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How much does Recycling Reduce Imports? Evidence from Metallic Raw Materials

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Working Paper 15-CER-03
March 17, 2015

Pour citer ce papier / How to cite this paper:

Dussaux D., Glachant M. (2015) How much does Recycling Reduce Imports? Evidence from Metallic Raw Materials. i3 Working Papers Series, 15-CER-03.

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How much does recycling reduce imports? Evidence from metallic raw materials

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March 2015

Abstract

In countries with limited exhaustible natural resources, reducing imports of raw materials is increasingly viewed as a significant side benefit of waste recycling. Using a panel of 21 developed and developing countries from 1994-2008, we seek to measure the size of this benefit by estimating the impact of metal scrap recovery on imports of metallic raw materials. We deal with the endogeneity of metal recovery with exogenous country characteristics including population density, the level of education, and knowledge of environmental technologies. We also develop a strategy for controlling for the price volatility in raw material markets. We find that increasing metal recovery by 10% reduces imports of metallic raw materials by 3.3% in our base specification. This result confirms that waste policies that favor recycling may have a sizeable impact on the balance of trade.

JEL Classification: F18, L61, Q53

Keywords: raw materials, trade, waste recovery, recycling, metal, input substitution

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1. Introduction

Many public policies all over the world promote waste recycling. In the European Union, several directives established ambitious recovery rate targets for packaging, end-of-life vehicles and electronic waste in the 1990s. Japan adopted the so-called Fundamental Law for Establishing a Sound Material-Cycle Society (*Junkangata Shakai*) in 2000. China made a similar move in 2009 with the Circular Economy Promotion Law. In the United States, policies have mostly been implemented at state level (e.g. California, Illinois, Wisconsin, Oregon, and New York). To achieve recycling targets, regulators have implemented subsidies, take-back obligations, landfill bans of recyclables, and so-called Extended Producer Responsibility Programs (EPR), by which the government makes producers responsible for collecting and recycling their products when they reach end of life. Regulators have also introduced landfill and/or incineration taxes that indirectly promote recycling by increasing the cost of waste disposal. These policies have led to a waste recycling boom in many countries. As an illustration, the real annual growth rate of the metal recovery industry is in double digits in six European countries covered in the present paper. Production doubled every two years in China and Malaysia between 2002 and 2008.

Recycling policies have primarily been introduced for environmental reasons. As recycling is partly a substitute for waste disposal, its development reduces externalities generated by landfilling and incineration, in particular local soil, water and air pollution, methane, carbon dioxide and N2O.[1] The fact that recycled waste can substitute virgin raw materials brings additional benefits because the processing and use of virgin raw materials usually produces more pollution than waste recycling and recovery. Although recycling processes generate

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[1] See the review by the European Commission (2000) on the valuation of environmental externalities arising from waste disposal. See also Hu and Shy (2001) who document the health effects of waste incineration.

their own externalities, life cycle assessments of solid waste management systems show that recycling has an overall positive environmental benefit (Cleary, 2009).[2]

In recent years, policy makers have put more emphasis on the potential economic benefits of recycling. The success of concepts such as resource efficiency and circular economy signals that evolution. For instance, the flagship initiative of a resource-efficient Europe was introduced in 2011 by the European Commission as part of an overall strategy to generate growth and jobs.

Among the economic arguments in favor of recycling, policy makers from countries or regions with limited exhaustible natural resources like Europe and Japan emphasize that recycling can reduce imports of raw material. As an illustration, the EU Steel Action Plan published in 2013 advocates increasing recycling, primarily on the grounds of reducing import dependency on raw materials (European Commission, 2013).

Using a panel of 21 developed and developing countries from 1994-2008, this paper aims to measure the size of this benefit by estimating the impact of metal scrap recovery on imports of metallic raw materials. We look at secondary material imports, and also at their virgin counterparts, because domestically produced secondary material can substitute virgin material. We deal with the endogeneity of metal recovery with exogenous country characteristics including population density, the level of education, and knowledge of environmental technologies. We also develop a strategy for controlling for the price volatility in raw material markets. We find that a 10% increase in metal recovery reduces imports of metallic raw materials by 3.3% in our base specification. These findings support the argument that waste policies contribute to improving the balance of trade.

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[2] In many cases, the economic cost of recycling is higher than the cost of waste disposal, particularly for household waste (EPA, 1994; European Commission, 2002). The net social benefit of recycling is thus a priori unclear. This question has been much less explored in literature. A recent study by Kinnaman et al. (2014) however shows that recycling rates are higher than the socially optimal rates in Japan.

To the best of our knowledge, this paper proposes the first empirical study on the impact of recycling on raw material imports. The most closely related work is a study on paper and lead by Beukering and Bouman (2001) who study the relationships between the international trade of recyclable materials, waste recovery and secondary material utilization rates. They address a different question, however: they try to identify the determinants of recycling performance with trade of recyclates as one explanatory variable. Hence trade is on the left-hand side of their equation, whereas it is on the right-hand side in the present paper. This difference highlights the concern of reverse causality between these variables because the recovery and trade of recyclable materials are simultaneously determined in the macroeconomic equilibrium. They do not address this issue while we devise an empirical strategy to control for endogeneity biases. Berglund and Söderholm (2003) make another cross-country econometric analysis of the determinants of national recovery and utilization rates, but they not consider trade as an independent variable. They find that recycling performance is mainly driven by non-policy country characteristics such as population density and urbanization rate.

Other works look at trade of waste and secondary raw materials, without paying attention to the role of domestic activities in waste recovery. Grace et al. (1978) produced the first paper to analyze the international trade dimension of recyclates. More recently, Kellenberg (2012) examined whether cross-country differences in environmental policy stringency was driving waste towards the laxest countries.

Several theoretical contributions also look at substitution between virgin raw materials and secondary raw materials, but without paying attention to trade issues. For example, Anderson and Spiegelman (1977) model substitution to investigate various policy options for the pulp and paper and steel industries. Di Vita (2007) develops an endogenous growth model to investigate how the degree of technical substitutability between virgin and secondary materials impacts the performance of the economy at an aggregate level.

The remainder of our paper proceeds as follows. Section 2 describes the empirical approach used to quantify the impact of metal recovery on metallic raw materials imports. In Section 3, we present the data and provide some descriptive statistics. Estimation results are presented in Section 4. We also perform several robustness checks. Section 5 discusses the results and concludes.

2. Empirical approach

2.1. Analytical framework

Waste recycling involves two steps. The first is waste recovery, which consists in collecting and processing recyclable waste in order to obtain secondary raw materials. In the second step, secondary raw materials such as ferrous scrap are used to produce new goods. In many industries, these can substitute virgin raw materials. As a result, all other things being equal, an increase in the supply of secondary raw materials is expected to diminish the demand for virgin materials. However, the technical substitutability between secondary and virgin metallic materials is not perfect (Radetzki and Van Duyne, 1985; Blomberg and Hellmer, 2000). For instance, several final products made of high-quality metal require inputs with a high percentage of purity. Several grades of secondary raw metal result from waste metal recovery. The lowest purity grades cannot be used in the production of complex metal products.

Estimating the impact of metal recovery on imports of metallic raw materials thus requires taking into account three industries that center around metal commodities. The first is the basic metal manufacturing industry, which inputs metallic raw materials such as iron ores to produce finished or semi-finished metal products such as crude steel or steel sheets. Metallic raw materials in this case come from two different upstream industries: the mining industry, which supplies virgin material, and the recovery industry, which collects and processes recyclable waste into secondary raw materials.

Material suppliers can be located at home or abroad. Our research question amounts to investigating the degree of substitutability between two sources of material inputs in basic metal manufacturing: imported raw materials (both virgin and secondary) and secondary materials produced on the domestic market. Econometrically, this involves regressing the volume of imports of raw materials to the size of waste recovery activities in the country. A consistent econometric analysis of the relationship between these two variables then requires controlling for two other factors: demand (captured by the size of the domestic basic metal manufacturing industry) and the size of the domestic mining industry supplying virgin materials that potentially compete with raw material imports.

Formally, we thus write the total import value of metallic raw materials ($import$) as a function of the domestic production value of secondary metals ($recovery$), the domestic production value of virgin metals ($mining$), and the domestic production value of the basic metal industry ($demand$) to proxy the demand for metallic raw materials:

$$import = F(recovery, mining, demand) \tag{1}$$

Assuming that imported metallic raw materials, domestic secondary metals, and domestic virgin metals are (imperfect) substitutes for the production of basic metals, we expect a negative relationship between $import$ and $recovery$ as well as between $import$ and $mining$. We also expect that $import$ increases with $demand$.

2.2. Econometric specification

A log linear specification of (1) that can be estimated with panel data is

$$\ln(import_{it}) = \alpha_0 + \alpha_1 \ln(recovery_{it}) + \alpha_2 \ln(mining_{it}) + \alpha_3 \ln(demand_{it})$$
$$+\alpha_4 \ln(GDP/capita)_{it} + \alpha_5 tariff_{it} + \delta_i + \gamma_t + u_{it} \qquad (2)$$

where indices i and t indicate country and year, respectively. In comparison with (1), we essentially add control variables.[3] δ_i are country fixed effects that control for any time invariant factors that may affect imports of metallic raw materials and may be correlated with other regressors. For instance, remote countries tend to import less than others. γ_t are year dummies that control for any time-varying factors such as variations in global industrial output or energy price changes that impact every country. We also include (the log of) GDP per capita to control for wealth effects. $tariff_{it}$ is a variable measuring the level of potential import barriers. Following standard practice in trade literature, we take the average of effective tariffs that apply specifically to imports of metal raw materials. We give more detail on this variable in the Data section. Finally, u_{it} is the error term that captures unobserved heterogeneity that varies over time and across countries.

2.3. Identification issues

For a given level of domestic metallic raw materials consumption, it is safe to assume that the variables $import$, $recovery$, and $mining$ are simultaneously determined: they are macroeconomic aggregates which result from choices made simultaneously by numerous local and foreign economic agents in the concerned industries, which decide how much raw material to produce and consume. As a result, $recovery$, and $mining$ are likely to be endogenous in (2).

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[3] Note that this functional form does not allow for the inclusion of a country that does not produce metal ore.

To solve this problem, we employ a General Method of Moments Instrumental Variable (GMM - IV) estimator to get an unbiased estimate of α_1. In our base specification, we use two instrumental variables to identify the equation: the log of population density, $\ln(popdens)$ and the level of education measured by the percentage of tertiary enrollment $(education)$. As a robustness check, we use an additional instrumental variable, which is the country's level of knowledge of environmental technologies.[4]

We judge that $\ln(popdens)$ is a valid instrument for $recovery$ because it does not directly influence raw material imports once total demand for metallic raw material controlled for whereas we expect that densely populated countries are more inclined to develop waste recovery. In densely populated areas, waste collection is less costly because short distances between numerous waste producers allow for economies of scale and density (for instance, see Hirsch, 1965; Stevens, 1978; Antonioli and Filipini, 2002; Koushki et al., 2004). In addition, lower collection costs imply more and cheaper waste available for recovery. Moreover, policies tend to promote waste recovery rather than waste disposal in densely populated areas: high land prices reduce the competitiveness of landfilling and environmental nuisances associated with waste disposal and incineration tend to be less accepted because they affect a larger population. These considerations are confirmed by Berglund and Söderholm (2003), who find that population density has a positive and significant impact on waste recovery. In contrast, there is less reason to believe that density could serve as an instrument for the second endogenous variable, $mining,$ as density can influence mining activities in opposite ways: for instance, density discourages economic activities generating local environmental nuisances, such as mining, but it reduces transportation costs, which raises the profitability of mining activities as ores are usually expensive to transport. This is

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[4] Employing the GMM-IV estimator in the case identified above is equivalent to performing a Two Stage Least Square IV estimator. In our base specification, equation (2) is just identified because we assume two endogenous regressors and use two instruments.

confirmed by the results of the first stage regression, which show no significant impact of $\ln(popdens)$ on $mining$ (see Appendix 7.6).

Turning next to the second instrument $ucation$, we consider that the percentage of high school graduates who successfully enroll in university is valid for both endogenous variables. The general point is that tertiary enrollment improves labor productivity (see Moretti, 2004 for empirical evidence) and total factor productivity (de la Fuente and Ciccone, 2003; Nicoletti and Scarpetta, 2003; Vandenbussche et al., 2006). More skilled labor thus leads to more productive industries and more output in general, particularly in metal recovery and metal mining. The instrument also exhibits the second property necessary for validity, i.e. there is no theoretical reason why the level of education would directly influence raw material imports. We consider the additional instrumental variable, which is the country's level of knowledge in environmental technologies, as a variant of $education$ which captures the sector-specific knowledge. Like $education$ it thus potentially improves productivity in the waste recovery sector.[5]

Non-stationarity is another potential concern. As pointed out by Saito (2004), GMM-IV can be highly biased when the data exhibit non-stationary series. We employ the group mean unit root test of Im et al. (2003) to test for stationarity of $import, demand, recovery,$ and $mining$. Whether a serial correlation is assumed or not, the tests indicate stationarity for $import, demand$ and $recovery$. Results for $mining$ are ambiguous because in one version of the test, where we subtract cross-sectional averages from the series, the null hypothesis of non-stationary series cannot be rejected. In any case, as both the dependent variable and the variable of interest are stationary, our results should not be affected by this issue.

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[5] An alternative instrument for mining could be a country's metal ore endowment because this clearly impacts economic agents' decisions when it comes to extraction. Unfortunately, country-comparable data are not available.

Finally we compute standard errors that are robust to heteroskedasticity and autocorrelation because the homogeneity of serial correlation dynamics does not usually hold with aggregate data like ours.

3. Data

This paper examines imports of raw material between 1994 and 2008 in 21 developed and developing countries that vary by size of recovery sector. We now describe how we constructed the data set.

3.1. Measuring material imports and production

The dependent variable to measure $import$ is the annual total import value of metallic raw material for 21 countries over the period 1994-2008.[6] These metallic raw materials include virgin raw materials (iron ore, copper ore, etc.) and secondary ones (ferrous scrap, copper waste and scrap, etc.).[7] We cover ferrous metal, every base metal, gold and silver, and more than 10 other non-ferrous metals. Data comes from the United Nations (UN) Comtrade database. Our sample does not include some large importers like the United States and Canada for which some data necessary for the analysis are not available; we nevertheless cover 75% of total world trade.[8]

Ideally we would like perform the analysis for each different metal in order to control for material-specific factors. However, this is not feasible because the data describing domestic production (waste recovery, mining, and basic metal manufacturing) are only available at aggregate level. This also explains why the dependent variable is not expressed in quantity,

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[6] The list of the countries is available in appendix 7.1.

[7] See appendix 7.2.

[8] Based on imports in 2007. The actual figure is slightly lower because our calculation is based on 72 countries for which data are available. The excluded economies are unlikely to weigh much in total trade.

but in value, as summing the quantity of different metals would be meaningless (such as adding tons of steel and gold).

Data on the annual production value of metal extraction, metal recovery, and basic metals manufacturing is taken from different sources. We obtain basic metals manufacturing output from the United Nations Industrial Development Organization (UNIDO) Industrial Statistics Database (INDSTAT2). Data on metal recovery annual output come from UNIDO INDSTAT4.[9]

Data on the metal mining industry has proved much more difficult to collect. For the 21 countries included in our sample, a reliable source is the U.S. Geological Survey Mineral Commodity Summaries, which give the annual quantity of metals produced[10]. The problem is that we need the output of the mining sector in value. To estimate this output value, we thus multiply for each metal the annual quantity with an estimate of its world price, which is the average unit value of metal ore imports using trade data from the UN Comtrade database. To check the consistency of our measure, we calculate yearly correlations between this estimate and reported values in the OECD STructural ANalysis Database (STAN) database in the 9 countries for which the data is available.[11] The yearly correlations are around 0.98 from 1996 to 2006.

Aggregating different metals into single metrics by summing metal-specific values may generate measurement errors because the relative prices of the different metals can vary significantly over time. Changes in the value of imports or outputs can thus simply be driven by changes in relative market prices while quantities remain stable. To circumvent the

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[9] In the International Standard Industrial Classification of All Economic Activities (ISIC) 3.1, basic metals manufacturing is classified under Division 27 while metal recovery is classified under Class 3710.

[10] We collect the quantity in terms of metal content of Aluminum, Antimony, Chrome, Cobalt, Copper, Gold, Iron, Lead, Molybdenum, Nickel, Silver, Tin, Titanium, Tungsten, and Zinc because metal content per gram of ores differs from a mine to another.

[11] The mining industry is identified under division 13 in ISIC Rev. 3.1.

problem, we deflate the values. As indices are not readily available for the set of countries and years included in the sample, we calculate our own price indices. For imports, we use a Tornqvist price index (see the formula in Appendix 7.3). The advantage of this type of index is flexibility, which is needed here because the degree of substitutability across products varies considerably: different metals are generally not substitutes (e.g., iron is not a substitute for copper) contrary to a virgin material and its secondary variant (e.g., virgin iron ore and ferrous scrap). The Tornqvist price index does not impose any restriction on the size of the elasticities of substitution between the goods. For waste recovery and metal mining, we rely on an arithmetic Paasche index as elasticities of substitution are very low, arguably zero (see Appendix 7.3 for details).[12]

All indices have a unique reference year. The main justification is that they are then less sensitive to price volatility than chained-base indices (Gaulier et al., 2008). We proxy prices with the unit values of trade flows as we do when computing the output values of the mining sector. Kravis & Lipsey (1974) and Silver (2007) have highlighted the empirical problems implied by using this solution. We mitigate them by applying Gaulier et al. (2008)'s outlier management methodology to get "clean of outliers" price datasets. Their method consists in identifying two types of outlier, i.e. trade flow observations that are likely to have been rounded[13] and observations that have unrealistic price variations over time for each importing country and product bundle. These observations are not used when calculating average unit value since they could yield an unrealistic unit value.[14]

3.2. Other data sources

Data on population density and GDP per capita come from the World Bank and gross enrollment ratio in tertiary education comes from the UNESCO Institute for Statistics.

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[12] We use the Paasche rather than the Laspeyres formula because the latter is not appropriate to deflate output at current prices (IMF, 2004).

[13] For instance a trade flow of 750 USD is reported as 1,000 USD.

[14] Recovery rates that are the share of total import value used to calculate the prices are available upon request.

The variable $tariff$ is the simple average of effectively applied tariffs to proxy the trade protection of each country towards the import of metal raw materials. More specifically, we divide the sum of the simple average of effectively applied tariffs towards all countries of the HS6 products defined above by the number of HS6 products for which tariff data are available.[15] Data on tariffs at the HS 6-digit level are extracted from the United Nations Conference on Trade and Development (UNCTAD) Trade Analysis and Information System (TRAINS) database.

This indicator is specific to metallic raw materials and thus superior to more general measures, such as WTO membership dummies. However, it does not measure non-tariff barriers to trade, such as countervailing duties and certain product regulations. Unfortunately, no sufficiently disaggregated data are available to construct a variable control for such barriers. We can however argue that non-tariff barriers are likely to be positively correlated with $tariff$.

The country's level of knowledge in environmental technologies, which we use as an additional instrument, is defined as the ratio between the stock of environmental patents and the stock of all patents[16]. This is a standard indicator in literature on green innovation (for instance, see Dechezleprêtre and Glachant, 2014). We select granted patents classified as "General Environment" defined in the classification adopted in the OECD Patent Database and summarized in appendix 7.5. We restrict our measurement to triadic or high-value patents to avoid flooding it with the numerous low-value patents. To account for technology obsolescence, we discount all stock by an annual depreciation rate of 15%, a value used in

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[15] These are ad valorem tariffs. We do not use trade-weighted average tariffs for different reasons. First, they lack theoretical foundation (Anderson and Neary, 1996). More practically, they underestimate the level of trade barriers. In particular, prohibitive tariffs that totally block trade are not included because their weight is zero (UNCTAD and WTO, 2012).

[16] The latter stock excludes Human Necessities and ICT patents because these two categories are very patent intensive and may overestimate the knowledge of industries located upstream in the value chain.

most literature. Data on patent filing come from the Worldwide Patent Statistical Database (PATSTAT) database.

3.3. Descriptive statistics

Table 1 gives the descriptive statistics. The final dataset is an unbalanced panel of 203 observations mainly limited by the availability of data on the metal recovery industry.

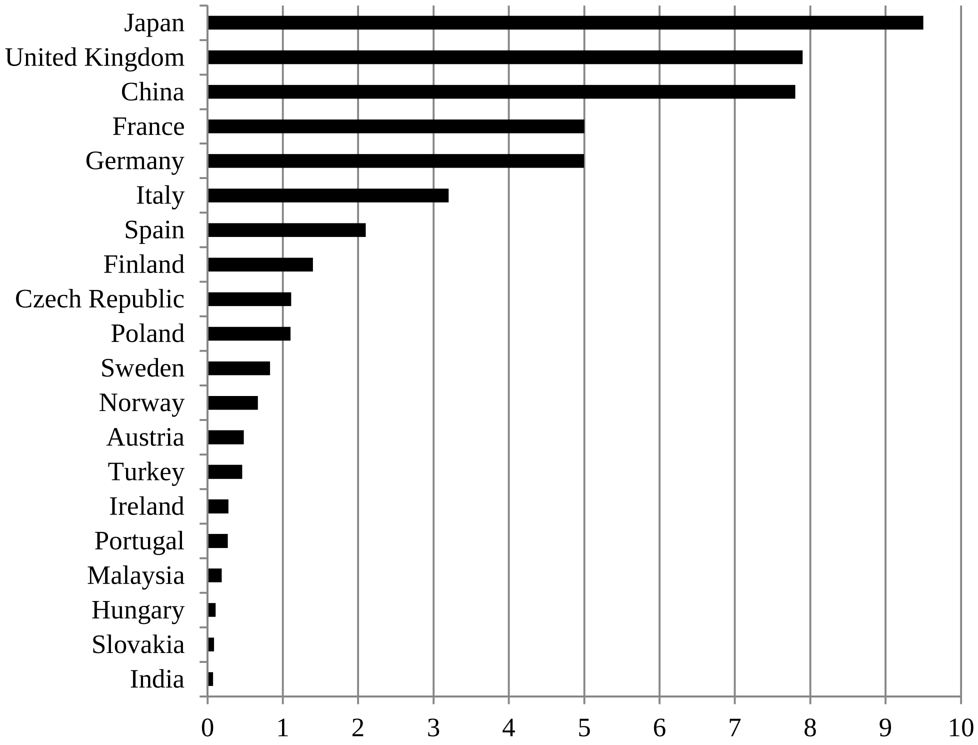
Table 1: Descriptive statistics

Variables	N	Mean	Between SD	Within SD	Min	Max
ln $(import)$	203	20.540	1.502	0.289	16.807	23.821
ln $(recovery)$	203	19.624	1.646	0.598	16.505	23.929
ln $(mining)$	203	18.107	2.486	0.493	11.460	24.020
ln (Demand)	203	23.103	1.575	0.183	19.497	26.606
ln (GDP per capita)	203	10.191	0.660	0.108	7.894	11.081
Tariff	203	0.613	3.238	0.690	0	19.51
ln (popdens)	203	4.539	0.936	0.026	2.662	6.213
Education (%)	203	53.428	19.409	8.136	9.780	97.510
Green Patent (%)	203	1.53	0.397	0.091	0.724	2.741

Notes. Import, recovery, mining, and demand are expressed in Billions 1994 USD. GDP per capita is expressed in purchasing power parity constant 2011 international dollars. Population density is expressed in people per square km of land area. Import, production and demand are expressed in constant 1994 USD. Nominal values are deflated using appropriate price indices (see section 2.1).

Figure 1 shows the size of the recovery sector in 2007 for the countries included in the sample. Beside major western economies where ambitious recycling public policies have been implemented for several years (Japan, United Kingdom, Germany, France), note that China also has a well-developed waste recovery sector.

Figure 1: Metal recovery output in billions current USD in 2007



Note: Data are not available for the Republic of Korea.

Figure 2 plots the evolution of the shares of three material inputs used by the basic metal manufacturing industry: imported raw materials, secondary materials produced by the domestic waste recovery sector, and virgin materials produced by the domestic mining sector. Input levels are in real USD and are summed across a subset of 10 countries for which the data is available over the whole period[17]. The graph shows that imports constitute the main source of materials to meet demand in these countries. However, this share decreases over time, along with the value of locally produced virgin material. This is compensated by a boom

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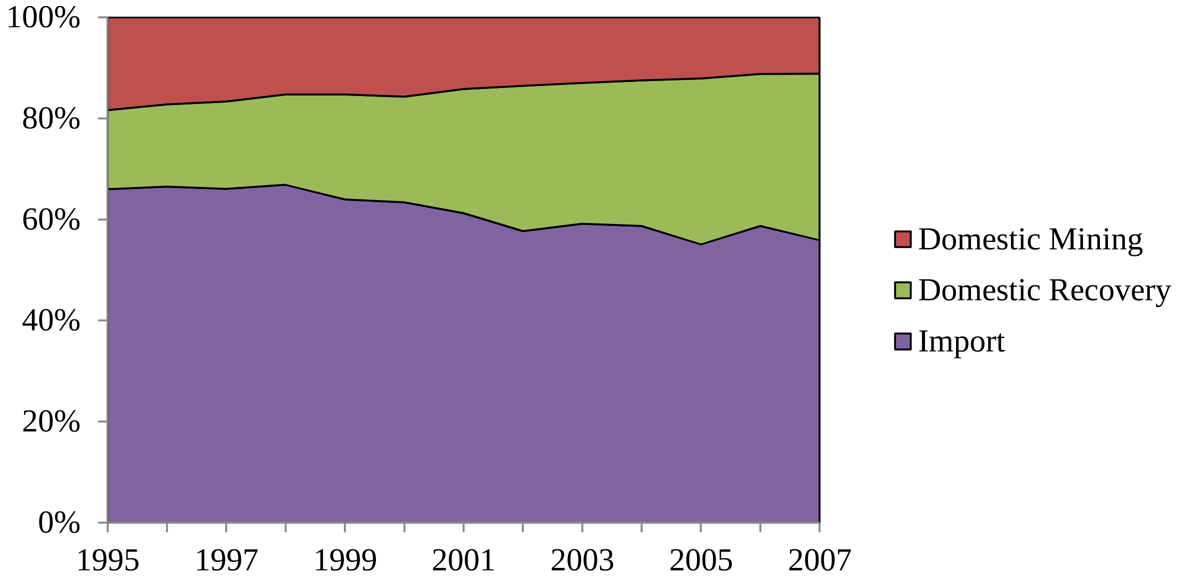
[17] Austria, Czech Republic, Finland, Hungary, Italy, Norway, Poland, Slovakia, Spain, and Sweden.

in waste recovery, whose output more than doubles in 12 years. This could suggest that the development of recovery has induced a decrease in imports and domestic mining. The objective of the econometric analysis is to test the first hypothesis.

Figure 2: Relative shares of imports of metallic raw materials, domestic metal mining sector and domestic metallic waste recovery sector (1995-2007)



Note: In real USD for ten countries from the sample: Austria, Czech Republic, Finland, Hungary, Italy, Norway, Poland, Slovakia, Spain, Sweden.

4. Results

Table 2 presents the main estimation results. Column 1 displays the estimates for the base specification (GMM-IV). In Column 2, we give the OLS fixed-effect estimates. This naive approach does not deal with the simultaneity issue and gives biased estimates. Column 3 and 4 are variants of the base specification that distinguishes the impact of recovery on virgin material imports (column 3) and secondary material imports (Column 4). For every GMM-IV estimate, the Kleibergen-Paap rank LM statistic for under-identification is reported. The joint null hypothesis of the Kleibergen-Paap rank LM statistic is that equation (2) is under-identified in all cases. This provides strong support for the instrument set. We also report in

Appendix 7.6 the first stage regressions performed during the GMM-IV estimation, which confirms our expectations about the impact of instruments on the two endogenous variables.

Results of the base specification indicate that the development of the metal recovery industry reduces total imports of metallic raw materials. The size of the coefficient estimate as an elasticity is substantial. All things being equal, a 10% increase in the output of the metal recovery industry is roughly associated with a 3.3% decrease in total imports of metallic raw materials with a 95% confidence interval [-6%, -1%]. Note that the OLS FE would lead us to underestimate that effect (see column 2).

This 3.3% effect is not economically insignificant when considering the size of the metal recovery industry relative to the size of imports, since gross imports are eight times as high as the metal recovery industry on average (see Appendix 7.4). The calculated marginal effect for a mean observation – a country × year in which the size of the waste recovery sector and the imports are set at the sample mean – is a 56 million USD decrease in imports for a 100 million USD increase in the size of the domestic waste recovery sector.[18] The fact that the relation is not 1:1 can be explained by the previously mentioned fact that virgin raw materials and secondary raw materials are not perfect substitutes. Models 3 and 4 tend to confirm this claim, as the impact of domestic recovery is mostly derived from a decrease in imports of secondary raw materials, while the impact on imports of virgin raw materials is negative, but not statistically significant. Another possible explanation is that a significant share of the secondary raw metal produced domestically is exported towards foreign markets, and thus does not serve as a substitute for imported metallic raw materials.

The other coefficients present the expected signs. The $demand$ variable increases imports. The influence of the size of the domestic mining sector is not significant, which is consistent

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[18] The precise formula is marginal effect = * (mean of *imports* / mean of *recovery*).

with results of Model 3. Note that the control variable $tariff$ is never significant, which is not that surprising as tariffs tend to be low for these goods - the average tariff is 0.6% - with limited variations – the standard variation is around 3% (see the descriptive statistics in Table 1).

Table 2: GMM-IV and OLS estimates of country import values of metallic raw materials

Model	GMM-IV All imports (1)	OLS FE All imports (2)	GMM-IV Imports of virgin material (3)	GMM-IV Imports of secondary material (4)
$\ln(recovery)$	-0.326***	-0.099*	-0.250	-1.074**
	(0.117)	(0.051)	(0.188)	(0.510)
$\ln(mining)$	0.006	-0.005	-0.265	0.980*
	(0.194)	(0.044)	(0.413)	(0.565)
$\ln(demand)$	0.545*	0.502***	0.940	-0.968
	(0.301)	(0.116)	(0.706)	(0.801)
$\ln(GDPpercapita)$	0.693*	0.525	1.496**	1.675
	(0.376)	(0.547)	(0.629)	(1.534)
$tariff$	0.034	0.001	0.124	-0.002
	(0.033)	(0.022)	(0.132)	(0.061)
Year dummies	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Instruments	$\ln(popdens)$ $education$	$\ln(popdens)$ $education$	$\ln(popdens)$ $education$	$\ln(popdens)$ $education$
Kleibergen-Paap rank LM statistic	6.84***		7.23***	5.85**
R^2	0.35	0.75	0.04	-0.75
Observations	203	203	203	203

Notes: The dependent variable is the log of metallic raw material imports in value for models 1 and 2. For model 3 and 4, it is the log of metallic virgin materials and metallic secondary materials, respectively. Standard errors robust to heteroskedasticity and autocorrelation in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

We perform multiple checks to assess the robustness of our results (see Table 3). We first look at the potential impact of outliers. In column 5, we replicate our base estimation but we drop China, which is the largest importer, metal miner, and basic metal producer. The coefficients obtained are similar in size to that obtained with the full sample.

We also test whether our results are sensitive to the price index used to deflate nominal metal recovery output or nominal import value into real terms. In column 6, import value is deflated using an arithmetic Paasche index. In column 7, metal recovery output is deflated using a Tornqvist index. The estimates obtained are respectively -0.305 and -0.294, which are close to our base specification estimate equal to -0.326.

To provide additional support to the validity of our instrumental variable approach, we replicate our base estimation using the share of green patents as an additional instrument in Model 8. Since we have more instruments than endogenous variables, we can then rely on the Hansen J-statistic. The over-identification test result indicates that we cannot reject the joint null hypothesis of the Hansen J-statistic that the instruments are valid. As we obtain a coefficient similar to that obtained in our base specification, this suggests that our overall identification strategy is valid.

Finally, we perform a placebo test in column 9: we replace the total import value of metallic raw materials with the total import value of agricultural commodities. Results are consistent because the coefficients of ln (*recovery*), ln (*mining*) and ln (*demand*) are no longer significant.

Table 3: Robustness checks estimation results

	China dropped (5)	**Alternative Price Index for Import (6)**	**Alternative Price Index for Recovery (7)**	**Additional Instrument (8)**	**Agricultural commodities (9)**
ln $(recovery)$	-0.333***	-0.305***	-0.294***	-0.400***	0.004
	(0.121)	(0.111)	(0.100)	(0.148)	(0.057)
ln $(mining)$	-0.009	-0.084	-0.052	0.113	0.171
	(0.196)	(0.203)	(0.193)	(0.184)	(0.105)
ln $(demand)$	0.575*	0.428	0.663**	0.396	-0.129
	(0.312)	(0.309)	(0.311)	(0.284)	(0.163)
ln $(GDPpercapita)$	0.794	1.091***	1.031**	1.059**	1.036***
	(0.484)	(0.412)	(0.408)	(0.440)	(0.326)
$tariff$	0.036	0.033	0.033	0.191*	-0.002
	(0.035)	(0.031)	(0.034)	(0.097)	(0.003)
Year dummies	Yes	Yes	Yes	Yes	Yes
Country fixed-effect	Yes	Yes	Yes	Yes	Yes
Instruments	ln (*popdens*) *education*	ln (*popdens*) *education*	ln (*popdens*) *education*	ln (*popdens*) *education* *green patents*	ln (*popdens*) *education*
Hansen-J statistic				< 0.01	
Kleibergen-Paap rank LM statistic	7.10***	6.84***	8.03***	6.86***	6.85***
R^2	0.33	0.37	0.39	0.26	0.65
N	197	203	203	199	203

Notes: All columns are estimated with the GMM-IV estimator. Standard errors robust to heteroskedasticity and autocorrelation in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

5. Concluding remarks

Our results indicate that the metal recovery industry has a significant economic impact on imports of metallic raw materials: a 10% increase in the size of the domestic metallic waste recovery sector reduces imports by 3.3%; or equivalently, a 100 million USD increase in waste recovery leads to a 56 million USD decrease in imports. Further estimations suggest that the reduction concerns imports of secondary raw materials rather than imports of virgin materials. We thus confirm that recycling reduces dependence on an international supply of raw materials, a virtuous effect for countries with low resource endowment.

Given that recycling is generally more expensive than waste disposal, is it thus worth the extra cost?[19] This question goes well beyond the scope of this paper. Note however that existing cost-benefit analyses of recycling policies (e.g., Kinnaman et al. 2014) do not take into account the potentially beneficial impact of recycling on resource dependence. Another aspect that we do not consider is the impact of domestic recovery on *exports* of secondary or virgin raw metallic materials. Hence, we are not able to look at the full impact of domestic recycling on the balance of trade. Another limitation is our focus on metallic waste, whereas other materials like paper, plastics and textiles are also recycled and traded internationally. Trade in metallic materials is however considerably greater (around 80% of global trade in secondary materials during the period 2009-2013).[20]

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[19] EPA (1994) reported on the recycling operating and maintenance cost and landfill tipping fees for 23 U.S. communities from various U.S. states. In 1990, the average recycling operating and maintenance cost was 101.5 USD per ton and the average tipping fee was 49.5 USD per ton. Recycling operating and maintenance costs were higher than landfill tipping fees in 74 % of communities. More recently, the European Commission (2002) reported for Austria that landfill costs ranged from 63 to 111 euro per ton, incineration costs from 111 to 340 euro per ton, and recycling costs from 50 to 493 euro per ton. These costs do not include revenues from energy production and/or material production.

[20] Based on author calculations from the UN Comtrade Database and products selected in appendix 7.2.

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7. Appendices

7.1. Panel composition of the base estimation sample

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Observations
Austria		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
China										X	X	X	X	X	X	6
Czech Republic			X	X	X	X	X	X								6
Finland		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
France			X	X	X	X	X	X	X	X	X	X	X	X	X	13
Germany		X	X	X												3
Hungary			X	X					X		X	X	X	X	X	8
India								X			X	X		X		4
Ireland				X	X	X	X	X		X	X	X		X	X	10
Italy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15
Japan	X	X			X	X	X	X	X	X	X	X	X	X		12
Korea, Rep.									X		X		X			3
Malaysia								X	X	X		X	X	X	X	7
Norway		X	X		X		X	X	X	X			X	X	X	10
Poland		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
Portugal			X			X	X	X	X	X		X	X	X	X	10
Slovakia									X		X	X	X	X		5
Spain	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15
Sweden		X	X	X	X	X	X	X	X	X	X	X	X	X	X	14
Turkey										X		X	X	X	X	5
United Kingdom	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	15

7.2. Metallic raw commodities by material and by harmonized system code

Material	6-digit HS code	Raw material	Description
Aluminum	260600	virgin	Aluminum ores and concentrates.
Aluminum	760200	secondary	Aluminum waste & scrap
Antimony	261710	virgin	Antimony ores and concentrates
Antimony	811020	secondary	Antimony waste & scrap
Beryllium	811213	secondary	Beryllium waste & scrap
Cadmium	810730	secondary	Cadmium waste & scrap
Chromium	261000	virgin	Chromium ores and concentrates.
Chromium	811222	secondary	Chromium waste & scrap
Cobalt	260500	virgin	Cobalt ores and concentrates.
Cobalt	810530	secondary	Cobalt waste & scrap
Copper	260300	virgin	Copper ores and concentrates.
Copper	740200	virgin	Unrefined copper; copper anodes for electrolytic refining.
Copper	740400	secondary	Copper waste & scrap
Gold	711210	secondary	Waste or scrap containing gold as sole precious metal
Gold	711291	secondary	Waste & scrap of gold, incl. metal clad with gold
Iron & Steel	260111	virgin	Iron ores and concentrates, other than roasted iron pyrites :-- Non-agglomerated
Iron & Steel	260112	virgin	Iron ores and concentrates, other than roasted iron pyrites :-- Agglomerated
Iron & Steel	720410	secondary	Waste & scrap of cast iron
Iron & Steel	720421	secondary	Waste & scrap of stainless steel
Iron & Steel	720429	secondary	Waste & scrap of alloy steel other than stainless steel
Iron & Steel	720430	secondary	Waste & scrap of tinned iron/steel
Iron & Steel	720441	secondary	Ferrous turnings, shavings, chips, milling waste, sawdust, filings
Iron & Steel	720449	secondary	Ferrous waste & scrap (excl. of 7204.10-7204.41)
Iron & Steel	720450	secondary	Ferrous waste & scrap
Lead	260700	virgin	Lead ores and concentrates.
Lead	780200	secondary	Lead waste & scrap
Magnesium	251910	virgin	Natural magnesium carbonate (magnesite)
Magnesium	810420	secondary	Magnesium waste & scrap
Molybdenum	261390	virgin	Molybdenum ores and concentrates (excl. Roasted)
Molybdenum	810297	secondary	Molybdenum waste & scrap
Nickel	260400	virgin	Nickel ores and concentrates.
Nickel	750300	secondary	Nickel waste & scrap
Other non-ferrous metals	260200	virgin	Manganese ores and concentrates
Other non-ferrous metals	261590	virgin	Niobium, tantalum or vanadium ores and concentrates

Material	6-digit HS code	Raw material	Description
Other non-ferrous metals	261790	virgin	Ores and concentrates (excl. iron, manganese, copper, nickel, cobalt, aluminum, lead, zinc, tin, chromium, tungsten, uranium, thorium, molybdenum, titanium, niobium, tantalum, vanadium, zirconium, precious metal or antimony ores and concentrates)
Other non-ferrous metals	280519	virgin	Alkali or alkaline-earth metals (excl. Sodium and calcium)
Other non-ferrous metals	280530	virgin	Rare-earth metals, scandium and yttrium, whether or not intermixed or inter-alloyed
Other precious	261690	virgin	Precious metal ores and concentrates (excl. Silver ores and concentrates)
Other precious	711290	secondary	Waste & scrap of precious metal or of metal clad
Platinum	711220	secondary	Waste/scrap containing platinum as sole precious metal
Platinum	711292	secondary	Waste & scrap of platinum
Precious metal	711299	secondary	Waste & scrap of precious metal/metal clad with precious metal
Silver	261610	virgin	Silver ores and concentrates
Tantalum	810330	secondary	Tantalum waste & scrap
Thallium	811252	secondary	Thallium waste & scrap
Tin	260900	virgin	Tin ores and concentrates.
Tin	800200	secondary	Tin waste & scrap
Titanium	261400	virgin	Titanium ores and concentrates.
Titanium	810830	secondary	Titanium waste & scrap
Tungsten	261100	virgin	Tungsten ores and concentrates.
Tungsten	810197	secondary	Tungsten (wolfram) waste & scrap
Zinc	260800	virgin	Zinc ores and concentrates.
Zinc	790200	secondary	Zinc waste & scrap
Zirconium	261510	virgin	Zirconium ores and concentrates
Zirconium	810930	secondary	Zirconium waste & scrap

7.3. Price Index formulas

$Tornqvist_{t/0} = \left(gP_{t/0}. gL_{t/0}\right)^{1/2}$

$gP_{t/0} = \prod_k \left(\frac{p_{kt}}{p_{k0}}\right)^{w_{kt}}$ is the geometric Paasche Index where p_{kt} denotes the price of product k at year t and p_{k0} denotes the price of product k at the reference year, and w_{kt} is the share of product k in total sales at year t.

$gL_{t/0} = \prod_k \left(\frac{p_{kt}}{p_{k0}}\right)^{w_{k0}}$ is the geometric Laspeyres Index where w_{k0} is the share of product k in total sales at the reference year.

$aP_{t/0} = \left(\sum_k w_{kt} \frac{p_{k0}}{p_{kt}}\right)^{-1}$ is the arithmetic Paasche Index.

7.4. Main economic variables average over 2002-2008 (output and import are expressed in constant thousand USD)

Country	Import of metallic raw materials	Metal recovery output	Metal mining output	Basic metal manufacturing output	GDP
Austria	866,000	169,857	28,200	9,650,000	331,428,571
China	15,786,667	3,173,333	18,266,667	293,833,333	7,866,666,667
Finland	970,857	281,414	95,629	6,308,571	194,285,714
France	1,405,714	2,730,000	14,100	30,185,714	2,271,428,571
Hungary	107,657	48,200	34,329	2,028,333	217,142,857
India	2,266,667	25,033	4,143,333	52,633,333	3,900,000,000
Ireland	141,400	100,240	307,200	418,400	192,000,000
Italy	2,250,000	1,821,429	141,286	43,328,571	2,085,714,286
Japan	8,056,667	12,058,333	136,833	135,666,667	4,300,000,000
Korea, Rep.	4,616,000	964,333	7,636	58,866,667	1,120,000,000
Malaysia	709,429	85,917	48,714	7,235,000	464,285,714
Norway	360,429	328,600	131,286	5,692,000	290,000,000
Poland	365,429	367,714	350,143	5,725,714	650,000,000
Portugal	125,917	108,217	53,550	2,588,333	270,000,000
Slovak Republic	164,833	21,240	26,833	1,974,000	105,166,667
Spain	2,678,571	1,366,286	181,714	22,842,857	1,414,285,714
Sweden	585,571	348,429	757,571	10,654,286	352,857,143
Turkey	2,301,429	109,880	203,143	15,880,000	1,021,428,571
United Kingdom	2,077,143	3,220,000	153	16,771,429	2,128,571,429
Median	**970,857**	**328,600**	**130,200**	**10,654,286**	**650,000,000**

Notes: Czech Republic and Germany do not appear in Table 1 and 2 because data are not available for this period of time.

7.5. General Environmental Management technology fields classification of the OECD[21]

A.1.	Air Pollution Abatement
A.2.	Water Pollution Abatement
A.3.	Waste Management
A.3.1.	Solid Waste collection
A.3.2.	Material recovery, recycling and re-use
A.3.3.	Fertilizers from waste
A.3.4.	Incineration and energy recovery
A.3.5.	Landfilling
A.3.6.	Waste Management – Not Elsewhere Classified
A.4.	Soil Remediation
A.5.	Environmental Monitoring

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[21] The detailed classification is available on : http://www.oecd.org/env/consumption-innovation/ENV-tech%20search%20strategies%20for%20OECDstat%20(2013).pdf

7.6. 1st stage regression results

Excluded instruments	**1st stage dependent variable**					
	1		**2**		**3**	
	ln $(recovery)$	**ln $(mining)$**	**ln $(recovery)$**	**ln $(mining)$**	**ln $(recovery)$**	**ln $(mining)$**
	Coefficient Std. Error	**Coefficient Std. Error**	**Coefficient Std. Error**	**Coefficient Std. Error**	**Coefficient Std. Error**	**Coefficient Std. Error**
ln (*popdens*)	9.916***	-0.230	9.661***	0.008	9.978***	-0.282
	(2.822)	(2.068)	(2.849)	(2.078)	(2.811)	(2.062)
education	0.027***	0.028***	0.027***	0.028***	0.026***	0.028***
	(0.006)	(0.009)	(0.006)	(0.009)	(0.006)	(0.009)
ln (*demand*)	0.076	1.262***	0.051	1.275***	0.109	1.251***
	(0.184)	(0.439)	(0.181)	(0.441)	(0.189)	(0.439)
ln (*GDPpercapita*)	-0.035	-0.535	0.026	-0.687	0.069	-0.530
	(0.722)	(0.868)	(0.728)	(0.917)	(0.728)	(0.874)
tariff	0.118**	-0.056**	0.053***	-0.036**	0.304***	-0.119
	(0.051)	(0.027)	(0.020)	(0.016)	(0.091)	(0.080)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
F-test on excluded instruments	10.73***	5.19***	10.74***	5.03***	10.59***	5.24***
No. obs.	203	203	203	203	203	203

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Data on population density (people per sq. km of land area) come from the World Bank. Education is defined as the gross enrollment ratio in tertiary education, for which data come from the UNESCO Institute for Statistics.