

# Dematerialization in part explained by the burst of the housing bubble

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VERY PRELIMINARY VERSION

## Abstract

We document that a set of countries grew their GDP while decreasing their Material Footprint (MF) over the 2007-2017 decade, breaking the previous trend. This paper analyzes the drivers of this absolute dematerialization. In accounting terms, it simply reflects a reduction in Material Intensity (MI) typically associated with technology. Nonetheless, we show that a wide range of variables related to technology can only explain between 2% and 10% of the MI variation. Alternatively, we hypothesize that the observed dematerialization is, in part, a cyclical phenomenon resulting from the housing prices bust that depresses construction activity and, under some conditions, hits MF harder than GDP. Indeed, the data analysis reveals that housing prices and construction explain between 19% and 46% of the dematerialization variance. Besides, we show that the absence of the housing boom would have accelerated the dematerialization, although insufficient to bring MF within its sustainable limits.

*Keywords:* Dematerialization, Asset Pricing, Economic Cycles, Technological change, Sustainability.

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# 1.- Introduction

The growing income per capita that characterizes modern societies depends on increasing levels of resource use (Georgescu-Roegen (1977)). Apart from the existence of biophysical limits, extracting and processing raw materials contribute to numerous environmental damages, including acidification, climate change, and losses of biodiversity (e.g., Dudka and Adriano (1997), Oberle et al. (2019)). In front of this problem, international institutions called for a transition to a *Green Growth* in which income growth continues but is decoupled from material inputs due to efficiency gains from better technologies and a shift towards less material-intensive sectors (e.g. UNEP (2011); OECD (2011); World Bank (2012); European Union (2022)).

Despite this call, empirical studies have consistently shown that Absolute Dematerialization was happening neither at the planetary scale nor for the technologically leading economies (Wiedmann et al. (2015); Krausmann et al. (2017); Pothén and Welsch (2019))<sup>1</sup>. However, it seems that something has changed after the Global Financial Crisis. Using a panel of 155 countries from 1996 to 2017, we show that a list of 12 countries have transited from a typical strong association between Material Footprints and GDP (1996-2006) to a dematerialization scenario (2007-2017), managing to grow the GDP consuming less materials<sup>2</sup>. The goal of the paper is to understand the forces behind this transition.

Scientific knowledge about the forces driving material use is still very limited (York et al. (2003); Steger and Bleischwitz (2011)). Studies usually focus on the IPAT identity, which decomposes the environmental impact (I) as the product of the scale of the human population (P), the level of income per capita or affluence (A), and impacts per unit of income typically interpreted as technology (T) (Ehrlich and Holdren (1971)). Thus, any dematerialization (i.e., reduction of impacts along with a positive income growth) must come from T. Nonetheless, the IPAT literature showed

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<sup>1</sup>Dematerialization has been commonly defined as the reduction of material used, per unit of economic output. It is necessary to distinguish between relative and absolute dematerialization. Relative dematerialization is when material resource use may still increase but at a slower pace than growth in GDP. The situation in which materials use declines in absolute terms while GDP is still increasing is called absolute dematerialization. Absolute reductions of material flows are generally only found in periods of very low economic growth and using production-based indicators (Steinberger et al. (2010), Shao et al. (2017); Wu et al. (2019); Steinberger and Krausmann (2011); Giljum et al. (2014); Shao et al. (2017); Wu et al. (2019)). When using consumption-based indicators that account for the imported flow of materials via imports, as Material Footprints do, only relative dematerialization has been reported (See Wiedmann et al. (2015); Haberl et al. (2020))

<sup>2</sup>The 12 countries that transited from a rematerialization to absolute dematerialization are Cyprus, Denmark, Finland, Iceland, Ireland, Malta, Netherlands, Portugal, Seychelles, Slovenia, Spain, UK, and USA.

that the role of T has been rather limited (e.g., [Steinberger et al. \(2010\)](#); [Karakaya et al. \(2021\)](#))<sup>3</sup>.

However, several works have reexamined the role of T, replacing its accounting definition (i.e., impacts per unit of income) by other proxies associated to technology such as Total Factor Productivity (TFP) (e.g., [Ulucak and Koçak \(2018\)](#); [Ulucak et al. \(2020\)](#)), R&D expenditures (e.g., [Germani et al. \(2014\)](#); [Wu et al. \(2019\)](#)), energy efficiency (e.g., [Steger and Bleischwitz \(2011\)](#); [Ansari et al. \(2020\)](#)) or renewable energy (e.g., [Sahoo et al. \(2021\)](#)). Unfortunately, none of these variables seems to diminish the use of materials significantly and, in some cases, they even increase it<sup>4</sup>. Moreover, shifts towards less material intensive sectors have attracted attention although it remains unclear whether such services contribute to dematerialization (e.g., [Steger and Bleischwitz \(2011\)](#), [Jackson \(2009\)](#))<sup>5</sup>. Based on this literature, one could argue that Absolute Dematerialization was not happening precisely due to the modest role played by Technology. Nonetheless, our data analysis shows that Technology accounts for no more than 10% of the Dematerialization dynamics despite including the array of proxies considered by the literature.

If Technology plays only a secondary role, what is driving Dematerialization? We suggest that it is, in part, a cyclical phenomenon reflecting the downwards phase of the housing market cycle. The hypothesis goes as follows. First, a Housing Price boom triggers a massive construction of dwellings. Investment in new buildings demands products from various suppliers, directly increasing GDP; besides, inputs of the construction industry consist mainly of Non-Metallic Minerals such as gravel or sand, raising the Material Footprint. The opposite would happen in a burst: a fall in Housing Prices, Construction, GDP, and MF. However, explaining a reduction in MF is not equivalent to explaining Dematerialization<sup>6</sup>; an increase in GDP must accompany the reduction

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<sup>3</sup>Thus, IPAT studies mainly find that economic growth has the biggest impact on the material use followed by population effect, consistent with the lack of absolute dematerialization ([Steinberger et al. \(2010\)](#); [Karakaya et al. \(2021\)](#); [Huang et al. \(2017\)](#); [Bringezu and Bleischwitz \(2017\)](#); [West and Schandl \(2018\)](#)). In this line, [Plank et al. \(2018\)](#) and [Karakaya et al. \(2021\)](#) found that only partially offset the increase of the use of materials.

<sup>4</sup>[Ulucak et al. \(2020\)](#), and [Ulucak and Koçak \(2018\)](#) showed signs of rebound effect when using TFP. [Sahoo et al. \(2021\)](#) found that renewable energy has a negative impact on material use due to its intensive use of minerals. [Ansari et al. \(2020\)](#) and [Steger and Bleischwitz \(2011\)](#) showed that energy consumption and energy efficiency leads to MF requirement. [Wu et al. \(2019\)](#) showed that R&D makes it possible for extractive economies to reduce their Domestic Material Consumption. However, the authors argued that it was worth investigating the material preconditions of this development and whether it accompanied the increasing reliance on imports of primary raw materials. Unfortunately, [Germani et al. \(2014\)](#) found that R&D expenditures carry an opposite sign, suggesting that an extra financial effort in R&D produces an increase in the emissions.

<sup>5</sup>[Steger and Bleischwitz \(2011\)](#), [Pothen and Welsch \(2019\)](#) and [Karakaya et al. \(2021\)](#) highlighted that an increase of services share of GDP inhibited the increase in material use. However, other studies as [Jackson \(2009\)](#) or [Scott \(2009\)](#) posited that a change in the demand structure towards service sectors and preferences towards fewer material needs (e.g., social well-being rather than purchasing products) could also lead to additional demand for resources.

<sup>6</sup>Imagine, for instance, a country that experiences a construction crash. Alternatively, a fall in construction

in MF. That will happen if GDP is less sensitive to Construction than MF, such that a decline in Construction would lead to a mild reduction in GDP that could be easily offset by other GDP drivers (such as TFP). At the same time, MF would fall firmly, taking more time to recover<sup>7</sup>. Thus, Absolute Dematerialization could be observed following a Housing Price-driven crisis.

Our hypothesis builds on a number of studies that have highlighted the role of the construction sector in driving MF (e.g. [Steger and Bleischwitz \(2011\)](#); [González-Vallejo et al. \(2015\)](#); [Giljum et al. \(2016\)](#); [Shao et al. \(2017\)](#); [Plank et al. \(2018\)](#); [Telega and Telega \(2020\)](#); [Hertwich \(2021\)](#); [Jiang et al. \(2022\)](#)). We expand that idea by linking construction to asset pricing as a cause and dematerialization as a consequence. Moreover, in general, capital formation has been regarded as a key force behind the use of materials; as countries develop, they need to build transport infrastructure, housing, factories, machines, and so on that are intensive in materials ([Zheng et al. \(2018\)](#); [Hertwich \(2021\)](#))<sup>8</sup>. Along these lines, [Steger and Bleischwitz \(2011\)](#) and [Bleischwitz et al. \(2018\)](#) have suggested a saturation hypothesis, according to which the use of materials would stabilize when a country has already reached a certain level of capital. We see our hypothesis as a potential cyclical complement to this saturation story: although rich countries have already been built, there could be investment cycles associated with rebuilding, replacing, or even expanding the capital stock<sup>9</sup>.

The data analysis reveals that Housing Prices and Construction explain almost 1/2 of the MF growth and almost 1/3 of the Dematerialization variation over a decade <sup>10,11</sup>. Roughly speaking, we find that the evolution of MF growth results from the balance between two opposite forces: Housing Price inflation that drives it up and a green force that drives it down<sup>12</sup>. This green force accounts for the other 1/2 of the MF growth variation; unfortunately, we have not been able to tie it

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activity would depress both MF and GDP, delivering no absolute dematerialization.

<sup>7</sup>The weight of Construction on GDP is about 6% while the Non-Metallic Minerals (which are strongly associated with Construction) represents about 55% of the MF on average for the selected countries. We show this is a sufficient condition for our hypothesis to work.

<sup>8</sup>[Hertwich \(2021\)](#) shows that the replacement of existing or formation of new capital stocks now accounts for 60% of material-related emissions.

<sup>9</sup>In fact, investment cycles

<sup>10</sup>Housing Prices explain the bulk of that numbers: 38% of MF growth and 21% of the Dematerialization variance.

<sup>11</sup>These are the central estimates for the Housing Prices and Construction share of the variance of MF growth and Dematerialization over a ten year horizon coming from a Panel SVAR. The 90% confidence intervals are [30%, 62%] for MF growth variance and [19%, 46%] for Dematerialization variance.

<sup>12</sup>Thus, during the housing boom Housing Prices dominated the green force, generally rendering growth in MF and rematerialization; in the years of the financial crisis Housing Prices collapsed and the green force also pushed down, bringing about important degrowth in Material Footprints; after the crisis, Housing Prices recovered but with less strength than before and then they were largely offset by the green force, yielding an almost zero growth.

to any observable variable, but it does not seem related to any technological factor. Finally, we run a counterfactual experiment showing that the absence of the housing boom would have accelerated the Dematerialization, yet not enough to bring Material Footprints within their sustainable limits.

The rest of the paper is structured as follows. In [Section 2](#) we describe the hypothesis linking Housing Prices and Dematerialization cycles using a stylized model. [Section 3](#) introduces the methodology; we discuss the IPAT framework's shortcomings and present the tool we use, a Panel Structural Vector Autoregression. [Section 4](#) reports the results of our analysis. [Section 5](#) discusses the findings and concludes.

## 2.- A hypothesis of Housing Price-driven Dematerialization

In this section, we describe a hypothesis that links Housing Prices and Dematerialization cycles. Using a highly stylized model, we tie Housing Prices to construction activity and the latter to Non-Metallic Minerals; then, by accounting identities, GDP and MF are affected. In that setup, we show that the Housing Price elasticity of MF must be greater than that of GDP for Housing Prices to affect Dematerialization dynamics and derive a necessary and a sufficient condition for that to happen. Altogether, the hypothesis explains Dematerialization as a result of a sectoral change in the economy, yet a cyclical rather than a structural one.

We illustrate the hypothesis through a minimalist causal model given by

$$C_t = C(HP_t, \cdot) \tag{1}$$

$$GDP_t = C_t + OS_t \tag{2}$$

$$NMM_t = N(C_t, \cdot) \tag{3}$$

$$MF_t = NMM_t + OM_t \tag{4}$$

where  $C$  is Construction Gross Value Added;  $HP$  are Housing Prices;  $OS$  stands for Other Sectors GVA;  $GDP$  is the Gross Domestic Product;  $NMM$  are Non-Metallic Minerals;  $OM$  are Other Materials;  $MF$  is Material Footprint. Housing prices and value added are in constant currency; materials are in tonnes. For simplicity, we assume that  $OS_t$  and  $OM_t$  follow a linear trend

$X_t = \alpha + \rho X_{t-1}$  with  $\rho < 1$  for  $X = \{OS, OM\}$ , capturing common factors driving up both MF and GDP. In this way, we impose that any difference between MF and GDP paths comes from Construction and Non-Metallic Minerals respectively.

The first piece is a link between Housing Prices and Construction output. In the spirit of the Tobin's Q theory of investment (Brainard and Tobin (1968)), function  $C$  is assumed to satisfy  $C_{HP} > 0$  conjecturing a positive reaction of construction activity to housing prices<sup>13,14</sup>. This positive reaction of construction to housing prices has already been suggested in some studies (e.g., Girouard and Blöndal (2001), Adam et al. (2012), Sun et al. (2013)). The second and third pieces are a link between construction and both GDP and Material Footprint. The former is an accounting definition: GDP is the sum of value added across sectors and then, it adds the construction sector value added to that of the other sectors. The latter involves a mapping from Construction to Non-Metallic Minerals and an accounting definition. First, producing a unit of value added in the construction sector entails the use of several materials such as sand or gravel. We assume the following properties for  $N$ :  $N_x > 0$  with respect to  $x$  input for all its arguments and it is homogeneous of degree 1. Thus, an increase in construction activity would augment the consumption of non-metallic minerals. Then, another accounting definition: MF is the sum of non-metallic minerals and other materials.

The following condition states what is needed for Housing Prices to affect Dematerialization:

**Condition 1.** *By definition, a Housing Price-driven Dematerialization requires a Housing Price elasticity of Material Footprint greater than that of GDP<sup>15</sup>*

$$\frac{\partial \tau}{\partial HP_t} > 0 \iff \frac{\partial MF_t}{\partial HP_t} \frac{HP_t}{MF_t} > \frac{\partial GDP_t}{\partial HP_t} \frac{HP_t}{GDP_t} > 0 \quad (5)$$

In this case, when Housing Prices decline both GDP and MF would follow, but at different intensities; the variable with higher elasticity would decline more, than opening a gap between MF

<sup>13</sup>Although this is a reduced-form equation, it could be microfounded, for instance, along the lines of Adam et al. (2012): a profit-maximizer house builder would increase their production if she expects higher future selling prices, and that expectations would depend somehow on today's price.

<sup>14</sup>We hold that this connection would hold even for countries like USA where regulations make large-scale housing promotions increasingly difficult. For instance, between 1996 and 2006 the number of housing units completed increased by 40%, while from 2007 to 2017 such amount decreased by 41%, which comoves with the housing price dynamics.

<sup>15</sup>Notice that  $\tau = i - g$  can be written as  $\tau_t = \frac{\partial MF_t}{\partial HP_t} - \frac{\partial GDP_t}{\partial HP_t}$  and then,  $\frac{\partial \tau_t}{\partial HP_t} = \frac{\partial MF_t / MF_t}{\partial HP_t} - \frac{\partial GDP_t / GDP_t}{\partial HP_t}$  from where the condition follows.

and GDP. Given the Housing Prices - Construction link, the following condition is necessary for Condition 1 to hold.

**A necessary and sufficient condition.** *Condition 1 holds if the marginal effect  $\beta$  of Construction on Non-Metallic Minerals is greater than the average material intensity of the economy, that is*

$$\beta > \frac{MF_t}{GDP_t} \quad (6)$$

An inconvenience of the necessary condition is that  $\beta$  is unobserved and its estimation requires further assumptions. Nonetheless, using the properties of  $N$ , we can state a sufficient condition based on observables:

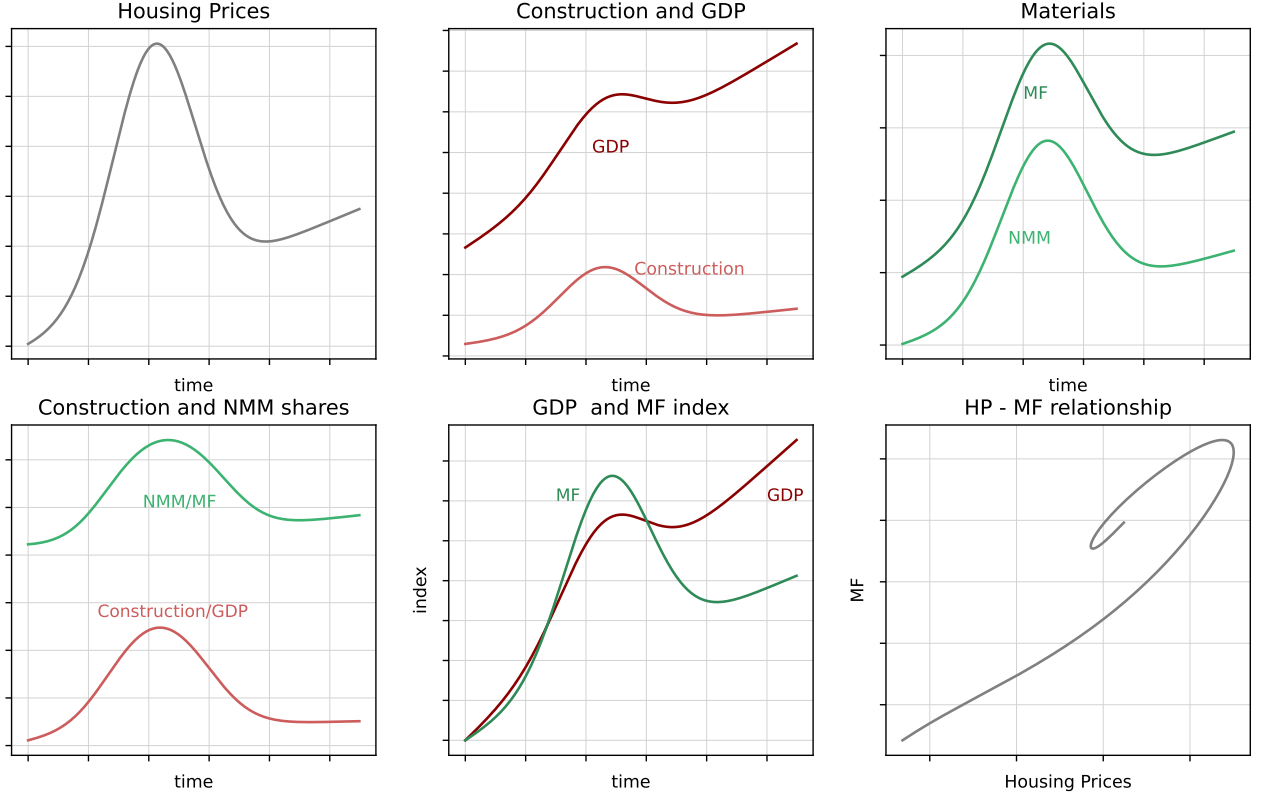
**A sufficient but not necessary condition.** *Condition 1 holds if the share of Non-Metallic Minerals on Material Footprint is greater than the Construction share of GDP, that is,*

$$\frac{NMM_t}{MF_t} > \frac{C_t}{GDP_t} \quad (7)$$

*Proof.* All we need to show is  $\frac{NMM_t}{C_t} \geq \beta = \frac{\partial NMM_t}{\partial C_t}$ . Since  $N$  is homogeneous of degree 1,  $NMM_t = N_c C_t + N'_z Z_t$  by the Euler Theorem's, where  $Z$  stands for a vector of other non-negative inputs of the  $N$  function and  $N_z$  is a vector of first derivatives. It follows that  $\frac{NMM_t}{C_t} = N_c + N'_z \frac{Z_t}{C_t}$  which implies  $\frac{NMM_t}{C_t} > N_c$  since all the elements in  $N'_z$  are positive and all the variables in  $Z_t$  are non-negative. Then,  $\frac{NMM_t}{C_t} \geq \beta > \frac{MF_t}{GDP_t}$ . In words: Condition 1 holds if the average Non-Metallic Minerals intensity of Construction is greater than the average material intensity of the GDP. Rearranging that, we get inequality (7). ■

Altogether, a Housing Price-driven Dematerialization cycle would unfold as follows. For some exogenous reason, Housing Prices go up; taking that as a signal of good times with high social valuation of their products, builders embark themselves in new housing promotions. Investment in new buildings demands products from a variety of suppliers, directly increasing GDP; besides, inputs of the construction industry consists mostly of Non-Metallic Minerals such as gravel or sand, raising then Material Footprints. The key point in the argument is that MF would grow more than GDP. A sufficient reason for that is that construction is more material-intensive than the overall economy or, what is equivalent, that construction share on GDP is lower than the Non-Metallic Minerals share on MF. Thus, the effect of this channel on GDP is smaller due to smaller weight of

Construction on GDP. A necessary and sufficient reason is that a new unit of value added in these new building projects demands more materials than the average economy, effectively raising the material intensity of the economy. Exactly the same but in the opposite direction would hold when Housing Prices go down. Given the existence of a common linear trend, a softer decline in GDP makes its recovery faster than that of MF such that, for some time, absolute dematerialization can be observed. Figure 1 shows a prototype of this Dematerialization cycle<sup>16</sup>.



**Figure 1: A prototype of a Housing Price-driven Dematerialization cycle.** This figure shows a simulation of the previous model given by equation (1)-(4). MF stands for Material Footprint; NMM for Non-Metallic Minerals; HP for Housing Prices. For the simulations, we have used the following functional forms:  $C_t = C(HP_t, \cdot) = \alpha_0 + \alpha_1 HP_t^\beta + t_{-1}$ ;  $OS_t = \alpha + \rho OS_{t-1}$ ;  $NMM_t = N(C_t, \cdot) = \alpha_2 + \alpha_3 C_t^\beta + \rho NMM_{t-1}$ ;  $OM_t = \alpha + \rho OM_{t-1}$ .

<sup>16</sup>It could be argued that we took a narrow approach: Housing Prices might not only affect investment but also consumption via wealth effects and collateralized debt; investment in construction spills over many related sectors via input-output networks; the use of more non-metallic minerals would demand higher demand of fossil fuels due to complementarities; etc. While we acknowledge these possibly powerful general equilibrium effects and leave some room for them in the statistical model, we wanted the simplest representation of the hypothesis. We could argue these 2nd round effects are not crucial to understand Dematerialization if we assume that they would increase GDP and MF in a proportional way.

### 3.- Methodology

In this section we present the methodology used to analyze the data and the hypothesis to be tested. We start with the popular IPAT framework to describe that decoupling must come from a residual typically associated with technology. However, we point out that IPAT is of limited help to understand the drivers since it misses potential dynamic interdependencies among the variables. We suggest that an Structural Vector Autorgression approach can help tackle this problem. Thus, we estimate a Panel SVAR whose results are explored via variance and historical decompositions as well as a counterfactual experiment.

The IPAT model poses the following identity:

$$\text{Impact} = \text{Population} \times \underbrace{\frac{\text{Production}}{\text{Population}}}_{\text{Affluence}} \times \underbrace{\frac{\text{Impact}}{\text{Production}}}_{\text{Technology}} \quad (8)$$

Applied to our case, the use of materials can be read as the product of population, production per capita and materials per unit of production (or Material Intensity). Through standard manipulations<sup>17</sup>, equation (8) can be restated in terms of growth rates as follows

$$i = p + a + \tau \quad (9)$$

where lower case letters stand for growth rates of  $i$  for the Material Footprint,  $p$  for Population and  $a$  for GDP per capita;  $\tau$  is a residual including Material Intensity growth and the approximation error. Besides, throughout the paper we define the GDP growth rate as  $g = p + a$ . With this notation, we define Dematerialization<sup>18</sup> as a situation of  $i < 0$  along with  $g > 0$ . In general, any excess growth of production over materials must come from a negative  $\tau$  (that is,  $g - i > 0$  implies  $\tau < 0$ ). Thus, throughout the paper we identify dematerialization with  $\tau$  such that  $\tau < (>)0$  would signal de(re)materialization.

By the variance sum law, to understand the variance of  $\tau$  within the IPAT framework one must account for the covariances between the remaining growth rates. Towards that end, the literature

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<sup>17</sup>Take natural logs and first difference (8), then it holds as a sum of log first differences which are an approximation of growth rates.

<sup>18</sup>For notational brevity, any time we talk of Dematerialization from now on we refer to Absolute Dematerialization unless otherwise stated.

has resorted to regression analysis, replacing  $\tau$  by some proxies (what has been renamed as STIRPAT starting with [Dietz and Rosa \(1997\)](#)). Nonetheless, a regression analysis typically imposes an endogenous-exogenous taxonomy of variables with a unidirectional causality that rules out a possible feedback among the variables<sup>19</sup>. Instead, we suggest that a Vector Autoregression (VAR) analysis might be useful to model dynamic interdependencies among all the variables.

In particular, consider the following model

$$\Delta y_{it} = A + B(L)\Delta y_{it} + \mathbb{1}(\text{cointegration=true})Cu_{it} + \mu_i + u_{it} \quad (10)$$

with  $i = 1, 2, \dots, I$ ;  $t = 1, 2, \dots, T$  for  $I$  countries and  $T$  years.  $\Delta$  is a first difference operator;  $y_{it}$  is a  $K \times 1$  vector of variables in log-levels for the country  $i$  in year  $t$ , with  $K$  being the number of endogenous variables;  $u$  stands for a possible cointegration relationship among all the variables in log-levels;  $\mathbb{1}()$  is an indicator variable that equals 1 if the variables in log-levels are cointegrated for the panel of countries and 0 otherwise;  $\mu_i$  is a  $K \times 1$  vector of country fixed effects;  $u_{it}$  is a  $K \times 1$  vector of shocks with  $\mathbb{E}(u_{it}) = 0$ ,  $\mathbb{E}(u_{it}u'_{it}) = \Sigma$  and  $\mathbb{E}(u_{it}u'_{is}) = 0$  for  $t > s$ .  $A$  is a  $K \times 1$  vector of constants;  $B(L)$  is a polynomial in the lag operator  $L$ , such that  $B(L)\Delta y_{it} = B_1\Delta y_{it-1} + B_2\Delta y_{it-2} + \dots$  where  $B_j$  is a  $K \times K$  matrix of coefficients associated with the endogenous variables;  $C$  is a  $K \times 1$  vector of coefficients associated with the exogenous cointegrating relationship<sup>20</sup>.

The specification in first differences renders a stationary model guaranteeing statistical moments are well-defined, the system is stable and then the PVAR can be inverted to get a PVMA representation. However, if a cointegrating relationship exists among the variables in levels, the model would be misspecified. Then, we test for panel cointegration and include the cointegrating relationship when needed. As remarked by [Pesaran \(2012\)](#), standard panel cointegration tests have problems dealing with heterogeneity. Since the panel has a decent time length, we analyze cointegration country-wise following a two-stage procedure: first we run a log-levels regression between all the variables with MF as the dependent one; then, we run ADF tests on the residuals of the previous regression ending up with a  $I \times 1$  vector of ADF statistics, that reveals an exact measure of the number of panels containing unit roots; the cointegrating relationship is included if residuals

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<sup>19</sup>An example of feedback are rebound effects: efficiency gains in principle would reduce the growth of consumption materials but then, less pressure on natural resource could reduce input costs, boosting production and then the use of materials ( $\downarrow \tau \rightarrow \downarrow i \rightarrow \uparrow (p+a) \rightarrow \uparrow i$ ).

<sup>20</sup>We assume the coefficients matrices are homogenous across units. This assumption is motivated by the fact that we obtained poolability in a static panel and the lack of a long enough time dimension in each panel.

are stationary for more than 2 of the panels. Appendix A describes the recipe in more detail.

We estimate the reduced-form equation (10) following the GMM approach used in [Love and Zicchino \(2006\)](#). Reduced-form residuals  $u_{it}$  are linear combinations of structural shocks, that is,  $u_{it} = D\epsilon_{it}$  with  $D$  being a non-singular matrix. Structural innovations can be recovered using  $\epsilon_{it} = D^{-1}u_{it}$  and  $K(K-1)/2$  additional restrictions. We resort to short run restrictions, based on the Cholesky decomposition of  $\Sigma$  that imposes a recursive order on the VAR with the last variable having no contemporaneous effect on the previous ones. We choose the order following theoretical guidelines that are discussed below and show the robustness of the results to a number of different orderings.

Once the structural shocks and coefficients are recovered, we explore the properties of the model by using three techniques: variance decomposition, historical decomposition and counterfactual analysis. The former indicates the contribution of each variable to explain the variance of one of them at different time horizons. The historical decomposition dissects  $y_{kt}$  (value of variable  $k$  at time  $t$ ) in a sum of factors associated to all  $K$  endogenous variables, that is,  $y_{kt} = \sum_{j=1}^K y_{kt}^j$  where  $y^j$  groups structural shocks and initial conditions for each variable. Due to the presence of an exogenous variable in the model, we proceed in two stages: first, the exogenous factor is subtracted from the series; then, shocks and initial conditions are grouped by variables such that at each point in time we can decompose the growth rate of variable  $k$  as the sum of factors coming from the other variables. Finally, we resort to counterfactual analysis. In particular, we explore the model prediction for the case of equal growth between housing and consumption prices. Since that counterfactual is in terms of levels, we reverse-engineer a synthetic series of structural shocks that delivers constant real housing prices. Appendix A describes the three techniques in a detailed manner.

## 4.- Results

This section reports the results of the analysis. In [Section 4.1](#) we explain the sample selection criterion and report some descriptive statistics that seems to be aligned with the Housing Prices hypothesis. [Section 4.2](#) shows the variance decomposition and [Section 4.3](#) the historical decomposition coming from the Panel SVAR estimation. In [Section 4.4](#), a counterfactual experiment is run.

Finally, a number of robustness tests are included in [Section 4.5](#).

#### 4.1.- Sample selection and descriptive statistics

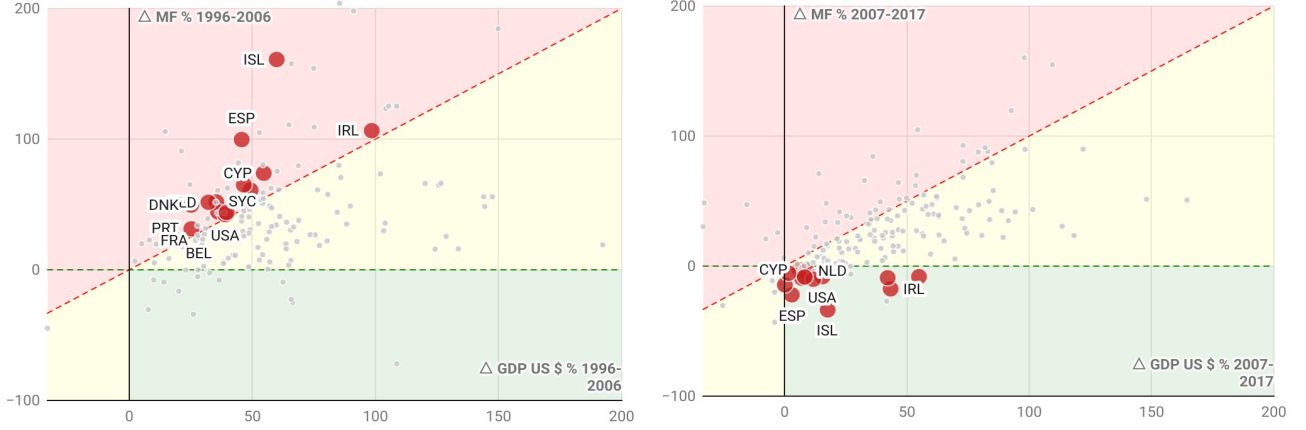
Using a panel of 155 countries from 1996-2017 we show that a set of countries have moved from no dematerialization over the 1996-2006 decade to absolute dematerialization the decade after (2007-2017). The selected sample stems from a two-stages procedure. First, we computed the accumulated growth between 1996 and 2006 for both MF and GDP for all 155 countries and keep the countries for which the growth rate of the MF was higher than the growth rate of GDP ( $i > g$ , following notation in equation (9)). For countries satisfying that criteria, we calculated  $i$  and  $g$  for the 2007-2017 decade. Then, we keep the countries exhibiting  $i < 0$  and  $g > 0$ . This was the final sample, formed by the countries that transitioned from a coupling scenario to an absolute decoupling scenario.

Figure 2 plots the transition that the selected countries experienced. The scatter plots the accumulated  $g$  against accumulated  $i$  over the 1996-2006 decade (top) and the 2007-2017 decade (bottom). The selected countries are Cyprus, Denmark, Finland, Iceland, Ireland, Malta, Netherlands, Portugal, Seychelles, Slovenia, Spain, UK and USA<sup>21</sup>.

Table 1 summarizes the descriptive statistics of the selected countries. Following the selection criterion,  $i$  and  $g$  showed the transition to Dematerialization, that is, in the first decade both are positive while  $i < 0$  and  $g > 0$  in the second. But what drives Dematerialization? Descriptive statistics seems to be consistent with what we hypothesized. First, the accumulated growth rate in Housing Prices is positive in the first decade and negative during the second. This positive growth rate in housing prices cohabited with both a higher growth rate in the value added of Construction and a greater growth rate of GDP during the first decade. This boom in the construction sector has an impact in the growth rate of Non-Metallic Minerals and, as a consequence, in the Material Footprint. The data showed a composition change in MF and GDP (the NMM share of MF and Construction over GDP increase in the first decade and decline in the second) that we regard as cyclical. Crucially, the stated sufficient condition for Housing Prices to trigger Dematerialization cycles holds in the data: the weight of the construction minerals over MF is higher than the weight

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<sup>21</sup>In the 2007-2017, there are only five more countries in Dematerialization territory: Swaziland, South Africa, Hungary, Estonia, Saudi Arabia. Thus, we explain an important part of global Dematerialization.



**Figure 2: The Red-to-Green Transition.** This graph plots the accumulated GDP growth ( $g$ ) against the accumulated MF growth ( $i$ ) for two decades, 1996-2006 on the left and 2007-2017 on the right. The dashed red line is the 45 degree line; the dashed green line is a  $i = 0$  line. Countries in the red area exhibit rematerialization ( $i > g$ ); countries in the yellow area have relative dematerialization ( $i < g$ ); countries in the green area exhibit absolute dematerialization ( $i < 0, g > 0$ ). The red big dots singularize countries moving from red to green. These countries are Cyprus, Denmark, Finland, Iceland, Ireland, Malta, Netherlands, Portugal, Seychelles, Slovenia, Spain, UK and USA. The gray small dots plots the rest of 155 countries.

of the construction value added over GDP. Finally, a high correlation between MF and Housing prices is observed, consistent with the last panel of Figure 1.

#### 4.2.- Variance Decomposition

This section presents a decomposition the variance of  $i$ ,  $g$  and  $\tau$  using the estimated Panel SVAR. The decomposition attributes a portion of the variance of  $i$ ,  $g$  and  $\tau$  to each variable of the model over a time horizon, pointing out the drivers over time. This technique reveals the limited role of technology to explain dematerialization, the remarkable part played by housing prices as well as the existence of an important part of the  $\tau$  variance that remains unexplained<sup>22</sup>.

The baseline model includes  $K=5$  variables, with  $y = [\text{Population, Housing Prices, TFP, GDP, Material Footprint}]$ <sup>23</sup>. Variables have been transformed, using logs and first differences such that all variables are  $I(0)$  and the VAR is well behaved (i.e., invertible). One lag has been used, since the information criteria are similar for 1 and 2 lags and we prefer to avoid losing observations.

<sup>22</sup>We do not report here neither the estimated coefficients nor Impulse-response functions. Both are reported in the Appendix. Basically, Housing Prices are the only variable with a significant coefficient in the Material Footprint regression. Besides, both Material Footprint and Material Intensity growth only respond significantly to a housing price shock. Thus, coefficients and IRFs seems consistent with our hypothesis.

<sup>23</sup>Note that this baseline version allows housing prices to directly influence GDP and MF, without imposing a single narrow channel via construction or non-metallic minerals whatsoever.

**Table 1: Descriptive statistics.** The table reports accumulated growths over each decade for Housing Prices (HP), Gross Domestic Product (GDP), Construction gross value added (C), Material Footprint (MF), Non-Metallic Minerals (NMM), the ratio between NMM and MF and the ratio between C and GDP. Besides, the last three columns report the mean of the NMM/MF ratio and C/GDP ratio and the correlation between HP and MF over the 1996-2017 period.

	HP	GDP	C	MF	NMM	$\frac{NMM}{MF}$	$\frac{C}{GDP}$	$\left(\frac{NMM}{MF}\right)$	$\left(\frac{C}{Y}\right)$	Corr(HP, MF)
	1996-06 2007-17	1996-06 2007-17	1996-06 2007-17	1996-06 2007-17	1996-06 2007-17	1996-06 2007-17	1996-06 2007-17	Mean	Mean	1996-2017
Cyprus	62.7 -22.5	54.6 6.1	93.8 -43.5	73.9 -2.8	97.1 -1.3	13.4 1.6	15.6 -56.7	73.1	8.4	0.8
Denmark	118.8 -10.2	25.2 9.1	45.2 7.2	49.5 -8.4	90.5 -9.7	27.4 -1.5	16.0 -1.8	46.0	5.1	0.9
Finland	94.4 18.5	46.5 1.6	86.0 9.2	65.0 -5.5	152.9 -16.2	53.2 -11.4	26.9 7.5	44.5	6.2	0.8
Iceland	147.3 4.7	61.2 16.1	149.7 -14.9	160.9 -33.7	200.6 -36.8	15.2 -4.7	54.9 -26.7	67.2	7.5	0.8
Ireland	189.8 -26.0	98.7 42.5	254.4 -58.2	106.5 -17.5	160.3 -22.1	26.1 -5.6	78.3 -70.7	53.7	5.4	0.9
Malta	162.6 9.1	55.3 58.7	63.4 35.0	43.9 -8.1	56.9 -11.0	9.1 -3.1	6.7 -17.4	66.2	5.4	0.9
Netherlands	86.7 -12.5	32.2 8.9	42.5 -12.5	51.7 -3.3	75.8 -3.7	15.9 -0.3	7.8 -19.6	50.1	5.1	0.9
Portugal	43.2 3.1	25.2 0.1	27.1 -41.1	31.3 -14.5	36.7 -21.1	4.0 -7.8	1.5 -41.2	59.7	6.2	0.4
Slovenia	46.4 -19.1	49.3 7.1	68.5 -26.8	60.9 -9.3	97.1 -13.1	22.5 -4.2	12.9 -31.6	50.2	6.3	0.9
Spain	120.3 -33.5	26.9 8.0	70.6 -45.5	99.7 -22.1	156.0 -26.6	28.2 -5.9	34.4 -49.6	50.5	9.1	0.9
UK	154.1 -0.2	36.5 11.6	67.4 10.0	44.3 -10.1	59.8 -12.4	10.7 -2.5	22.6 -1.5	53.2	6.0	0.7
USA	58.2 -5.6	39.0 16.1	73.8 -2.8	42.2 -8.1	57.1 -18.9	10.5 -11.7	25.0 -16.3	46.7	4.2	0.8

Thus, we end up with a panel of 12 countries over 21 years ( $I=12$ ,  $T=21$ ). It turns out the baseline variables in log-levels are only cointegrated in one country, so that the indicator function in equation (VAR) is turned off. Structural shocks are identified via short run restrictions. As it is well known, the Cholesky decomposition used to implement them is not unique but depends on the variables ordering. Our baseline order is Population, Housing Prices, TFP, GDP and Material Footprint. We opt for an order consistent with our hypothesis; fortunately, results are robust to many different orders, as we report in [Section 4.5](#). Apart from the baseline, we use other models in the variance decomposition, which are specified later.

Now we discuss some aspects of the baseline ordering. First, we make Population immune to contemporaneous movements of all the other variables since it is a slow moving object typically led by long run trends. Second, TFP might be contemporaneously affected by price shocks, since higher prices could directly reallocate resources towards the construction sector affecting aggregate TFP<sup>24</sup>. Besides, GDP is allowed to respond contemporaneously to Housing Prices, reflecting a possible effect of the latter on construction activity but also on other components of GDP, as consumption via wealth effects. Finally, Material Footprint is affected by all the shocks, to subdue it to the maximum amount of contemporaneous variation<sup>25</sup>.

Figure shows the variance decomposition of  $i$ ,  $g$  and  $\tau$  for different models<sup>26</sup>. First, what we call the “identity” model, which only includes the IPAT variables (i.e., Population, GDP and MF), shows that  $\tau$  is mostly driven by  $i$  (that explains about 80% of its variance over time), while  $p$  accounting for just 5%<sup>27</sup>. Hence, explaining  $\tau$  essentially amounts to understanding  $i$ . Subsequent models intend to do so.

First, technology proxied by TFP is included<sup>28</sup>. It turns out it explains a modest 2% of  $\tau$  variance over time, despite accounting for about 2/3 of  $g$  evolution<sup>29</sup>. The reason is that TFP explains little of  $i$  variation (about 10%) and precisely is the variation coming from  $g$ , so when  $g$

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<sup>24</sup>[Gopinath et al. \(2017\)](#) or [Doerr \(2018\)](#) provide evidence on the negative relationship between the housing boom and TFP in the US, Spain and other countries.

<sup>25</sup>According to our experience, explaining the variance of material footprint is way harder than that of GDP.

<sup>26</sup>The notation comes from equation (9). To avoid perfect collinearity, we have to exclude either  $i$  or  $g$  from the estimation. We opt for excluding  $g$  for reasons that are clear in the text.

<sup>27</sup>If  $g$  is included instead of  $i$ , it explains only 5% precisely showing that  $\tau$  variation is basically driven by  $i$ .

<sup>28</sup>The variable ordering is Population, TFP, GDP, MF for the reasons sketched above.

<sup>29</sup>Throughout the section, we report the central estimates for the variance share of each potential driver over a 10 year horizon. Confidence intervals are reported in the Appendix for some relevant cases.

is subtracted from  $i$  to get  $\tau$ , almost nothing comes from TFP<sup>30</sup>. If technology was a dematerialization force, it would not only increase  $g$  but also reduce  $i$ ; nothing like this is observed in the data. Unfortunately, this is not a TFP issue; Section 4.5. reports that an array of other variables such as services share, the renewable energy share or energy per dollar do not yield better numbers.

In front of that considerable unexplained  $\tau$  variance, we try an alternative model consistent with the housing price cycle hypothesis. Thus, when Housing Prices are included into the previous model, they account for about 20% of  $i$  variation. Indeed, Housing Price growth is an important driver of both  $i$  and  $g$ , explaining about 40% of their evolution over a decade. Note, though, that since  $\tau$  is mostly driven by  $i$  and  $i$  is more volatile than  $g$ <sup>31</sup>, explaining almost the same fraction of  $i$  and  $g$  means that Housing Prices growth is able to account for a remarkable chunk of  $\tau$  variation. Finally, a construction activity proxy is introduced accounting for a further 8% of  $\tau$  variance. Altogether, housing prices and construction activity explain about half of  $i$  variance and about 1/3 of  $\tau$  variance, suggesting that an important part of dematerialization is a cyclical phenomenon in line with the stated hypothesis.

### 4.3.- Historical Decomposition

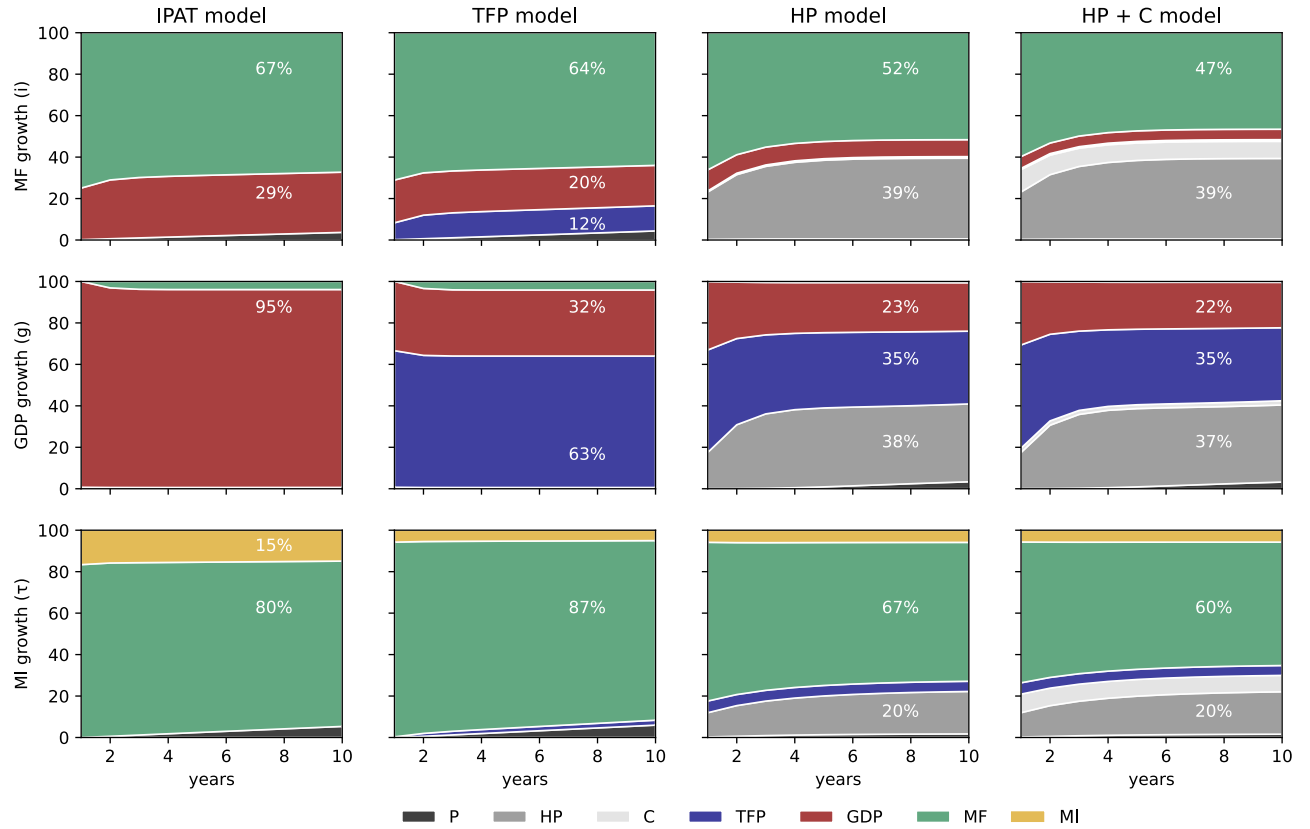
In this section we decompose the time series of  $i$  and  $g$  at each point in time as a sum of components associated to each of the variables in the SVAR system. For instance, the Material Footprint growth time series is decomposed as a sum of a MF growth time series implied by Housing Prices, another series implied by TFP and so on, that is,  $i_t = i_t^P + i_t^{HP} + i_t^{TFP} + i_t^{GDP} + i_t^{MF}$ .

Figure 4 shows the baseline Material Footprint growth ( $i$ ) historical decomposition for all the countries. An stylized pattern can be visually identified:  $i$  is mostly driven by two opposed forces, a gray force that drives it up and a green force that drives it down such that their relative strength largely determined the evolution of Material Footprints. Thus, during the first decade the gray force dominated the green one, generally rendering a positive  $i$  and then, higher MF; in the years of the financial crisis the gray force collapsed, even yielding a negative contribution and the green force strongly pushed down, showing an important degrowth in Material Footprints; after the crisis, the

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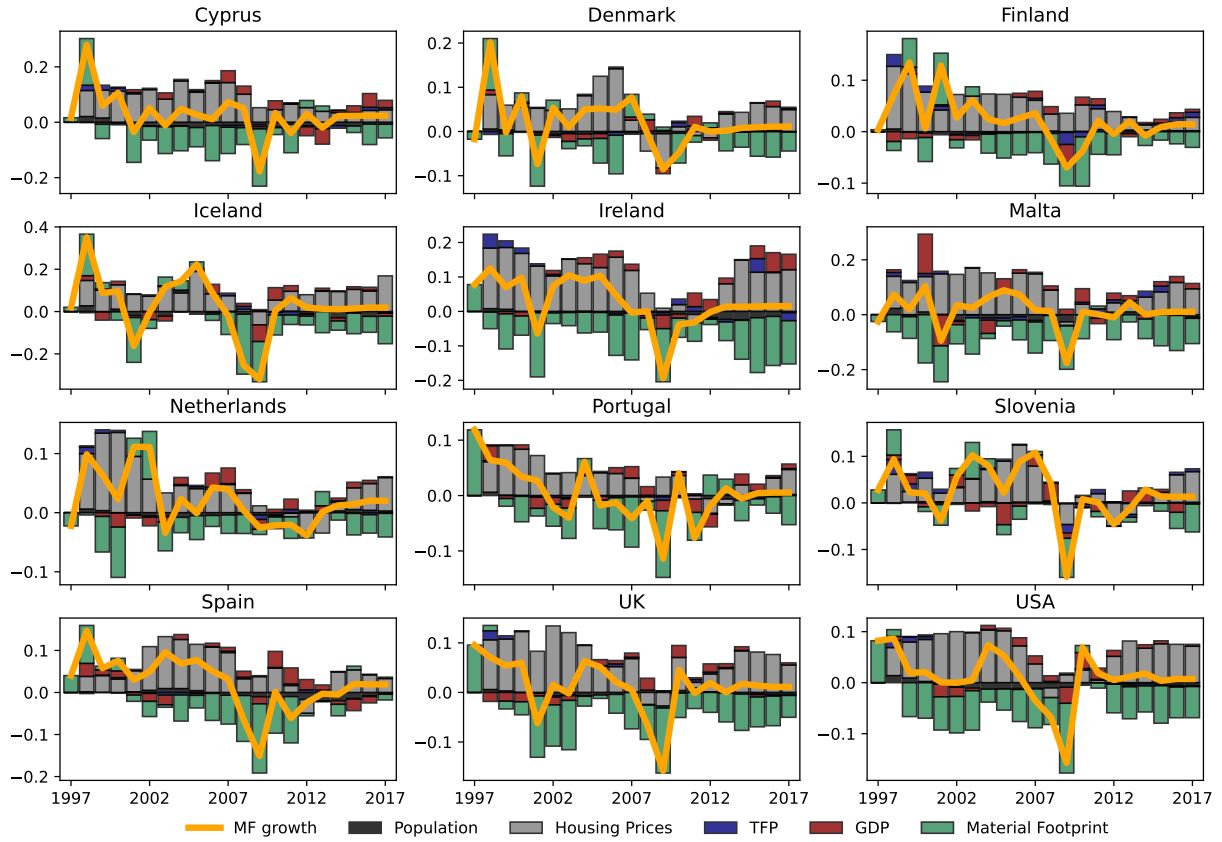
<sup>30</sup> $g$  alone explain about 30% of  $i$  variance. When TFP growth is added, the contribution of TFP and  $g$  still adds up to about 30%, showing that TFP growth is simply explaining the part of the  $i$  that has to do with  $g$ . To explain  $\tau$ , TFP would have to explain a part of  $i$  unrelated to  $g$ .

<sup>31</sup>On average across time and countries,  $i$  is about 2.5 times more volatile than  $g$ .



*Figure 3: Variance Decomposition of Material Footprint, GDP and Material Intensity using different models. The first column shows the results of the IPAT model, including Population, GDP and MF in that order; the second column adds TFP after Population; the third column adds Housing Prices before TFP; the last column adds Construction (proxied as intermediate consumption in construction) after Housing Prices. The first row shows the variance decomposition of Material Footprint growth; the second of GDP; the last one of Material Intensity. The decomposition use estimations of the Panel SVAR for the different models. Annual data from 1996 to 2017 for the selected sample.*

gray force recovered but with less strength than before<sup>32</sup> and then it was largely offset by the green force, yielding an almost zero growth. In other words, the observed decline in Material Footprints is due to both a strong degrowth during the crisis that results from the joint action of the green and a depressed gray force and an almost steady state afterwards due to the green offsetting of gray. The gray force is Housing Prices; the green force was not identified but does not seem technology in any of its measures. Since the variance decomposition pointed out that Dematerialization  $\tau$  was basically driven by MF growth  $i$ , this green-gray balance is indeed the key factor driving the historical dynamics of  $\tau$ <sup>33</sup>.



*Figure 4: **Historical Decomposition of the Material Footprint growth by country.** The graph plots the Historical Decomposition of the Material Footprint growth  $i$  resulting from the baseline Panel SVAR estimation. The orange line plots the observed  $i$ . The coloured bars decompose  $i$  at each point in time such that the sum of the bars equal the orange line at each point in time. Annual data from 1996 to 2017 for the selected sample.*

<sup>32</sup>Housing Prices recovered quite notably in countries like US, UK or Ireland, exerting a pressure on  $i$  similar to the one during the boom years.

<sup>33</sup>Given its secondary relevance, the  $g$  historical decomposition is relegated to the Appendix.

#### 4.4.- What would have happened without the housing boom and bust?

In this section, a counterfactual experiment explores the effects of an alternative Housing Prices trajectory on the dynamics of GDP and MF. In particular, we set prices as following the Consumption Price Index such that Housing Prices relative to the CPI are constant. Set it differently, we simulate a trajectory without the housing price cycle. According to our hypothesis, constant prices would have avoided a rematerialization - dematerialization cycle; in reality, though, other forces are at play as set out in the variance and historical decompositions.

Figure 5, 6 and 7 show the observed and counterfactual trajectories of Housing Prices, Material Footprints and GDP for all selected countries. Invariably, stable Housing Prices would have delivered lower Material Footprints. In some countries as Cyprus and Slovenia, MF would have grown only about half of the observed trajectory; in others as Denmark, Finland, Iceland, Ireland, Netherlands and Spain, MF would have been virtually constant; it would have even gone moderately down in Malta, Portugal, UK and USA. As for GDP, the pattern is that the absence of a housing boom would have sacrificed some growth in the first decade although by the end of the sample the GDP level would have been almost the same. That is particularly true for countries as USA, Slovenia, Ireland or Cyprus. For others, as Spain or the UK, GDP growth was very dependent on the housing boom to the point that stable housing prices would have completely killed  $g$  in the first decade, although certain recovery would have taken place in the second decade driven by TFP and other factors. Altogether, stable Housing Prices would have accelerated the dematerialization in all the countries. The reason is the existence of the green force that push MF down as well as the fact that TFP is an important force driving up GDP without boosting MF.

#### 4.5.- Robustness tests

In this section we show that our main findings are robust to some alternative choices. We focus on three dimensions: SVAR identification, additional measures of Technology and other potential drivers.

**SVAR identification.** The identification of structural shocks relied on a recursive scheme. As we have already mentioned, the SVAR results depends on the variables ordering. Since for the 5 variables in the baseline model there would be a total of 120 possible permutations, we opt for



Figure 5: **Counterfactual: Material Footprints and GDP trajectories in the absence of a housing boom (I).** The graph plots the observed and simulated paths for Housing Prices, Material Footprint and GDP for a number of countries. The series are index numbers using 1997=100. The counterfactual series imposes a housing price inflation equal to consumer price inflation such that real housing prices remain constant.

playing with the order of the two main variables of interest, TFP and Housing Prices, leaving the rest of the variables of the baseline in the same relative position. It turns out results are remarkably similar. Table 2 show the share of the variance of both  $i$  and  $g$  explained by TFP and HP over a decade. In all reasonable cases, Housing Prices explains about a third of MF growth. The share is reduced to 13% when Housing Prices are placed in the last position (i.e., allowing all the other shocks to affect them contemporaneously); note, though, that the fact that shocks in the use of materials affects in the same period Housing Prices is probably hard to justify in terms of standard asset pricing theory. Besides, when changing the order of TFP, it can improve its performance from 0.8% to 6.7% of MF growth variance, still a modest contribution.

**Technology measurement.** The aim of the paper was to understand the drivers of  $\tau$  which is typically associated to Technology. Throughout the study, we operationalized Technology in a standard way as Total Factor Productivity and found that the latter seems to have played a modest role. Yet, it would be still possible that TFP was a bad or at least incomplete measure and other omitted variables were playing a part. To tackle that possibility, we include four additional variables related



Figure 6: **Counterfactual: Material Footprints and GDP trajectories in the absence of a housing boom (II).** The graph plots the observed and simulated paths for Housing Prices, Material Footprint and GDP for a number of countries. The series are index numbers using 1997=100. The counterfactual series imposes a housing price inflation equal to consumer price inflation such that real housing prices remain constant.

to different aspects of Technology. First, the share of renewable energy over total energy sources, since renewables would rise more intensely after the financial crisis. Again, renewables growth contribution is negligible. Besides, since some studies unfold that part of the Solow's residual is in fact due to energy [Steger and Bleischwitz \(2011\)](#), we included energy intensity and energy per capita that, however, explain less than 5%. In a different direction, the rise of intangible capital could be a green force by representing a growing share of productive inputs being presumably divorced from materials use (e.g., software vs. machines). This intangible capital does not seem to be behind the Dematerialization either. Moreover, as suggested by [Wu et al. \(2019\)](#) and [Germani et al. \(2014\)](#), we consider a technological measure including public and private expenditure in Research and Development share of GDP. Then again, the effect of the aforementioned variable over the MF variation is almost unperceptive. Finally, as some authors have highlighted a change in the structure of demand towards service sectors could lead to either a decline of material-intensive industries or give incentives for sectoral innovation [Steger and Bleischwitz \(2011\)](#). However, when including it in the baseline model our main results do not drastically change; the share of services in GDP and TFP



Figure 7: **Counterfactual: Material Footprints and GDP trajectories in the absence of a housing boom (III).** The graph plots the observed and simulated paths for Housing Prices, Material Footprint and GDP for a number of countries. The series are index numbers using 1997=100. The counterfactual series imposes a housing price inflation equal to consumer price inflation such that real housing prices remain constant.

explains only 1.2%. Panel a of Table 3 reports the contribution to the variance of all these variables.

**Other candidates.** In this section, we consider three alternative stories. First, we have included the labour share and real consumption per capita. The idea would be that rising inequality in a context of recession and limited access to credit would reduce consumption for both unemployed and borrowing constrained households and then, the consumption would have gone down, perhaps taking the MF with it, as suggested by López et al. (2015). However, the power of explanation of the labour share and the real consumption per capita are rather limited, 2.2% and 7.6% of the MF variation over a decade respectively. Additionally, we included international trade as a possible explanation of the MF variation since it is a phenomenon that has social, political and economic aspects and directly affects production-consumption, environment and human behaviors<sup>34</sup> (Bilgili et al. (2020); Ulucak et al. (2020); Sahoo et al. (2021)). Again, its predictive

<sup>34</sup>According to Ulucak et al. (2020) globalization enables countries to improve their welfare by eliminating trade barriers and diffusing technological progress that is useful to decrease resource use and to produce less waste and pollution. It is also one of the main drivers of environmental awareness since people easily get in touch worldwide through increasing interaction and integration tools thanks to globalization. On the other hand, trade increases the

Table 2: **Robustness of the SVAR identification scheme.** This table reports the variance of Material Footprint and GDP explained by Housing Prices and Total Factor Productivity over a decade (horizon = 10). Each line represents an alternative recursive order in the SVAR with Cholesky restrictions. The first variable is contemporaneously unaffected by the others, the second only contemporaneously affected by the first and so on.

	MF Response to:		GDP Response to:	
	HP	TFP	HP	TFP
<i>Ordering</i>	<i>Changing the order of Housing Prices</i>			
P <b>HP</b> GDP TFP MF	38.9	0.8	37.6	35.1
<b>HP</b> P TFP GDP MF	38.4	0.8	36.2	23.4
P TFP <b>HP</b> GDP MF	33.6	6.1	24.2	48.5
P TFP GDP <b>HP</b> MF	27.2	6.1	21.8	48.5
P TFP GDP MF <b>HP</b>	13.4	6.1	16.6	48.5
	<i>Changing the order of TFP</i>			
P HP <b>TFP</b> GDP MF	38.9	0.8	37.6	37.6
<b>TFP</b> P HP GDP MF	33.6	6.1	24.2	48.5
P <b>TFP</b> HP GDP MF	33.6	6.1	24.2	48.5
P HP GDP <b>TFP</b> MF	38.9	3.4	37.6	0.6
P HP GDP MF <b>TFP</b>	38.9	0.8	37.6	0.9

power was rather small, 6.7% of the MF growth dynamics. Finally, human capital has been added, following sociological theories that suggest that as GDP grows then a country will improve human capital and this, in turn, would affect people preferences towards environmentally responsible actions (Inglehart (1971)). Indeed, other studies found that human capital helps reduce the material footprint significantly (Sahoo et al. (2021); Ulucak et al. (2020)). Unfortunately, our results show that human capital's contribution is tiny. Panel b of Table 3 reports the results for these variables.

## 5.- Conclusions

Breaking with a history of coupled paths of GDP and material use, a dozen of rich countries have managed to grow their GDP while decreasing their use of materials over the decade after the Global Financial Crisis. Moreover, this Absolute Dematerialization seems aligned with Green Growth theories that international institutions have endorsed.

size of economic activities such as trade and transportation, leading to more resources use, wastes and pollution.

*Table 3: Robustness to alternative proxies of Technology and other potential drivers. This table reports the variance of Material Footprint and GDP explained by Housing Prices, Total Factor Productivity and an array of new variables over a decade (horizon = 10). Both panels uses short run restrictions for identifying the structural shocks. Panel a uses the baseline ordering and places the new variable right after TFP (P HP TFP New Variable GDP MF); panel b places the new variable right before TFP (P HP New Variable TFP GDP MF).*

	MF Response to:			GDP Response to:		
	HP	TFP	New Variable	HP	TFP	New Variable
	<i>a: Alternative proxies for Technology</i>					
Renewable Energy Share	38.0	0.8	0.5	34.8	35.4	2.4
Energy Consumption pc	37.5	0.8	3.4	37.1	35.6	3.6
Energy Intensity	37.5	0.8	4.0	37.1	35.6	0.7
Services share of GDP	39.0	0.8	0.4	37.7	34.3	4.0
Intangible Capital to GDP ratio	35.0	3.9	2.2	38.9	39.4	0.3
R&D share of GDP	37.8	1.74	0.5	35.5	36.1	4.3
	<i>b: Alternative drivers</i>					
Human Capital	33.6	0.6	7.1	36.4	34.8	1.2
Real Consumption pc	35.2	0.2	7.6	29.7	28.8	14.1
Labour Share	38.9	3.8	2.2	35.2	23.4	14.4
Net Exports share of GDP	33.8	4.5	6.7	44.4	35.2	3.8

Unfortunately, we have not found many roles for Green Growth related variables in the Dematerialization dynamics. A wide array of variables related to it, such as TFP, the share of renewable energies, intangible capital, or the services share of GDP, accounts for no more than 10% of the Dematerialization variance over the 1996-2017 period. This piece of evidence contributes to the existing literature by pointing out that even when Dematerialization is happening, Technology does not play a prominent role, at least so far.

Alternatively, we suggest that the observed Dematerialization is, in part, a cyclical phenomenon linked to the housing bubble burst. We show that if Construction activity follows Housing Prices and the MF is more sensitive to Construction than GDP, Housing Price cycles will lead to Rematerialization-Dematerialization dynamics, as observed in the data. Indeed, the data analysis shows that the Housing Price hypothesis explains about 1/3 of the observed Dematerialization.

The results could inspire some policy reflections. Since Dematerialization would have gone faster in the absence of the housing boom, policies leaning against that boom would have helped push toward environmental sustainability. In other words, monetary and fiscal policy via interest rates, capital taxes, and regulations could have avoided part of that exuberant housing boom, contributing not only to macroeconomic and financial stability but also to the Green transition. Thus, in a moment when Governments and Central Banks are all setting up plans to boost that transition, this paper suggests a concrete connection between macroeconomic policies and environmental sustainability via asset prices that could be worth it to explore.

Nonetheless, Material Footprints would have remained way above their sustainable limits had the excesses associated with the housing bubble been avoided. In other words, even without the instability of capital markets and the potential resource misallocation they trigger, prosperous economies do not seem to navigate fast enough towards environmental sustainability. Perhaps worse, their modest progress does not seem much related to Technology. Altogether, this result raises skepticism about any policy plan relying primarily on Technology and calls for more research to understand the drivers of Material Footprints.

## References

- Adam, K., Kuang, P., and Marcet, A. (2012). House price booms and the current account. *NBER Macroeconomics Annual*, 26(1):77–122.
- Ansari, M. A., Haider, S., and Khan, N. (2020). Environmental kuznets curve revisited: An analysis using ecological and material footprint. *Ecological Indicators*, 115:106416.
- Bilgili, F., Ulucak, R., Koçak, E., and İlkay, S. Ç. (2020). Does globalization matter for environmental sustainability? empirical investigation for turkey by markov regime switching models. *Environmental Science and Pollution Research*, 27(1):1087–1100.
- Bleischwitz, R., Nechifor, V., Winning, M., Huang, B., and Geng, Y. (2018). Extrapolation or saturation—revisiting growth patterns, development stages and decoupling. *Global Environmental Change*, 48:86–96.
- Brainard, W. C. and Tobin, J. (1968). Pitfalls in financial model building. *The American Economic Review*, 58(2):99–122.
- Bringezu, S. and Bleischwitz, R. (2017). *Sustainable resource management: global trends, visions and policies*. Routledge.
- Dietz, T. and Rosa, E. A. (1997). Effects of population and affluence on co2 emissions. *Proceedings of the National Academy of Sciences*, 94(1):175–179.
- Doerr, S. (2018). Collateral, reallocation, and aggregate productivity: Evidence from the us housing boom.
- Dudka, S. and Adriano, D. C. (1997). Environmental impacts of metal ore mining and processing: a review. *Journal of environmental quality*, 26(3):590–602.
- Ehrlich, P. R. and Holdren, J. P. (1971). Impact of population growth: Complacency concerning this component of man’s predicament is unjustified and counterproductive. *Science*, 171(3977):1212–1217.
- European Union, T. (2022). Decision (eu) 2022/591 of the european parliament and of the council of 6 april 2022 on a general union environment action programme to 2030.
- Georgescu-Roegen, N. (1977). The steady state and ecological salvation: a thermodynamic analysis. *BioScience*, 27(4):266–270.

- Germani, A. R., Morone, P., and Testa, G. (2014). Environmental justice and air pollution: A case study on italian provinces. *Ecological Economics*, 106:69–82.
- Giljum, S., Dittrich, M., Lieber, M., and Lutter, S. (2014). Global patterns of material flows and their socio-economic and environmental implications: a mfa study on all countries world-wide from 1980 to 2009. *Resources*, 2(1):319–339.
- Giljum, S., Wieland, H., Lutter, S., Bruckner, M., Wood, R., Tukker, A., and Stadler, K. (2016). Identifying priority areas for european resource policies: a mrio-based material footprint assessment. *Journal of Economic Structures*, 5(1):1–24.
- Girouard, N. and Blöndal, S. (2001). House prices and economic activity.
- González-Vallejo, P., Marrero, M., and Solís-Guzmán, J. (2015). The ecological footprint of dwelling construction in spain. *Ecological Indicators*, 52:75–84.
- Gopinath, G., Kalemli-Özcan, Ş., Karabarbounis, L., and Villegas-Sanchez, C. (2017). Capital allocation and productivity in south europe. *The Quarterly Journal of Economics*, 132(4):1915–1967.
- Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., et al. (2020). A systematic review of the evidence on decoupling of gdp, resource use and ghg emissions, part ii: synthesizing the insights. *Environmental Research Letters*, 15(6):065003.
- Hertwich, E. G. (2021). Increased carbon footprint of materials production driven by rise in investments. *Nature Geoscience*, 14(3):151–155.
- Huang, C., Han, J., and Chen, W.-Q. (2017). Changing patterns and determinants of infrastructures’ material stocks in chinese cities. *Resources, Conservation and Recycling*, 123:47–53.
- Inglehart, R. (1971). The silent revolution in europe: Intergenerational change in post-industrial societies. *American political science review*, 65(4):991–1017.
- Jackson, T. (2009). *Prosperity without growth: Economics for a finite planet*. Routledge.
- Jiang, M., Behrens, P., Yang, Y., Tang, Z., Chen, D., Yu, Y., Liu, L., Gong, P., Zhu, S., Zhou, W., et al. (2022). Different material footprint trends between china and the world in 2007-2012 explained by construction-and manufacturing-associated investment. *One Earth*, 5(1):109–119.

- Karakaya, E., Sari, E., and Alataş, S. (2021). What drives material use in the eu? evidence from club convergence and decomposition analysis on domestic material consumption and material footprint. *Resources Policy*, 70:101904.
- Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., and Haberl, H. (2017). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences*, 114(8):1880–1885.
- López, L. A., Morenate, M., Zafrilla, J. E., and Arce, G. (2015). Financial crisis and consumption patterns effects on carbon and material footprint.
- Love, I. and Zicchino, L. (2006). Financial development and dynamic investment behavior: Evidence from panel var. *The Quarterly Review of Economics and Finance*, 46(2):190–210.
- Oberle, B., Bringezu, S., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Clement, J., Cabernard, L., Che, N., Chen, D., Droz-Georget, H., et al. (2019). Global resources outlook 2019: natural resources for the future we want.
- OECD, T. G. G. (2011). Monitoring progress: Oecd indicators. *Paris: Organization for Economic Co-operation and Development*, page 10.
- Pesaran, M. H. (2012). On the interpretation of panel unit root tests. *Economics Letters*, 116(3):545–546.
- Plank, B., Eisenmenger, N., Schaffartzik, A., and Wiedenhofer, D. (2018). International trade drives global resource use: a structural decomposition analysis of raw material consumption from 1990–2010. *Environmental Science & Technology*, 52(7):4190–4198.
- Pothen, F. and Welsch, H. (2019). Economic development and material use. evidence from international panel data. *World Development*, 115:107–119.
- Sahoo, M., Saini, S., and Villanthenkodath, M. A. (2021). Determinants of material footprint in brics countries: an empirical analysis. *Environmental Science and Pollution Research*, 28(28):37689–37704.
- Scott, K. (2009). A literature review on sustainable lifestyles and recommendations for further research.

- Shao, Q., Schaffartzik, A., Mayer, A., and Krausmann, F. (2017). The high ‘price’ of dematerialization: A dynamic panel data analysis of material use and economic recession. *Journal of Cleaner Production*, 167:120–132.
- Steger, S. and Bleischwitz, R. (2011). Drivers for the use of materials across countries. *Journal of Cleaner Production*, 19(8):816–826.
- Steinberger, J. K. and Krausmann, F. (2011). Material and energy productivity.
- Steinberger, J. K., Krausmann, F., and Eisenmenger, N. (2010). Global patterns of materials use: A socioeconomic and geophysical analysis. *Ecological Economics*, 69(5):1148–1158.
- Sun, M. Y., Mitra, M. P., and Simone, M. A. (2013). The driving force behind the boom and bust in construction in europe.
- Telega, I. and Telega, A. (2020). Driving factors of material consumption in european countries—spatial panel data analysis. *Journal of Environmental Economics and Policy*, 9(3):269–280.
- Ulucak, R. and Koçak, E. (2018). Rebound effect for energy consumption: the case of turkey. *EconWorld*, pages 1–10.
- Ulucak, R., Koçak, E., Erdoğan, S., and Kassouri, Y. (2020). Investigating the non-linear effects of globalization on material consumption in the eu countries: Evidence from pstr estimation. *Resources policy*, 67:101667.
- UNEP, U. (2011). Towards a green economy: Pathways to sustainable development and poverty eradication. *Nairobi, Kenya: UNEP*.
- West, J. and Schandl, H. (2018). Explanatory variables for national socio-metabolic profiles and the question of forecasting national material flows in a globalized economy. *Journal of Industrial Ecology*, 22(6):1451–1464.
- Wiedmann, T. O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., and Kanemoto, K. (2015). The material footprint of nations. *Proceedings of the national academy of sciences*, 112(20):6271–6276.
- World Bank, T. (2012). *Inclusive green growth: The pathway to sustainable development*. The World Bank.

- Wu, Z., Schaffartzik, A., Shao, Q., Wang, D., Li, G., Su, Y., and Rao, L. (2019). Does economic recession reduce material use? empirical evidence based on 157 economies worldwide. *Journal of cleaner production*, 214:823–836.
- York, R., Rosa, E. A., and Dietz, T. (2003). Stirpat, ipat and impact: analytic tools for unpacking the driving forces of environmental impacts. *Ecological economics*, 46(3):351–365.
- Zheng, X., Wang, R., Wood, R., Wang, C., and Hertwich, E. G. (2018). High sensitivity of metal footprint to national gdp in part explained by capital formation. *Nature Geoscience*, 11(4):269–273.