (GDP, W, L, A, Water) are extracted from OECD (2018a,b,c,d,e), data on population were found on United Nations Population Division (UN, 2017). Material proxy were provided by United Nations Environment Programme (UNEP, 2016). The proxy for capital were calculated based on data from 2017 International

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[7] 20 countries were chosen from among all OECD countries. If the availability of data has driven the selection of the countries for control and instruments variables, these countries sufficiently represent the OECD countries, given that even if they are only 59% of the countries, they jointly account for 70% of its population and 77% of its GDP in 2012.

Monitory Fund (IMF 2017) database[8] (Kamps, 2006; Gupta et al., 2014). Human Capital data were retrieved from World Bank (2018). The data for the IV EPS was collected from Botta and Kozluk (2014). The data sources are further described in Table B 1 in the Appendix B. Figure *4* - Statistics on variables used as dependent and control variablesFigure 4 shows the descriptive statistics on the variables used in the study.

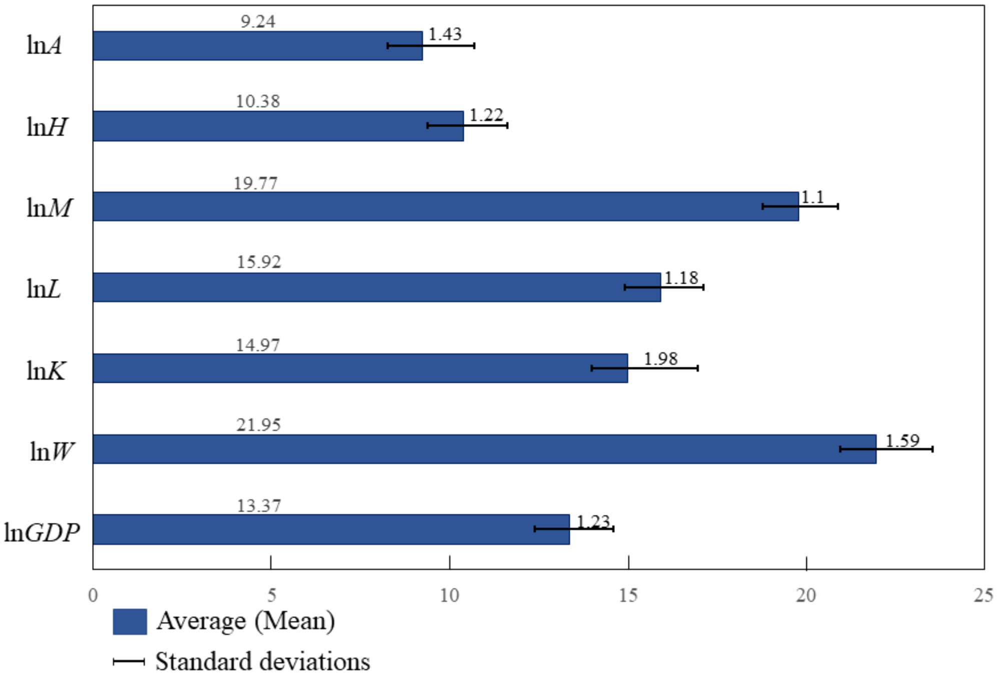

Figure 4 - Statistics on variables used as dependent and control variables Sources: OECD (2018a,b,c,d,e), UN (2017), UNEP (2016), IMF (2017), Kamps, (2006) Gupta et al. (2014), World Bank (2018).

GDP is used to represent a country's economic output *Y*, which is measured in million constant USD at 2010 prices and corrected for PPP exchange rates. The explanatory variable of interest is waste recycled (*W*), in total kilograms per country. Waste recycled is the measured weight of municipal waste recycled. Figure 5 a illustrates that for most of the

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[8] This variable is calculated using the IMF Investment and Capital Stock Dataset, 2017, which extended the methodology of Kamps (2006) and Gupta et al. (2014). The IMF (2017) file provides comprehensive data on public investment and capital stock (i.e. general government), private investment and capital stock, as well as investment and capital stock arising from public-private partnerships (PPPs), across the Fund membership countries.

countries in Europe waste recycled amount increase while in Asia the aggregate amount decreases over the studied period. Figure 5 b highlights the large variation of recycling waste over time and countries. Starting from a very low level of recycling, Poland had a rise of over 809% from 2000 to 2012, while the average increase in the countries studied was 132%.

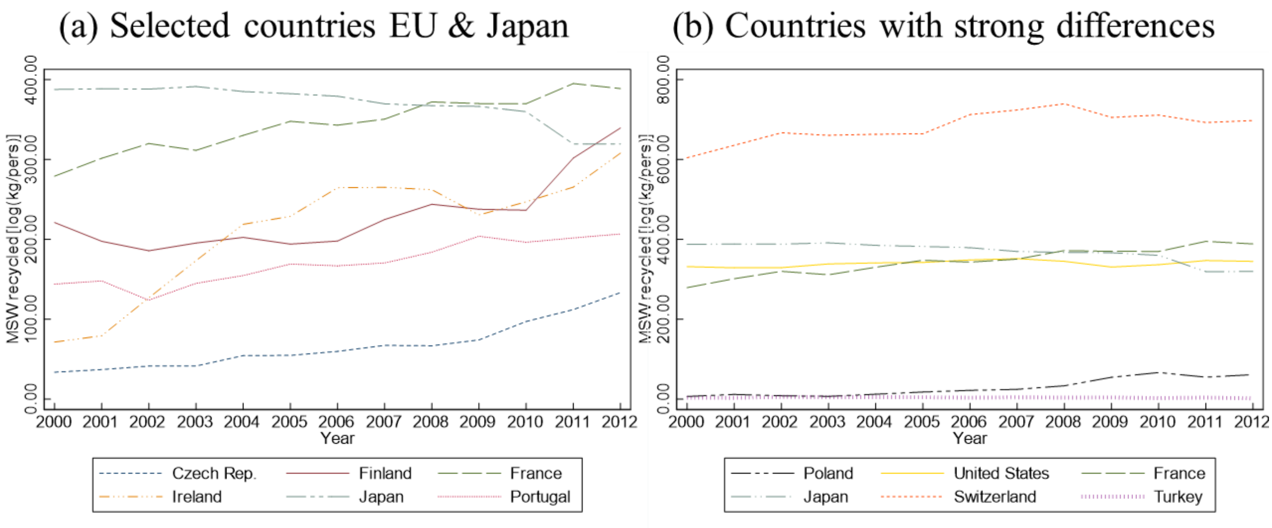

Figure 5 - Waste recycled in selected countries Source: OECD (2018,b)

Figure 6 shows a clear and strong positive relationship between GDP and waste recycled. Countries with high economic development are generally places where the recycling activities are intensive. Our theory is that this relationship reflects the effect of waste recycling through an improved sustainable growth mechanism.

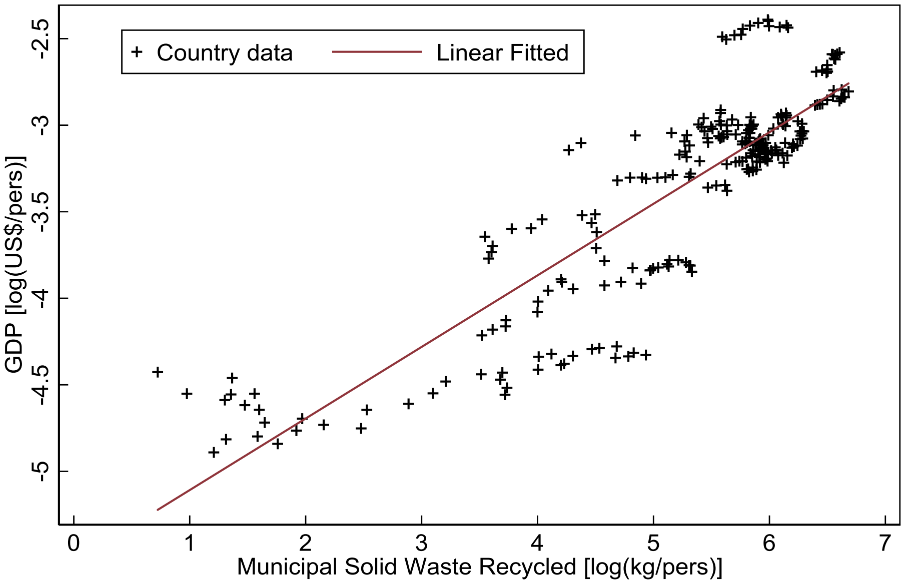

Figure 6 - Scatter plot of per capita GDP and waste recycled Source: OECD (2018a,b)

Note: The figure plots the logarithm of GDP per capita against the logarithm of the municipal solid waste being recycled for the sample analysed. The linear fitted trend is arbitrary. The purpose of this paper is to analyse whether such a trend exists, linking the two variables.

To evaluate the relevance of our hypothesis and to limit the chance of omitted variables, we include different control variables in our regressions. The capital stock (*K*) is expressed by the sum of public and private capital. Labour (*L*) is the labour resource of workers, who are people available for work among the working age population.

To account for resource flows (*M*), we use Direct Material Input (DMI)[9]. DMI measures the total amount of material directly used within an economy. It includes biomass, metal, minerals, and fossil fuels and is defined as the weight of domestically extracted raw materials, plus direct material imports and direct material exports.

Human Capita (*H*) is captured by government expenditures (in real terms) dedicated to tertiary students. Government investment in research and development (R&D) is used as a proxy for the technological variable.

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[9] A robustness check is undertaken in Section 5 using DMC as alternative data for resource flows.

To control for concerns on macroeconomic series characteristics, all data were checked for unit root (Nelson, 1982; Stock and Watson, 1989). Following Dickey and Fuller (1979), augmented Dickey-Fuller tests (ADF) are applied across all control variables to confirm the stationarity of the cross-sectional panel data. The results of the ADF unit root tests for levels and first differences show that in all countries, the variables are stationary. The results are detailed in Appendix A.

4. Results

Table 2 presents the estimated results for our model. The specifications of equations (2) and (3) are entitled “time trend” and “no time trend”, respectively. For each of the specifications, both ordinary least squared fixed effects model (FE) and Two-Stage Least Squares regressions with instruments (2SLS) are presented.

Overall, we observe that there is a strong positive and statistically significant effect of waste recycling on economic output. The results obtained with FE and 2SLS can be considered similar. For the fixed effects model, the results for both specifications are 0.044 and 0.037 (columns (1) and (3), respectively), while with 2SLS, the coefficients are 0.054 and 0.043 in columns (2) and (4), respectively. By comparing the results with and without time trend, we find that the estimated coefficients are smaller when time trends are included.

The magnitude of the coefficient of waste is larger in the 2SLS specification compared to the FE. This is probably due to an inherent measurement error bias in FE estimators that underestimates the effect of waste recycling on economic outputs. The 2SLS estimator is considered to provide the more solid results. These findings suggest that an increase in 1% in waste recycled will lead to an increase of up to 0.05% in GDP.

In all regressions, the estimated coefficients for all the control variables are consistent and statistically significant. Material (resource flows) and labour have high (above average) positive effects on economic output as they are the two major inputs for economy-wide production. The coefficients show that a 1% increase in labour contributes to a more than 0.3% increase in GDP, while the effect of material is over 0.2%. Both physical and human capital are positive and statistically significant for GDP. The effect of physical capital is much higher (by 39%) than human capital, with estimated coefficients up to 0.111 and 0.067, respectively.

Table 2 – Estimation results

	No time trend		Time trend	
	FE	2SLS	FE	2SLS
	(1)	(2)	(3)	(4)
$\ln W$	0.0443***	0.0536***	0.0372***	0.0425***
	(0.0082)	*(0.0203)*	*(0.0079)*	*(0.0185)*
$\ln K$	0.115***	0.111***	0.0776***	0.0759***
	(0.0206)	*(0.0249)*	*(0.0213)*	*(0.0210)*
$\ln L$	0.358***	0.348***	0.335***	0.330***
	(0.0628)	*(0.0790)*	*(0.0599)*	*(0.0804)*
$\ln M$	0.242***	0.247***	0.244***	0.247***
	(0.0187)	*(0.0205)*	*(0.0192)*	*(0.0215)*
$\ln H$	0.0707***	0.0670***	0.0468***	0.0453***
	(0.0143)	*(0.0162)*	*(0.0144)*	*(0.0150)*
$\ln A$	0.117***	0.115***	0.112***	0.111***
	(0.0194)	*(0.0187)*	*(0.0193)*	*(0.0201)*
t	-	-	0.0117***	0.0114***
	-	-	*(0.0023)*	*(0.0026)*
t^2	-	-	-0.000551***	-0.000541***
	-	-	*(0.0001)*	*(0.0002)*
Country FE	yes	yes	yes	yes
Adj R^2	0.89	0.889	0.902	0.901
N	260	260	260	260

F	354.7	285.8	300	251.1

Note: The results are estimated with FE and 2SLS. The dependent variable is ln*GDP*. The Hausman test was conducted to confirm the validity of the choice for FE. For the 2SLS, EPS and Water are used jointly as external instrument variables. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors.

The estimated coefficient for R&D is higher than for those of physical capital, implying that technological innovation is one of the main drivers of growth in developed countries. The time trend evidences the quadratic impact of technological changes on economy.

The positive sign of the estimates of t and negative sign of those of $t2$ explain that the general technical improvement is increasing at a decreasing rate. Therefore, the impact of general technology improvement, which is captured by the time trend, shows a strong positive effect on economic performance.

The effect of waste recycling on GDP can be argued to be low compared to the other variables. According to Pittel et al. (2010), this low level of impact can be explained by the lack of investments in the recycling industry. Among OECD countries, on average, only 1.46% of material used in the economy (according to the DMI data) is reinjected through the recycling of municipal solid waste. This ratio is particularly low in Turkey, representing only 0.001% of the material initially injected. Switzerland has the highest rate of recycling of the developed countries studied in this paper, with a rate of 5.5%. The effects of recycling waste on GDP are positive for all countries.

Figure 7(a) illustrates the marginal effects of waste recycling on GDP across countries. It confirms the effects of recycling waste on GDP are positive and similar for all countries. This can be explained by the commonly ratified international agreements and standardised level of environmental awareness among countries. Figure 7(b)) shows the deviation of country individual effect from the mean value of all countries. We observe that the deviation is positive for the first few years and then becomes negative for European countries, but not for non-European countries like Japan. One explanation for this is the change of leadership. In the early 21st century countries in Europe were the leaders in waste management (Milligan and O'Keeffe, 2019). As non-European countries start to improve their regulations on waste trade and management, they take the leadership from European countries in this field.

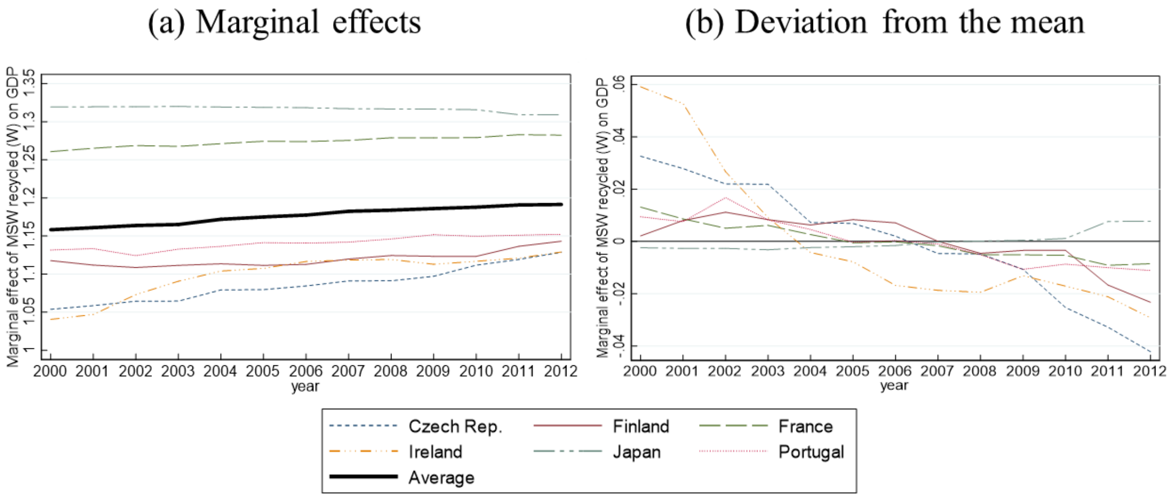

Figure 7 - Marginal effect of waste recycling on GDP by country

Note: Panel (a) shows the marginal effect of waste recycling on GDP for 6 selected countries and the average values. Panel (b) shows the deviation of country individual effect from the mean value of all countries.

Our analysis shows evidence of the positive effect of waste recycling on economic performance at the national level and confirms empirically the theoretical work on endogenous growth undertaken by Di Vita (2001). These results also complement to the literature that highlights the positive impact of waste recycling at within-country levels (Mazzanti and Zoboli, 2008; Slade, 1980) and at microeconomic level for Italy (Mazzanti and Zoboli, 2008).

5. Robustness Check

To assert the validity of our results, we conduct a series of robustness checks. Our findings are robust to a rich set of sensitivity checks addressing alternative waste and material indicators, reverse causality, endogeneity and geopolitical considerations. We now explain and show each of the analyses.

5.1. Effects of recycling rate, long term policies and the role of households

Three alternative measures of waste recycling are considered. The first model variation introduces one period lag. This change also controls for endogeneity and estimates self-accumulation of the variables. Our second alternative test is to turn each variable into per capita value. This variation allows us to estimate the role of households in the recycling sector. Our third alternative is to use the share of waste recycled over the total amount of waste collected as a variable to account for *W*. This proxy can be interpreted as the recycling rate.

Table 3 displays the results of three alternative specifications with both the FE (columns noted as a) and the 2SLS approach (columns noted as b). All columns with odd numbers (1, 3, 5) do not consider a time trend, while columns with even index (2,4, 6) consider a time trend. These results are all significant and consistent with the original model (results Table 2), which confirms the validity of our results. Columns 1 and 2 of Table 3 show the model results when one period lag of *W* is introduced. We find that the effect of recycled waste on economic performance is higher (at 12.7%) when estimated with the 2SLS approach compared to our benchmark results. As we use environmental policy stringency (EPS) as an instrument for recycled waste (*W)*, this first variable is taken with one period lagged. We can consider that the repercussions of recycling regulations are even stronger one year after being implemented. Thus, once a recycling policy is enforced, the effects are enhanced the year later, leading to a stronger effect of recycling in this alternative approach. This finding validates the theory first developed by Jenkins et al. (2003) on the need for long-term recycling policies.

The third and fourth columns of Table 3 summarizes the results when data are accounted for by per capita values. The effect of recycled waste on GDP per capita is up to 0.0624, namely, 1% increase of per capita waste recycled will result in a 0.062% increase in GDP. This suggests that the positive effect of waste recycling is not affected by the population size. Therefore, governments should legislate the enhancement of waste recycled per person or at household level, as it further raises GDP (16.4% more than with aggregate recycling).

The last columns (5, 6) of Table 3 exhibits the results when the share of waste recycled over the total amount of waste collected is used. It shows that a one unit increase of waste recycling rate contributes up to a 5.66% increase in GDP. Increasing the waste recycling ratio increases economic outputs at a higher rate (about 6.5% higher) compared to increasing the total amount of waste recycled. This result provides empirical support for waste reduction policies and encourages higher market penetration in the waste recycling industry.

Our main findings hold and strengthen the need for policies both for waste reduction and increasing the recycling rate, when using different measures of waste recycled.

Table 3 - Results with alternative measures of recycled waste (*W*)

	Lag *W*				Per capita data				Share of waste recycled			
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)	(5a)	(5b)	(6a)	(6b)
ln*W*	0.0359***	0.0604***	0.0299***	0.0533***	0.0473***	0.0624**	0.0416***	0.0461*	0.0455***	0.0566**	0.0400***	0.0478**
	(0.0092)	*(0.0213)*	*(0.0085)*	*(0.0171)*	*(0.0084)*	*(0.0264)*	*(0.0080)*	*(0.0244)*	*(0.0085)*	*(0.0244)*	*(0.0081)*	*(0.0216)*
ln*K*	0.132***	0.113***	0.0766***	0.0620**	0.107***	0.0978***	0.0644***	0.0624***	0.119***	0.115***	0.0790***	0.0770***
	(0.0256)	*(0.0336)*	*(0.0267)*	*(0.0310)*	*(0.0205)*	*(0.0253)*	*(0.0217)*	*(0.0223)*	*(0.0205)*	*(0.0251)*	*(0.0211)*	*(0.0210)*
ln*L*	0.338***	0.319***	0.318***	0.301***	0.299***	0.265***	0.304***	0.294***	0.397***	0.394***	0.366***	0.365***
	(0.0661)	*(0.0941)*	*(0.0612)*	*(0.0954)*	*(0.0673)*	*(0.0998)*	*(0.0640)*	*(0.0949)*	*(0.0623)*	*(0.0769)*	*(0.0591)*	*(0.0787)*
ln*M*	0.242***	0.258***	0.246***	0.261***	0.248***	0.259***	0.249***	0.252***	0.236***	0.241***	0.240***	0.243***
	(0.0194)	*(0.0225)*	*(0.0197)*	*(0.0222)*	*(0.0191)*	*(0.0230)*	*(0.0194)*	*(0.0243)*	*(0.0185)*	*(0.0203)*	*(0.0189)*	*(0.0209)*
ln*H*	0.0622***	0.0553***	0.0395***	0.0342**	0.0705***	0.0650***	0.0458***	0.0445***	0.0633***	0.0572***	0.0390***	0.0353**
	(0.0154)	*(0.0168)*	*(0.0149)*	*(0.0157)*	*(0.0140)*	*(0.0167)*	*(0.0144)*	*(0.0155)*	*(0.0147)*	*(0.0195)*	*(0.0147)*	*(0.0171)*
ln*A*	0.120***	0.112***	0.116***	0.109***	0.114***	0.109***	0.111***	0.110***	0.122***	0.121***	0.117***	0.116***
	(0.0207)	*(0.0188)*	*(0.0197)*	*(0.0198)*	*(0.0194)*	*(0.0198)*	*(0.0192)*	*(0.0207)*	*(0.0193)*	*(0.0181)*	*(0.0191)*	*(0.0190)*
Time trend	*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*
N. of obs	240	240	240	240	260	260	260	260	260	260	260	260
R^2	0.878	0.874	0.896	0.892	0.839	0.836	0.855	0.855	0.89	0.889	0.902	0.902
F	292	220.1	261.4	220.4	229.4	198.9	194.7	171.6	353.6	280.7	302.6	247.4
KP LM (under id)		15.974		15.549		13.306		12.434		15.676		17.179
KP Wald F (weak id)		10.825		11.191		9.611		10.507		11.305		13.595
Hansen J		11.717		4.676		8.096		0.134		9.739		0.746
Prob > chi²		0.0006		0.0306		0.0044		0.7143		0.0018		0.3878
Endog. test		1.05		1.369		0.273		0.021		0.164		0.093
Prob > chi²		0.3054		0.242		0.6012		0.8861		0.6858		0.7598

Note: The table reports estimates for the regressions using different data to measure *W* only (one period lag of *W* in columns 1 & 2 and share of MSW recycled over the total of MSW treated for 5 & 6) and per capita data for all the variables (columns 3 & 4). The dependent variable is ln*GDP*. The columns with odd index are for regressions that do not include any "time trend", while those with even index are for regressions that do include a time trend. The Hausman test was conducted to confirm the validity of the choice for FE. For the 2SLS, EPS and Water are used jointly as external IVs. For all regressions estimated with 2SLS, the Cragg–Donald Wald F stat. (weak id) is 19.93 at 10% and 11.59 at 15%. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

5.2. Effects of raw material imports

The alternative indicator used to analyse the resource flows is DMC. This indicator is similar to DMI but does not include importations of materials (DMC = DMI – imports). All regressions yielded results – summarized in Table 4 - nearly identical to those for DMI in our benchmark model (results Table 2). All estimates are consistent and significant at least at the 10% level.

Table 4 - Results with alternative measures of material (*M*)

	Using DMC for Material			
	FE	2SLS	FE	2SLS
	(1a)	(1b)	(2a)	(2b)
ln*W*	0.0434***	0.0485**	0.0363***	0.0395*
	(0.0087)	*(0.0220)*	*(0.0084)*	*(0.0210)*
ln*M*	0.199***	0.202***	0.200***	0.202***
	(0.0181)	*(0.0194)*	*(0.0186)*	*(0.0218)*
ln*K*	0.120***	0.117***	0.0819***	0.0809***
	(0.0219)	*(0.0257)*	*(0.0227)*	*(0.0214)*
ln*L*	0.320***	0.313***	0.294***	0.290***
	(0.0696)	*(0.0848)*	*(0.0666)*	*(0.0871)*
ln*H*	0.0775***	0.0757***	0.0541***	0.0533***
	(0.0154)	*(0.0162)*	*(0.0154)*	*(0.0150)*
ln*A*	0.123***	0.122***	0.121***	0.120***
	(0.0206)	*(0.0204)*	*(0.0204)*	*(0.0222)*
Time trend	*No*	*No*	*Yes*	*Yes*
N. of obs	260	260	260	260
R^2	0.876	0.875	0.889	0.888
F	309.3	253.8	261.7	206.3
KP LM		17.184		17.709
KP Wald F		12.186		13.984
Hansen J		6.951		0.075
Prob > chi^2		0.0084		0.7844
Endog. test		0.038		0.018
Prob > chi^2		0.8458		0.8947

Note: The table reports estimates for the regressions using different data to measure M only (DMC). For all regressions estimated with 2SLS, the Cragg–Donald Wald F stat. (weak id) is of 19.93 at 10% and of 11.59 at 15%. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

The effect of waste recycling on GDP is lowered by 5% (2% for FE and 8% for 2SLS) when DMC is used instead of DMI as proxy for resources. Material imports also have a 5%

effect on the GDP.[10] The results highlight the role of the imports of raw materials as a transmission channel for waste recycling, as detailed in Section 6.

5.3. Geopolitical considerations

To address the potential biases attributed to geopolitical diversity, we construct different sub-samples of the dataset. We cluster the countries alternatively into three different geopolitical groups to evaluate if our estimated elasticities are valid. The results are reported in Table 5. In most cases, the estimated elasticities of waste are consistent with the benchmark model and significant.

Firstly, we cluster the countries members of the European Union (EU), as EU members are required to follow similar regulations that may affect their economic behaviours and outputs. The first columns (1 and 2) suggest that among EU members, a 1% increase in MSW recycling increases GDP by up 0.088%. The second group is made up of countries under the Schengen agreement and the third group consists of countries in the Euro zone. The results indicate that the positive effect of waste recycling on GDP is higher compared to the benchmark results. A possible reason for this result could be that the opportunities for free travel within the Schengen region helps to spread waste recycling technology and social behaviours. Also, the Euro zone countries lead in the recycling markets and technological advancement. These countries probably merge and encourage others to improve their recycling systems. Therefore, the positive results are possibly enabled by the core structure of the EU, Schengen area and Euro zone. It results that in Europe, the implementation of policies on waste recycling would have stronger effects on the national economic performance than in other OECD countries.

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[10] The calculation was done by comparing the mean of the difference between DMI and DMC over DMI and multiply it by the effect of M on GDP. The effect of recycled waste (W) over GDP is lessened by 5.3% while the importations are responsible for 4.8%.

Table 5 - Results with countries clustered

	Using the sample for EU				Using the sample for Schengen Area				Using the sample for Euro zone			
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)	(5a)	(5b)	(6a)	(6b)
ln*W*	0.0371***	0.0593**	0.0423***	0.0883***	0.0431***	0.0507*	0.0496***	0.0833***	0.011	0.0714**	0.0137	0.0693***
	(0.0109)	*(0.0236)*	*(0.0109)*	*(0.0234)*	*(0.0106)*	*(0.0261)*	*(0.0105)*	*(0.0239)*	*(0.0144)*	*(0.0284)*	*(0.0143)*	*(0.0244)*
ln*K*	0.165***	0.135***	0.117***	0.0385	0.139***	0.129***	0.0918**	0.0441	0.150***	0.0403	0.162***	0.0685
	(0.0309)	*(0.0425)*	*(0.0407)*	*(0.0483)*	*(0.0286)*	*(0.0401)*	*(0.0355)*	*(0.0401)*	*(0.0423)*	*(0.0671)*	*(0.0503)*	*(0.0520)*
ln*L*	0.441***	0.457***	0.450***	0.486***	0.455***	0.464***	0.477***	0.521***	0.532***	0.544***	0.501***	0.503***
	(0.0741)	*(0.0913)*	*(0.0735)*	*(0.0946)*	*(0.0784)*	*(0.0964)*	*(0.0767)*	*(0.1030)*	*(0.0802)*	*(0.0998)*	*(0.0853)*	*(0.0926)*
ln*M*	0.252***	0.245***	0.231***	0.213***	0.280***	0.277***	0.250***	0.235***	0.195***	0.216***	0.187***	0.206***
	(0.0236)	*(0.0258)*	*(0.0247)*	*(0.0250)*	*(0.0240)*	*(0.0273)*	*(0.0249)*	*(0.0271)*	*(0.0290)*	*(0.0280)*	*(0.0315)*	*(0.0282)*
ln*H*	0.0468***	0.0382**	0.0386**	0.0186	0.0402***	0.0367*	0.0264*	0.00935	0.0507***	0.0528***	0.0548**	0.0590***
	(0.0157)	*(0.0185)*	*(0.0160)*	*(0.0188)*	*(0.0152)*	*(0.0215)*	*(0.0153)*	*(0.0205)*	*(0.0193)*	*(0.0198)*	*(0.0217)*	*(0.0206)*
ln*A*	0.112***	0.105***	0.113***	0.0975***	0.116***	0.114***	0.116***	0.105***	0.0970***	0.0952***	0.104***	0.104***
	(0.0203)	*(0.0192)*	*(0.0207)*	*(0.0207)*	*(0.0190)*	*(0.0188)*	*(0.0195)*	*(0.0202)*	*(0.0207)*	*(0.0152)*	*(0.0213)*	*(0.0178)*
Time trend	*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*
N. of obs	195	195	195	195	208	208	208	208	130	130	130	130
R^2	0.893	0.89	0.896	0.885	0.89	0.89	0.897	0.891	0.88	0.86	0.881	0.864
F	273	247.4	212.3	202.3	283.9	236.9	228.2	192.5	159.5	162.2	121.9	131.9
KP LM		8.464		7.124		7.037		5.963		9.361		12.984
KP Wald F		13.851		9.79		8.997		7.231		13.631		19.218
Hansen J		2.03		0.01		1.391		0.005		0.313		0.051
Prob > chi²		0.1542		0.919		0.2383		0.9464		0.5759		0.822
Endog. test		1.021		3.404		0.161		1.609		6.22		9.466
Prob > chi²		0.3123		0.065		0.6887		0.2047		0.0126		0.0021

Note: The table reports estimates for the regressions clustering different countries (European Union 1 & 2, Schengen area for columns 3 & 4 and lastly Euro zone for columns 5 & 6). All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

5.4. Alternative control for endogeneity

We use the Hausman and Taylor (1981) (HT) with the Amemiya-MaCurdy (AM) specification to control for endogeneity. By modifying the HT estimator, Amemiya and MaCurdy (1986) developed an instrumental variable estimator to control for individual-specific unobservable effects that may be correlated with other explanatory variables. Additionally, the HT AM method is robust under heteroskedasticity. To verify the consistency of the HT AM estimator and thus the validity of the instruments, two specification tests were passed. The two Hausman tests passed and confirmed the appropriateness of using the AM specification instead of a basic FE or HT regressor. The results of these tests are reported in

Table *6*.

As the AM estimator requires time invariant variables, we incorporate two additional variables in the model: the size of countries and the mean value of patents. We choose the size of countries because the recycling activity differs by country. This time invariant effect has a strong influence on the waste recycling rate and on social behaviour. In addition, knowledge accumulation will give rise to heterogeneous technology levels across countries. Following Verdolini and Galeotti (2011), the average number of patents available (*PAT*) over the period studied (2000-2012) is used as a proxy for the country-specific technological changes. The results are reported in

Table *6* and suggest that, the overall picture is consistent with the results from both the FE and 2SLS specifications.

Table 6 - Results based on Hausman Taylor Amemiya-MaCurdy method

	Hausman Taylor	
	No trend	With trend
	(1)	(2)
ln*W*	0.0454***	0.0375***
	(0.0081)	*(0.0078)*
ln*K*	0.0905***	0.0503***
	(0.0189)	*(0.0189)*
ln*L*	0.304***	0.303***
	(0.0473)	*(0.0434)*
ln*M*	0.247***	0.250***
	(0.0185)	*(0.0188)*
ln*H*	0.0786***	0.0498***
	(0.0137)	*(0.0139)*
ln*A*	0.132***	0.123***
	(0.0189)	*(0.0188)*
T		0.0127***
		(0.0023)
t^2		-0.000583***
		(0.0001)
Ep	0.113***	0.158***
	(0.0430)	*(0.0387)*
lnSize	-0.0916*	-0.0448
	(0.0486)	*(0.0440)*
Number of obs	260	260
Hausman test 1 Chi^2(4)	14.65**	9.44*
Hausman test 2 Chi^2(4)	0.07	1.06
sargan-hansen	5.1890	5.1890

Note: The table reports estimates for the regressions using Hausman Taylor Amemiya-MaCurdy specifications. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

6. Transmissions Channels and Mechanisms

We found that positive relationship between waste recycling and economic performance of a country. In this session, we try to identify the channels through which that waste recycling enhances the performance of an economy. Waste recycling may affect economic outputs through different socio-economic channels. As the reduction of waste might have positive consequences on environmental conditions but also might impact economic activities. Guided by economic theories (Pittel, 2010; Di Vita, 2001; Ayres, 1999; Hoel, 1978) this section explores the channels of R&D, labour and material supposed to be drivers to the relationship between recycling and economic output.

The exiting literature highlights R&D as a main mechanism driving recycling through which the positive impact of waste recycling on economic output can be reinforced (Slade, 1980; Di Vita, 2001; Sidique et al., 2010). It seems acceptable that technology is needed in order to provide high quality secondary material able to concurrence raw material. Investment into R&D would provide recycled material sufficient economic and technic attractivity to rival virgin one. This variable is supposed to be an important and main mechanism driving the positive effect of recycling for economic development.

Chang (1997) states that the number of people working for waste recycling determines the amount of waste that can be recycled and the benefit thereafter. Moreover, Di Vita (2001) shows that labour is one of the main channels through which waste recycling impacts on economic performance. People are needed to sort waste, as sorting technology are not sufficiently effective. Therefore, waste management and recycling industries are labour-intensive sectors. In a context of underutilization of the workforce – common in OECD - additional public investment in labour will be favourable to employment and growth – following the Keynesian multiplier theory. Labour could be one possible transmission channel that can enhance the effect of waste recycling.

Another transmission channel could be material, because the economic performance of developed economies depends mainly on resource flows (Ayres, 1999). As shown by Hoel (1978), material recycling is bound by the raw material input into the economy. Di Vita (2001) confirms, on the one hand, that the amount of waste dedicated for recycling is bounded by the use of raw material in the economy. Additionally, waste recycling works as a substitute for raw material as input for production on the other hand. We thus expect that this channel – material - will lower the positive effect of waste recycling on economic outputs.

To identify the effects of the different channels, we extend the model by introducing interaction terms. We interact these supposed transmission channels with the waste recycled. The revised model to be estimated is as follows:

$$\ln\left(Y_{i,t}\right) = \beta_W ln\left(W_{i,t}\right) + \sum \beta_{WT} \ln\left(W_{i,t}\right) * \ln\left(T_{i,t}\right) + \beta_{iT} \boldsymbol{X}_{\boldsymbol{i,t}} + \varepsilon_{T_{i,t}} \text{ , \#(7)}$$

where T represents the transmission channels, either R&D, labour or material input or both last one. The effect of waste recycling therefore includes both the direct and indirect effects through variable that are expected to explain the underlying mechanism of the relationship between waste and economic outputs. We can estimate the net effect of waste recycling on GDP when the channel reinforcement effect is captured using the formula:

$$\frac{\partial \ln(Y)}{\partial \ln(W)} = \beta_W + \sum_T \beta_{WT} E(T) \text{ , \#(8)}$$

where T represents the transmission channels, either R&D, labour or material input.

The results are presented in Table 7 - Results of the estimations when considering R&D as a driver explaining the effect of MSW recycling on GDP and The two underlying channels being emerged from this study are labour and material flow. Thanks to these mechanisms, the total effect of waste recycling reaches over 0.06%. Overall, the estimates presented in **Erreur ! Référence non valide pour un signet.** are consistent with the results in Table 2. When both transmission channels are simultaneously included in the model, the direct effect of waste recycling on GDP is further enhanced.

Table 8. It is peculiar that empirical results do not highlight R&D as a mechanism through which the positive impact of waste recycling on economic output can be reinforced. Technology advancement is empirically not enhancing economic productivity through

recycling. When comparing results from Table 7 - Results of the estimations when considering R&D as a driver explaining the effect of MSW recycling on GDP and The two underlying channels being emerged from this study are labour and material flow. Thanks to these mechanisms, the total effect of waste recycling reaches over 0.06%. Overall, the estimates presented in **Erreur ! Référence non valide pour un signet.** are consistent with the results in Table 2. When both transmission channels are simultaneously included in the model, the direct effect of waste recycling on GDP is further enhanced.

Table *8*, one can observe that R&D is actually refraining the positive impact of recycling on economic performance. The results can be explained by the already advance enough technology existing among the studied panel. OECD country secondary market is already mature, and no further R&D investment is needed in this industry. R&D investment in recycling prevent investments from beneficial sectors of recycling. Policy makers should redirect their investments into other drivers while considering recycling for sustaining their development.

Table 7 - Results of the estimations when considering R&D as a driver explaining the effect of MSW recycling on GDP

	T: {R&D, Labour, Material}							
	FE	2SLS	FE	2SLS	FE	2SLS	FE	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lnW	0.109	0.100**	0.233*	0.196***	0.597***	0.653***	0.402**	0.437***
	(0.1020)	(0.0497)	(0.1160)	(0.0574)	(0.1940)	(0.1630)	(0.1500)	(0.1430)
lnR&D*lnW	-0.00782	-0.00679	-0.0240*	-0.0195***	0.00123	0.00866	-0.0307*	-0.0207**
	(0.0126)	(0.0060)	(0.0137)	(0.0068)	(0.0138)	(0.0072)	(0.0159)	(0.0097)
lnR&D	0.278	0.256**	0.592*	0.503***	0.0708	-0.0862	0.723**	0.517**
	(0.2780)	(0.1290)	(0.2930)	(0.1430)	(0.3050)	(0.1540)	(0.3400)	(0.2030)
lnL*lnW					0.0142	-0.00101	0.0446**	0.0255
					(0.0226)	(0.0199)	(0.0206)	(0.0202)
lnL	0.381**	0.378***	0.386**	0.376***	0.0863	0.366	-0.472	-0.117
	(0.1340)	(0.0839)	(0.1400)	(0.0866)	(0.4680)	(0.3860)	(0.4290)	(0.3950)
lnM*lnW					-0.0394	-0.0331*	-0.0413	-0.0319*
					(0.0247)	(0.0183)	(0.0253)	(0.0168)
lnM	0.235***	0.236***	0.240***	0.241***	1.081*	0.961**	1.096*	0.909***
	(0.0258)	(0.0202)	(0.0285)	(0.0205)	(0.5250)	(0.3830)	(0.5300)	(0.3490)
Net effect of W	0.0366*	0.0376**	0.0108	0.0157	0.0557*	0.06176***	0.0130	0.0221*
	(0.0870)	(0.0111)	(0.0177)	(0.1140)	(0.0283)	(0.0132)	(0.0237)	(0.0127)
Time trend	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Other control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.899	0.891	0.917	0.909	0.903	0.894	0.92	0.913
F	275.9	252.4	249.2	266	172	211.1	215.7	224.4

Note: . * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

The two underlying channels being emerged from this study are labour and material flow. Thanks to these mechanisms, the total effect of waste recycling reaches over 0.06%. Overall, the estimates presented in **Erreur ! Référence non valide pour un signet.** are consistent with the results in Table 2. When both transmission channels are simultaneously included in the model, the direct effect of waste recycling on GDP is further enhanced.

Table 8 - Results of the estimations of the effect of MSW recycling on GDP when interactions are included

	FE	2SLS	FE	2SLS
	(1)	(2)	(3)	(4)
ln*W*	**0.587*****	**0.769*****	**0.620*****	**0.746*****
	(0.1440)	*(0.1630)*	*(0.1350)*	*(0.1530)*
ln*L**ln*W*	**0.0153**	**0.0418****	**0.0186**	**0.0380****
	(0.0128)	*(0.0174)*	*(0.0121)*	*(0.0169)*
ln*L*	**0.0685**	**-0.447**	**-0.0211**	**-0.398**
	(0.2580)	*(0.3470)*	*(0.2430)*	*(0.3310)*
ln*M**ln*W*	**-0.0393*****	**-0.0694*****	**-0.0439*****	**-0.0656*****
	(0.0137)	*(0.0170)*	*(0.0129)*	*(0.0159)*
ln*M*	**1.076*****	**1.708*****	**1.178*****	**1.632*****
	(0.2890)	*(0.3570)*	*(0.2720)*	*(0.3320)*
Net effect of *W*	**0.05445*****	**0.06179*****	**0.048201*****	**0.05335*****
	(0.0087)	***(0.0103)***	***(0.0082)***	***(0.0086)***
Time trend	No	No	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Other controls	Yes	Yes	Yes	Yes
R^2	0.896	0.893	0.908	0.907
F	282	229.5	259.6	220.7

Note: * p<0.10, **p<0.05, ***p<0.01. Values in parenthesis are the standard errors

Our results on these two transmission mechanisms are consistent with the literature (Pittel, 2010; Di Vita, 2001; Ayres, 1999; Chang, 1997; Hoel, 1978). We therefore show the evidence of the Keynesian multiplier effects: injecting additional public investment in workforce and material efficiency towards the recycling sector, will further benefit and sustain the economic development.

On the one hand, the indirect effect of material use is negative for the reasons explain above regarding the substitution effect between waste and material (Hoel, 1978). Indeed, to a certain level, recycled materials can substitute for virgin resources. On the other hand, the overall effect of material on economic outputs is further enhanced while interacting with recycled waste. The rationale is that recycling is bounded by the injection of raw material into the economy. As the literature emphasises the material input limits the recycling rate. Our findings provide a new direction for exploring the positive effects of recycling. Our results are in line with the existing literature regarding the substitutional equivalence between recycled and virgin materials (Calcott and Walls, 2005). Additionally, we demonstrate the strong connection between virgin material input and recycling possibilities. As mentioned by Pittel et al. (2010), there is a significant lack of investment in the recycling sector. Therefore, increasing investment in recycling could decrease the dependency that economic output currently has on raw material input. This would allow developed countries to move towards a dematerialisation of the economy.

With regard to labour, the indirect effect is positive while the overall effect is negative. Our results are consistent with the literature on the role of labour as a driver for the recycling industry. Increasing recycling requires labour, which is taken from the labour pool available and directed towards the recycling sector. The total direct effect is positive and confirms the role of labour as a transmission channel that can enhance the effect of waste recycling.

Figure 8 illustrates the overall marginal effects of waste recycling across countries, when presenting the underlying mechanism positively driving the relationship between recycling and economic outputs.

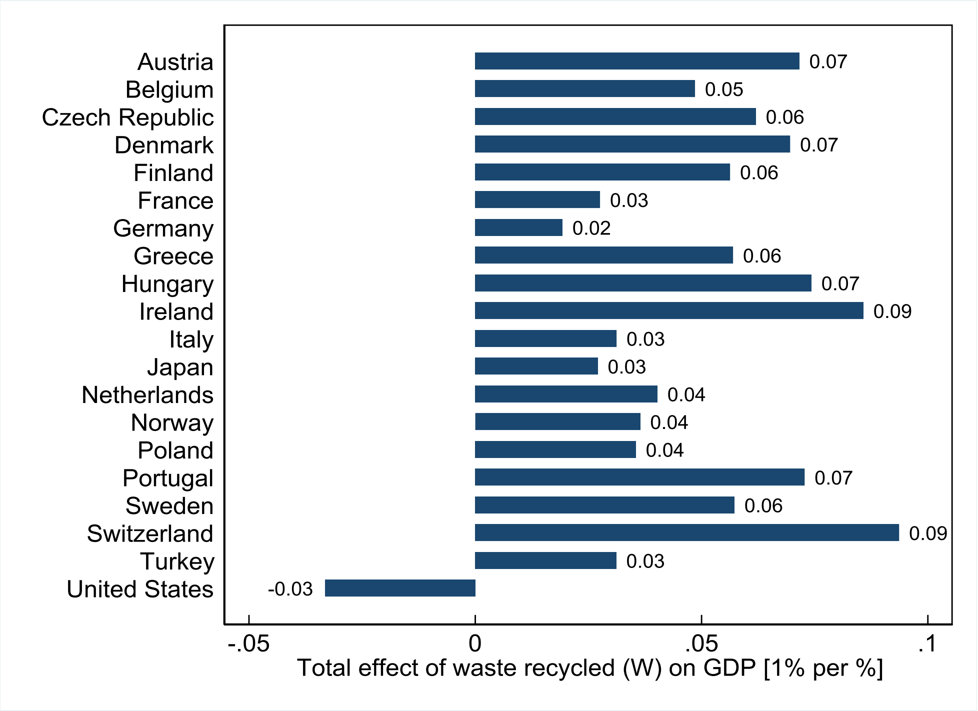

Figure 8 – Overall marginal effect of waste recycling on economic performance per country

The first observation is that the effect is positive for all countries except the United States. Furthermore, we find that the marginal effect is heterogeneous across countries. Possible explanations for this result are the variation in levels of training of the labour force in different countries, cultural differences in terms of working time, the import and export of materials, and the structural difference in terms of waste management. The United States is the only country among the panel studied where these interaction effects of labour and material inputs with waste recycled are negative. Indeed, the United States has more labour involved in the extraction industry than in recycling. Additionally, a significant portion of the United States' economic output is based on raw material trade. The United States has depletion subsidies for extraction as well as reduction taxes for the transportation of raw materials but not for scraps, which unbalances the economy of recycled material (Slade, 1980). If this country is excluded from the analysis, the results are similar (see Appendix C).

When the channels are considered individually, the results are less significant. This lack of significance can be explained by the heterogeneity of the effects of the transmission channels among countries. With regard to labour, the difference in working policies can explain such disparities. With regard to materials, the unbalanced economic importance of imports and exports of materials can explain the disparities.

In fact, the development of the recycling industry brings in new business and job opportunities for low educated workforce. It is of particular interest for mature economies, as it reactivates both their educated -and less educated- labour pool. It also helps to decrease the unemployment rate in OECD countries, which already have a workforce with high environmental awareness. Moreover, the economy can grow by using recycled materials instead of extracting new ones, and thus cut the use of scarce natural resources.

7. Conclusion

This paper provides the first empirical study on the positive effects of waste recycling on the economic performance of developed countries. We approach the question from a macroeconomic aspect and provide empirical evidence to support the linkage between economic growth and waste recycling. We quantify the effect of waste recycling on data from OECD over 13 years (2000–2012). This novel paper complements the scarce empirical literature where the positive impact of waste recycling has already been highlighted at microeconomic level. We find positive and statistically significant effects of waste recycling on the economy. Our results show that an increase of 1% in recycled waste leads to an increase in GDP by up to 0.06%. This effect is also stronger at the 10% level when considering per capita ratio. Our results are robust to a series of sensitivity checks, controlling for reverse causality, endogeneity, and other econometric biases. Our results provide robust evidence confirming the existing theoretical models that link growth and recycling.

This study provides strong support for establishing environment and resource recovery policies, at least for OECD countries. These findings could be used in developed countries to assist policy makers to enforce recycling policy. Our paper highlights that waste management, if well planned, can be a catalyst for a stagnating economy. Using alternative measures of waste recycling, our results suggest that recycling policy at household level results in stronger economic outcomes, and the government should promote higher market penetration for the waste recycling industry. This paper foregrounds waste management as a new growth point for stagnating economies.

In addition, we highlight the underlying drivers of the relationship between recycling and economic outcomes. Our empiric findings show that R&D is not a mechanism enhancing economic performance through recycling, contradicting expectations. The benefits of waste recycling are rather drive through two channels: labour and material use. Investments should be intensified in the recycling sector to enhance its positive effect on economic performance. Such investments would decrease the dependency of economic output on raw material input and allow a transition to a dematerialisation of the economy. Furthermore, it will reactivate their labour pool and decrease the unemployment rate. Besides, governments could consider fostering labour in the recycling industry, as it will not only enhance environmental management but also bring in benefits to overall economic performance.

Managing waste through recycling could be an effective way to reduce the cost of environmental policies, as it lowers the greenhouse gas emissions and prevents environmental degradation due to excess resource extraction and consumption. As such, recycling can be considered a global and competitive strategy for climate change mitigation. These conclusions might be of a special interest for policy makers devoting to circular economy.

A limitation of the study is the use of country as the unit of analysis. Waste management policies and practices are mostly locally governed and can vary significantly within a country. A microeconomic approach might be more appropriate for studying the local responsibilities of waste recycling among OECD countries. However, obtaining precise data on waste management at the local level is a significant challenge. Additionally, the recycling sector is currently experiencing considerable change. It is of a high interest to compare the results with similar analyses that will be done in the next decennial.

Appendix A

This appendix compiles the different tests carried out on the data.

Table A 1 - Correlation matrix between the residuals and the control variables

	ln*K*	ln*L*	ln*M*	ln*H*	ln*A*	residual
ln*K*	1					
ln*L*	0.563***	1				
ln*M*	0.499***	0.947***	1			
ln*H*	0.332***	0.432***	0.454***	1		
ln*A*	0.571***	0.845***	0.827***	0.729***	1	
residual	-0.317***	0.205***	0.234***	0.414***	0.420***	1

Note: This table is obtained after estimating equation 2 with OLS FE specification. The residual estimate through this approach is then extracted to study its correlation with the control variable. Similar results are obtained for the correlation between the control variables and the residuals estimated for equation 3 through the same approach. * p<0.10, **p<0.05, ***p<0.01

Table A 2 - Granger Causality test

	ln*W*->ln*GDP*	ln*GDP*->ln*W*
N	12	12
adj. R^2	0.907	0.569
wbar	2.5959	8.1228
zbar	5.0468***	13.6910***
zbart	4.4090***	2.5477**

Note: The test applied is the one suggested by Dumitrescu and Hurlin (2012)

H0: X does not Granger-cause Y.

H1: X does Granger-cause Y for at least one panel var (id)

* p<0.10, **p<0.05, ***p<0.01.

Table A 3 – Statistical test results of the first step of 2SLS IV approach

	Water&EPS			EPS			Water		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Water	-1.294***	-1.352***	0.0968	-	-		-1.288***	-1.354***	1.035***
	(0.2260)	*(0.2250)*	*(0.181)*	-	-		*(0.2598)*	*(0.2502)*	*(0.1670)*
EPS	0.0663**	0.00668	0.287***	0.0636*	0.0218	0.297***	-	-	
	(0.0351)	*(0.0436)*	*(2.9230)*	*(0.0486)*	*(0.0474)*	*(0.0263)*	-	-	
Time trend	*no*	*yes*	*no*	*no*	*yes*	*no*	*no*	*yes*	*no*
Add. Control	*yes*	*yes*	*no*	*yes*	*yes*	*no*	*yes*	*yes*	*no*
KP Wald F stat. (weak id)	13.13	15.29		1.71	0.22		24.57	29.27	
KP Wald stat. (under id)	27.04***	31.77***		1.76	0.21		25.20***	30.28***	
KP LM stat. (under id)	18.092***	18.55***		1.66	0.22		17.75***	18.00***	
partial R^2	0.1339	0.136	0.292	0.0122	0.0091	0.294	0.1206	0.1359	0.066

Note: The results are estimated with 2SLS. The dependant variable is ln$W$. Country and year fixed effects are included. Standard errors are clustered and reported into brackets. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. KP holds for the Kleibergen and Paap (2006) tests. They account for underestimation and weak identification instruments (Bazzi and Clemens, 2013). * p<0.10, **p<0.05, ***p<0.01.

Table A 4 - Augmented Dickey-Fuller stationary test results on the panel data

	Fisher unit-root test			
	For panel unit root using an augmented Dickey–Fuller test (0 lag)	Unit-root test based on augmented Dickey–Fuller tests (0 lag)		
	Inverse Chi^2 (40)	Inverse normal	Inverse logit t (104)	Modified Inverse Chi^2 (40)
$\ln GDP$	89.8151***	-5.1562***	-5.0579***	5.5695***
$\ln W$	80.2782***	-3.6677***	-3.8000***	4.5032***
$\ln K$	111.1646***	-5.6444***	-6.1568***	7.9564***
$\ln L$	70.0210***	-2.9081***	-2.8754***	3.3564***
$\ln H$	83.1695***	-4.1707***	-4.2858***	4.8265***
$\ln M$	96.9172***	-5.3537***	-5.1814***	5.5689***
$\ln A$	112.6701***	-3.5101***	-5.0158***	8.1248***
EPS	98.4427***	-5.1716***	-5.3176***	6.5341***
Water	113.2944***	-4.2669***	-4.8650***	8.1946***

Note: Inverse chi-squared (40) P

Inverse normal Z

Inverse logit t (104) L*

Modified inv. chi-squared Pm

H0: All panels contain unit roots

Ha: At least one panel is stationary

Standard errors are clustered and reported into brackets. * $p<0.10$, **$p<0.05$, ***$p<0.01$

Appendix B

This appendix summarizes the definitions of the variables used in this paper.

Table B 1 - Data Sources and definitions of variables of interest

Variable	**Definition**	**Source**
Pop	Total population	UN (2017)
GDP	Gross domestic product (indicator)	OECD (2018a)
W	Municipal solid waste amount designated for recycling and energy recovery operations	OECD (2018b)
Kp	Private capital stock (current cost)	IMF (2017)
Kg	General government capital stock	
L	Employment rates are defined as a measure of the extent to which available labour resources (people available to work) are being used.	OECD (2018c)
M	DMI measures the direct input of materials used in production and consumption activities (excluding water flows). It is calculated as domestic extraction plus imports (in economy-wide material flow accounting).	UNEP (2016)
H	Government expenditure for tertiary students	World Bank (2018)
R&N	Gross domestic expenditure on R-D	OECD (2018d)
Water	Waste water treatment indicator presents sewage treatment connection rates	OECD (2018e)
EPS	Environmental Policy Stringency Index	Botta and Kozluk (2014)
PAT	Number of patents available by country under the classification of International Patent Classification (IPC), referenced by inventor(s)'s country(ies) of residence	OECD (2018d)
Country Size	Size of countries. International territories acquired during colonial periods were not considered.	Combined by authors
DMC	DMC measures the total amount of materials directly used by an economy and is defined as the annual quantity of raw materials extracted from the domestic territory, plus all physical imports minus all physical exports.	UNEP (2016)

Appendix C

This appendix details the results obtained for the transmission channels when the country "United State" is dropped.

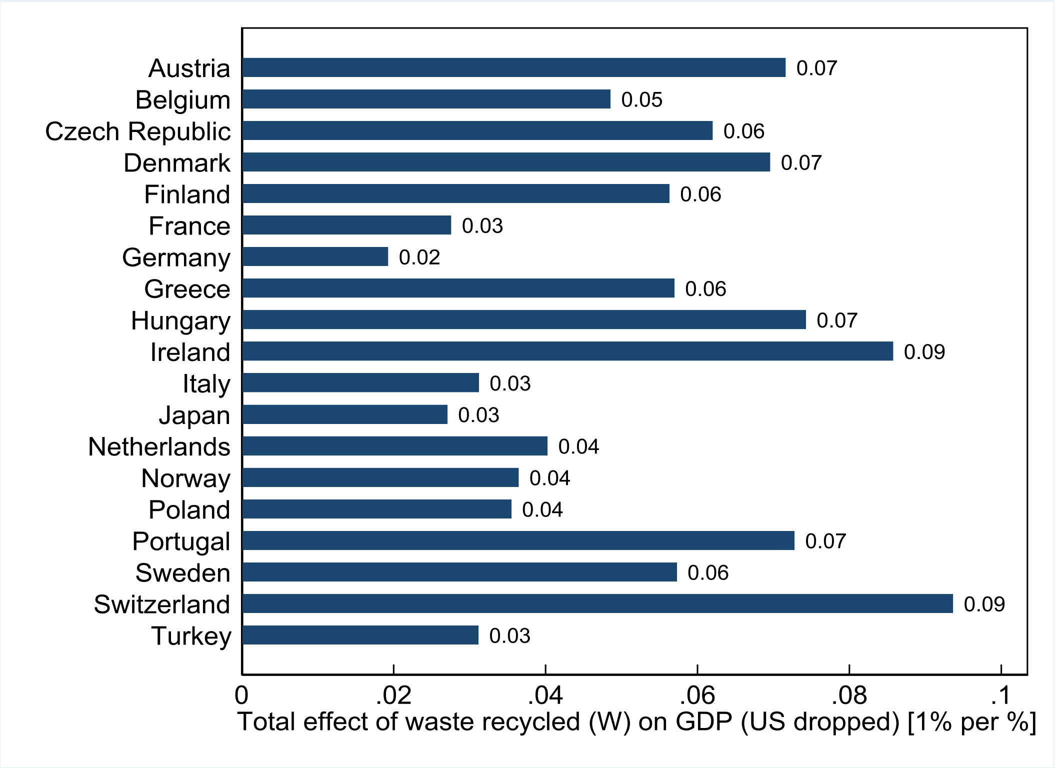

Figure C 1 - Overall marginal effects of waste on economic performance per country when transmission channels are considered (US dropped)

Table C 1 - Results of the estimations of the effects of MSW recycling on GDP when interactions are included and United States dropped

	T: {Labour, Material} - US dropped			
	FE	2SLS	FE	2SLS
	(1a)	(1b)	(2a)	(2b)
ln*W*	**0.588*****	**0.354***	**0.613*****	**0.883****
	(0.1480)	*(0.377)*	*(0.141)*	*(0.345)*
ln*L**ln*W*	**-0.00475**	**-0.0164**	**0.00109**	**-0.0107**
	(0.0143)	*(0.0170)*	*(0.0136)*	*(0.0162)*
ln*L*	**0.456**	**0.681****	**0.320**	**0.553***
	(0.2860)	*(0.3270)*	*(0.2720)*	*(0.3080)*
ln*M**ln*W*	**-0.023**	**-0.00205**	**-0.0293****	**-0.0334**
	(0.0153)	*(0.0259)*	*(0.0145)*	*(0.0229)*
ln*M*	**0.755****	**0.314**	**0.887*****	**0.985****
	(0.3190)	*(0.5450)*	*(0.3030)*	*(0.4830)*
Net effect of *W*	**0.05723*****	**0.05089*****	**0.05285*****	**0.05307*****
	(0.0086)	***(0.0082)***	***(0.0092)***	***(0.0100)***
Time trend	No	No	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
R^2	0.901	0.899	0.912	0.909
F	283.3	256.35	240.6	191.5

Note: The results are estimated with 2SLS and FE. FE: fixed-effect ordinary least squares and 2SLS: two-stage least squares with external instruments. The dependent variable is ln*GDP*. The estimates for the transmission channels variables are consistent with the results in The two underlying channels being emerged from this study are labour and material flow. Thanks to these mechanisms, the total effect of waste recycling reaches over 0.06%. Overall, the estimates presented in **Erreur ! Référence non valide pour un signet.** are consistent with the results in Table 2. When both transmission channels are simultaneously included in the model, the direct effect of waste recycling on GDP is further enhanced.

Table *8*. The estimates for all the other variables are positive, significant at least at the 5% level and consistent with the results in Table 2 The Hausman test was conducted to confirm the validity of the choice for FE. For the 2SLS, EPS and Water are used jointly as external instrument variables. Standard errors are clustered and reported in brackets. All test statistics in the table are robust to heteroscedasticity and arbitrary within-correlation. * p<0.10, **p<0.05, ***p<0.01

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