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Evidence from International Panel Data

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Abstract

Between 1990 and 2008, many industrializing countries have experienced tremendous economic growth, which coincided with a substantial increase in the use of materials. That poses the question how a continued economic convergence of developing nations will affect the use of biomass, fossil fuels, and minerals. Building on the Environmental Kuznets Curve hypothesis, this study investigates whether material use reaches a maximum at a certain level of economic development and declines in income thereafter. Two indicators operationalize material use. Domestic Material Consumption (DMC) measures the apparent use of materials in a country. The Material Footprint (MFP) quantifies all materials extracted to produce a country's final demand, including materials embodied in imports. Employing a panel consisting of 144 countries, initial estimations results suggest an S-shaped (cubic) relationship between GDP per capita and material use, but the relationship is monotonically positive over most of the income range. The coefficients of the cubic model tend to become nonsignificant once endogeneity and non-stationarity are accounted for. A linear specification yields a significant (positive) coefficient irrespective of the estimation method and can thus be considered a satisfactory approximation to the income-material use relationship. The linear models that account for endogeneity and non-stationarity suggest a greater income-materials elasticity for MFP than for DMC. The long-run income elasticity is estimated to be 0.562 for DMC and 0.752 for MFP.

JEL Classifications: C36, O13, Q32

Keywords: Economic Development; Material Use; Material Footprint; Environmental Kuznets Curve; Economic Transformation

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1 Introduction

The years between 1990 and 2008, from the fall of the Iron Curtain until the advent of the financial crisis, were characterized by tremendous economic growth in parts of the world. Industrializing nations in the former Eastern Bloc and in Asia converged rapidly to high-income developed countries. Real Gross Domestic Product (GDP) per capita grew, for instance, by 128% in Poland and by 155% in India. China's GDP per capita rose from 2,321 US$ to 7,411 US$, an increase of 219%.

During the same period, the amount of materials used in the world economy rose substantially as well. In 1990, 37.2 billion metric tons of minerals, fossil fuels, and biomass were extracted and subsequently consumed or used in production processes. This number rose to 69.7 billion tons in 2008, an increase of 87.4%

The extraction, processing, and utilization of raw materials are responsible for diverse environmental problems. These include local water, air, and soil pollution as well as the emission of greenhouse gases. Some scholars interpret the use of materials as a measure of the physical scale of global economic activity and its impact on sustainability (Fischer-Kowalski and Hüttler 1998). Hoekstra and Wiedmann (2014) find that the utilization of materials already exceeds sustainable levels.

Considering that China's GDP per capita was only about 17% of the USA's level in 2008, the question arises how the use of materials changes if developing nations' convergence continues. The Environmental Kuznets Curve (EKC; Grossman and Krueger, 1991) hypothesis gives rise to optimism. It postulates an inverted U-shaped relationship between income and environmental damages. In the early phase of economic development, income growth has a detrimental effect on sustainability. Economic activities expand and nations build up infrastructure. Both lead to rising pollution (scale effect). When countries grow further, their technologies improve and their environmental regulations get more stringent (technique effect). In addition, structural transformation in the process of economic growth may change the sectoral structure of economic activity towards less pollution-intensive sectors (composition effect). The EKC hypothesis predicts that, as a result of the scale, composition and technique effects, environmental damage reaches a maximum and declines in income thereafter.

This study investigates the relationship between national income growth and material use and, specifically, whether there is evidence for an Environmental Kuznets Curve for material use. We employ two indicators to operationalize material use. Domestic Material Consumption (DMC) quantifies a country's apparent use of materials. It equals domestic extraction plus imported minus exported materials and constitutes a production-based indicator of material use. The Material Footprint (MFP) is a consumption-based indicator. It records all materials extracted to produce a country's final demand. These include indirect flows which are necessary in the manufacturing process, but which become unobservable once a good crosses a border. The amount of imported steel can be recorded easily, for instance, but the coal needed to reduce the iron ore is not observed. We measure both indicators in per capita terms. Material use serves as an umbrella term for the two indicators throughout the paper. Due to a higher data quality, we restrict our study to used materials which enter the production and consumption processes. Unused extraction, such as overburden from mining, is not considered.

The distinction between DMC and MFP is important with respect to the EKC hypothesis. With rising income, rich countries may switch from producing material-intensive goods to importing them, for instance to circumvent environmental damages at home. DMC and MFP may hence respond differently to income growth, and the response may differ by the stage of economic development. From a sustainability point of view, what matters is how MFP, rather than DMC, evolves in the development process.

We construct a panel consisting of 144 countries and spanning from 1990 to 2008. Data on DMC is taken from the SERI/WU Global Material Flows Database (SERI 2013; Lutter et al. 2014). We use the Material Footprints compiled by Wiedmann et al. (2015). GDP data is taken from the Penn World Tables version 8.1 (Feenstra et al. 2015). Population data stems from the same source.

We first employ a fixed-effect (FE) panel econometric model, allowing us to control for country-level particularities and for time trends. Models which presume a quadratic, linear, and cubic relationship between GDP per capita and DMC as well as MFP per capita are estimated. Furthermore, we conduct an instrumental variable estimation, using data on infant mortality from the World Bank's World Development Indicators as an instrument for GDP per capita. The instrumental variable estimation accounts for endogeneity issues and provides an indication if income changes are causal for changes in material use. As a further alternative to the FE model, a between estimator (BE) is used to account for issues of non-stationarity. In our preferred specification, we conduct an IV estimation of country averages to jointly cope with endogeneity and non-stationarity.

This study makes three major contributions. First, previous EKC literature has only studied the apparent use of materials. We are the first to investigate whether there is evidence for an EKC for Material Footprints and for Domestic Material Consumption.[2] Second, we employ a dataset that includes both developing and developed economies and has the most comprehensive country coverage of all studies investigating EKCs on material use. This allows us to draw more general conclusions, in particular compared to research limited to developed nations. Third, our study is the first to investigate whether the relationship between income and material use is causal.

Since the initial contribution by Grossman & Krueger (1991), a comprehensive literature searching for Environmental Kuznets Curves has emerged. Reviews are provided by Dasgupta et al. (2002), Stern (2004), Dinda (2004), and Stern (2014). Most researchers have analyzed local air and water pollutants or carbon emissions. Only four studies have been published which explore the EKC hypothesis for material use.[3] Employing data on 16 industrialized countries between 1960 and 1998, Canas et al. (2003) study the relationship between income and the Direct Material Input (DMI). DMI consists of domestic extraction and imported materials.[4] Canas et al. (2003)'s results are consistent with the EKC hypothesis but also with an N-shaped relationship between income and DMI. Bringezu et al. (2004) come to similar conclusions. Vehmas et al. (2007) study the DMI and DMC of the EU15 between 1980 and 2000. For DMI, they find an EKC only for Germany. In case of DMC, they report EKCs for the EU15 as a whole and for five member states. Steinberger et al. (2013) investigate the link between economic growth and DMC between 1970 and 2005. Employing a sample consisting of both developed and developing nations, they find weak evidence for an EKC of Domestic Material Consumption. An inverted U-shaped relationship between GDP per capita and DMC per capita is only observed in mature economies. It is not statistically significant, however.

Our results do not provide evidence for an Environmental Kuznets Curve for material use. We only find an inverted U-shaped relationship between income and DMC in OECD countries. Instead, the results suggest a cubic, S-shaped relationship between GDP per capita and material use. When agricultural economies begin to grow, they enter a phase of economic growth in which infrastructure is constructed and material-intensive sectors emerge. Both DMC and MFP increase convexly in income in this phase.

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[2] Bagliani et al. (2008) as well as (Wang et al. 2013) search for an EKC relationship between income and Ecological Footprints.

[3] Some studies have searched for Environmental Kuznets Curves for specific materials. Examples include copper (Guzmán et al. 2005) and aluminium (Jaunky 2012).

[4] Exported materials are not subtracted from the DMI. They are included in the DMI of both the exporting and the importing nation, leading to double counting.

After an inflection point, material use rises concavely until it reaches a maximum. The income levels at which DMC and MFP reach their maximum are very high, however, suggesting a positive income-material relationship over most of the income range. In addition, the coefficients of the cubic model become nonsignificant (though retaining their signs) once endogeneity and non-stationarity are accounted for. A linear specification yields a significant (positive) coefficient irrespective of the estimation method and can thus be considered a satisfactory approximation to the income-materials relationship. The linear models that account for endogeneity and non-stationarity suggest a greater income elasticity for MFP than for DMC. The long-run income elasticity is estimated to be 0.562 for DMC and 0.752 for MFP.

This study proceeds as follows. Section 2 provides a brief overview on the theory behind the EKC hypothesis. The estimation approach is outlined in section 3, the data in section 4. We present and discuss our results in section 5. Section 6 concludes.

2 Theoretical Background

Numerous theoretical models have been developed to explain the relationship between income and environmental pressures, and why this relationship can take an inverted U-shape (see e.g. Dinda 2004 for an overview). Copeland and Taylor (2004) present a model with which they can illustrate key rationales of the EKC, including the role of trade.

One can distinguish three channels through which economic growth affects material use: the magnitude of economic activities (scale effect), the sectoral structure of the economy (composition effect), and the industries' material intensity (technique effect).[5]

When economies grow, the scale effect increases material use. More goods are produced and consumed, increasing the demand for materials. Without policies restricting material use, the effect of growth, furthermore, depends on its nature and causes. If the accumulation of (human) capital or technological progress favors material-intensive industries, the economy as a whole grows and the relative importance of material-intensive activities rises. Both the scale and the composition effect contribute to an increasing material use. If sectors which do not use materials intensively grow, the composition effect dampens material use. If this structural change is strong enough, it can compensate for the growth effect. An EKC can emerge if heavy industry drives growth in early phases of development and services or light manufacturing in later phases, crowding out the material-intensive activities.

Most models aiming at explaining the EKC are well-suited for local pollutants. These emissions are tied to specific activities. SO_2, for instance, is emitted when burning fossil fuels or processing copper. Furthermore, local emissions can often be avoided using end-of-pipe technologies. Employing more sophisticated production technologies, including end-of-pipe measures, reduces the emissions of pollutants (technique effect).

Material use, on the other hand, occurs in almost all economic activities. It is tied more closely to the development of the economy as a whole. In this respect, material use is similar to the emission of carbon dioxide for which no end-of-pipe abatement technologies have been implemented on a larger scale.

It is well documented (Syrquin 1988; Duarte & Restuccia 2010; Herrendorf et al. 2014) that economic development coincides with a characteristic pattern of structural transformation. In early development, economic activities are focused on agriculture. In an intermediate phase, manufacturing sectors develop,

[5] Pothen and Schymura (2015) apply an Index Decomposition Analysis (Ang & Liu 2001) to disentangle the growth of downstream material utilization into these three effects.

shifting production away from agriculture. In the late phase, manufacturing shares decline and services become the dominant sector. The stylized facts of structural transformation have two implications. First, a quadratic, hump-shaped model might not be able to capture the transition from the first to the intermediate phase accompanied by a sharp increase in the use of materials thereafter. Second, the crucial question is if the combination of structural change towards services and technological change can limit the use of materials.

An EKC can also arise if preferences for environmental quality rise with income. If citizens of low-income countries are more willing to accept environmental damages, their environmental policy will be lax. This creates a comparative advantage for material-intensive industries. If the citizens' valuation for a clean environment rises in income, they will demand increasingly tight regulations. Households might, furthermore, shift their consumption towards less material-intensive goods.

International trade has become increasingly important for global material flows (Bruckner et al. 2012). From a theoretical perspective, trade has an ambiguous effect on material use. Reducing inefficiencies and allowing for specialization, trade leads to growth and thereby to a scale effect. Countries with comparative advantages in services or light manufacturing will specialize in these activities. They experience a composition effect which reduces the use of materials. Nations with comparative advantages in material-intensive industries exhibit a composition effect which boosts material use. Trade can still reduce material use, however, if increasing material efficiency (technique effect) dominates the scale and composition effects. This can be the case if international trade improves the technologies used or if a higher income due to trade allows for a more stringent regulation.

These arguments as well as empirical observations (e.g. Wiedmann et al. 2015) constitute a warning. Reductions of apparent material use might reflect the outsourcing of material-intensive production with rising income rather than a real dematerialization of economic activity (Rothman 1998). From a sustainability point of view, the Material Footprint is, therefore, the more meaningful indicator when assessing how economic growth and convergence affects the use of materials. If material intensive-production is outsourced from developed to less developed countries, the Material Footprint is less likely to fall with rising income than is Domestic Material Consumption.

3 Estimation Approach

A panel econometric model is employed to estimate the relationship between GDP per capita and our indicators of material use, Domestic Material Consumption per capita and Material Footprint per capita. The panel structure allows us to control for time-invariant country characteristics such as geographical location. We expect these characteristics to be correlated with GDP per capita. Therefore, we opt for a fixed-effect (FE) model (Wooldridge 2010).

Equation (1) is the standard estimation equation in the EKC literature, applied to material use. It includes natural logarithms on both sides of the equation to center the data. This reduces the impact of outliers in the highly right-skewed data. Furthermore, a logarithmic specification ensures that we estimate a positive material use (Stern 2004).

$$\ln\left(\frac{MU_{r,t}}{N_{r,t}}\right) = \alpha_r + \gamma t + \beta_1 \ln\left(\frac{Y_{r,t}}{N_{r,t}}\right) + \beta_2 \ln\left(\frac{Y_{r,t}}{N_{r,t}}\right)^2 + \epsilon_{r,t} \qquad (1)$$

$MU_{r,t}$ represents the indicators of material utilization in country r and year t, either $DMC_{r,t}$ or $MF_{r,t}$. $N_{r,t}$ is r's population and $Y_{r,t}$ its real GDP. β_1 and β_2 are the parameter estimates for the log of GDP per capita and the squared log GDP per capita. α_r denotes the aforementioned country fixed effect and

$\epsilon_{r,t}$ an orthogonal error term. γ is a linear time trend which captures drivers of material use that change over time but affect countries in a similar way. It records, among other influences, autonomous technical change.

The Environmental Kuznets Curve hypothesis implies that $\beta_1 > 0$ and $\beta_2 < 0$. The turning point τ can be computed as:

$$\tau = exp\left(\frac{-\beta_1}{2\beta_2}\right) \qquad (2)$$

In addition to the quadratic model (equation 1), we estimate linear and cubic models in order to find specifications that best represent the data. Endogeneity issues are addressed by means of an instrumental variable (IV) estimator using infant mortality to instrument per capita GDP. As a further alternative to the fixed-effect (FE) estimator, a between estimator (BE) is used to account for panel non-stationarity (Pesaran and Smith 1995; Stern 2010). We employ an IV estimation of country averages to tackle endogeneity and non-stationarity issues jointly, see the discussion below.

4 Data

Material Footprints are taken from Wiedmann et al. (2015). They compute the MFP by using the global multi-region input-output dataset EORA (Lenzen et al. 2013). Inverting the input-output table yields the Leontief inverse which records how many dollars of inputs from sector j are needed to produce one dollar worth of goods from sector i. The Leontief inverse is multiplied with final demand and domestic extraction to compute the Material Footprints. The dataset contains 186 countries from 1990 until 2008.[6]

Data on DMC stems from the Global Material Flow Database constructed by the SERI (Sustainable Europe Research Institute) and the Vienna University of Economics and Business (WU Vienna). See SERI (2013) and Lutter et al. (2014) for a documentation. DMC is computed by adding up domestic extraction as well as imported materials and subtracting exported materials. There are 182 countries which have DMC data, with some missing values up until 1993.[7]

We use expenditure-side real GDP at chained purchasing power parities in million US$ of 2005 from the Penn World Tables version 8.1 (Feenstra et al. 2015) to quantify income. It allows us to compare income between countries and over time. Matching population data is also from the Penn World Tables. We have GDP and population data for 167 countries.

All countries for which GDP, DMC, or MFP is unavailable are dropped. Belarus and Macedonia are excluded because their Material Footprint is below 1 ton per capita in all years, which appears to be a data problem. We end up with 144 nations for which we have GDP, MFP, and DMC data. Some countries, in particular in the former Eastern Bloc, only have data from 1991 or 1992 onwards. The panel is, thus, slightly unbalanced. It encompasses about three quarters of all nations in the world which reduces the out-of-sample prediction problem for which the fixed-effect model is criticized (Stern 2004).

[6] The Material Footprint data can be downloaded at http://worldmrio.com/.
[7] The DMC data is publicly available at http://www.materialflows.net/.

5 Results

5.1 Descriptive Statistics

We begin the presentation of our results by outlining some descriptive statistics of our panel. Table 1 displays the mean, standard deviation, minimum, and maximum of our variables.

Variable	Mean	Std. Dev.	Min.	Max.
DMC per capita (t)	11.8	10	1.5	112.4
MFP per capita (t)	12.4	13.7	0.1	182.4
GDP per capita (2005US$)	10,885	12,226	225	124,558
Observations	2696			

Table 1: Descriptive Statistics

The countries in our sample exhibited, on average, a Domestic Material Consumption of 11.8 tons per capita. The mean Material Footprint was higher (12.4 tons per capita), implying that countries which are not part of the sample are net exporters of materials. The MFP also shows more variation between countries. It ranged from less than one ton per capita in some developing countries to 182.4 tons per capita in Bermuda in 2008. GDP per capita ranges from 225 US$ (Nigeria in 1995) to more than 120,000 US$ (Qatar in 2008), with an average of 10,815 US$. We have 2696 observations.

Figure 1 and Figure 2 plot the log of DMC per capita as well as the log of MFP per capita against the log of GDP per capita. The figures distinguish between OECD members (as of 2015) and non-OECD countries. Note that OECD members account for the majority of high-income countries, while non-OECD countries are overwhelmingly low and middle-income nations.

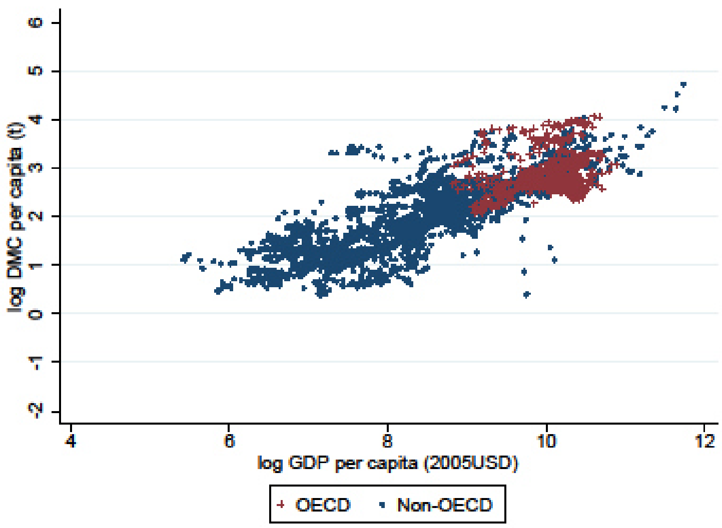

Figure 1: GDP and DMC per capita

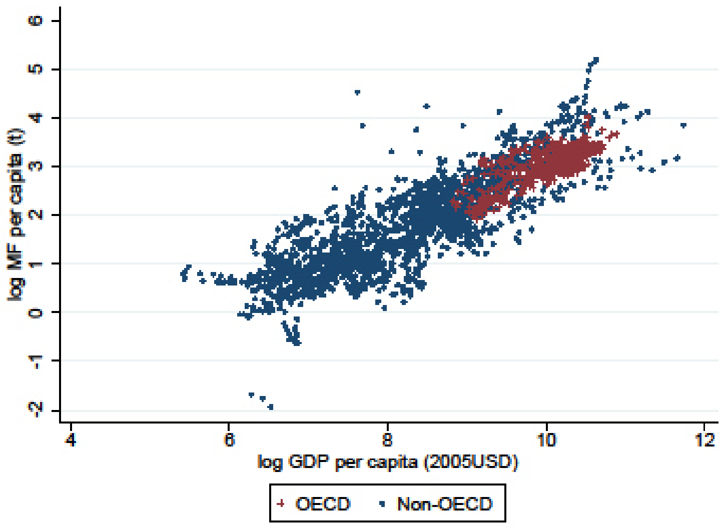

Figure 2: GDP and MFP per capita

At first glance, the logs of material use and income appear to be related in a linear fashion. The Material Footprint seems to react more elastically to income changes than DMC, possibly reflecting outsourcing of material-intensive activities from higher to lower income countries. However, the figures neither account for countries' particularities nor for time trends and might, thus, be deceiving.

5.2 Quadratic Model

In the spirit of the EKC literature, we first estimate the quadratic model presented in equation (1). Table 2 shows the results. The first three columns display estimates for the log of DMC per capita as the endogenous variable (logDMCpc), the other three for the log of MFP per capita (logMFPpc). For each indicator of material use, we estimate the quadratic model on three samples: Full represents the full dataset. In the OECD subsample, we restrict our estimation to OECD countries. The nonOECD subsample contains all non-OCED member states.

	logDMCpc			logMFPpc		
	Full	OECD	nonOECD	Full	OECD	nonOECD
logGDPpc	-0.331 (0.244)	4.151** (1.979)	-0.559** (0.257)	-0.740* (0.387)	1.016 (1.256)	-0.577 (0.417)
$logGDPpc^2$	0.040*** (0.015)	-0.180* (0.100)	0.054*** (0.016)	0.061** (0.024)	-0.019 (0.063)	0.051* (0.026)
Trend	0.002 (0.002)	-0.008** (0.004)	0.004** (0.002)	0.004 (0.003)	0.004 (0.005)	0.002 (0.003)
τ	60	104,035	185	435	2.215e+11	297
N	2696	616	2080	2696	616	2080
R^2	0.289	0.396	0.304	0.161	0.585	0.113
F	31.766	15.721	28.438	17.207	45.639	9.662

Table 2: Results of the Quadratic Model

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The estimates based on the full sample do not provide an indication for an Environmental Kuznets Curve. On the contrary, for both for DMC and MFP, the coefficient on the log of GPD per capita (logGDPpc) is negative whereas the coefficient on the squared log of GDP per capita ($logGDPpc^2$) is positive. Hence, the relationship between income and material use appears to be U-shaped. However, the coefficient of the linear term (logGDPpc) is nonsignificant in the case of DMC. In addition, the turning points τ, that is, the minimum of the U-shaped function, occur at very low income levels. We find τ to be 60 US$ per capita in the case of DMC and 435 US$ in the case of MFP. Mozambique and Nigeria are the only countries in our sample which exhibit a GDP per capita below 435 US$ in some years. Therefore, material use appears to grow monotonically for all but the least-developed countries.

In the light of the structural transformation paradigm discussed in section 2, the impact of income changes may differ by a country's level of development. To test this hypothesis, we conduct our estimation on two subsamples, the OECD member states and the non-OECD members.

The results reveal a striking difference between OECD and non-OECD countries. If we restrict our estimation to the OECD, we find an inverted U-shape for DMC, consistent with the Environmental Kuznets Curve hypothesis. Both the linear and the quadratic term are significantly different from zero. The turning point is at 104,035 US$ per capita, which is rather high in view of the maximum income observed (124,558 US$). The inverted U-shape corresponds to the findings of Vehmas et al. (2007) for EU15 and Steinberger et al. (2013) for mature economies. In contrast to the latter study, the coefficients in our model are statistically significant (at the 5 and 10 percent level, respectively).

Interestingly, the results for the non-OECD countries are exactly opposite to those in OECD countries: the estimates show a statistically significant U-shape. This suggests that the (nonsignificant) U-shape found for the full sample reflects the dominance of observations from non-OECD (2080 out of 2696 observations). The minimum is at 185 US$ per capita, which is below the minimum income in the sample (225 US$).

The time trend has a negative and significant effect in the OECD subsample, amounting to 0.8 percent per year, and a positive and significant effect (0.4 percent per year) in the non-OECD subsample. It is nonsignificant in the full sample.

For the Material Footprint, the direction of effects for the OECD and non-OECD subsamples are the same as for DMC, but the coefficients are nonsignificant except for squared income in non-OECD countries. The time trend is nonsignificant for both OECD and non-OECD.

The results so far indicate that the relationship between income and DMC differs between development stages: in developing countries, economic growth is accompanied by structural change in favor of material-intensive sectors. Domestic Material Consumption rises monotonically in income. In developed countries, the mechanisms proposed in the EKC literature (transition to a service economy) imply a downward sloping income-materials relationship at high levels of income.

The sign pattern of coefficients suggests that similar mechanisms may apply to the material footprint, but, importantly, the coefficients tend to be nonsignificant. Thus, neither in poor developing nor in rich developed economies income growth reduces the material footprint, presumably because direct material use is replaced with indirect (embodied) material use.

5.3 Cubic and Linear Models

As stated in the introduction, our aim is to study the income-materials relationship for a common dataset comprising both developing and developed economies. In the remainder of this paper, we estimate models for OECD and non-OECD jointly, building on the results from the preceding subsection. Combining the U-shaped relationship for low-income (non-OECD) and high-income (OECD) countries suggests that the overall income-materials relationship may be best captured by a cubic function. Table

3 reports the results from estimating such a specification (which is otherwise equal to equation 1). $logGDPpc^3$ denotes the parameter estimate for the log of the third power of GDP per capita.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.290*** (1.590)	0.343*** (0.062)	-6.952*** (1.808)	0.276*** (0.071)
$logGDPpc^2$	0.512*** (0.195)		0.801*** (0.211)	
$logGDPpc^3$	-0.018** (0.008)		-0.029*** (0.008)	
Trend	0.001 (0.002)	0.003 (0.002)	0.003 (0.002)	0.005** (0.003)
τ^{min}	566		974	
τ^{ip}	11,400		11,075	
τ^{max}	229,644		125,959	
N	2696	2696	2696	2696
R^2	0.305	0.271	0.183	0.138
F	25.051	37.291	20.088	21.997

Table 3: Results for OECD and Non-OECD Combined

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Consistent with the results in the preceding subsection, we find a significant S-shaped relationship between income and both DMC and MFP. The polynomial of degree 3 has a (local) minimum τ^{min} which is reached at low levels of GDP per capita (566 US$ for DMC, 974 US$ for MFP). Thereafter, material use increases convexly in GDP per capita. This reflects the intermediate phase of development in which nations build up manufacturing sectors and infrastructure.

At an income of 11,400 US$ (DMC) or 11,075 US$ (MFP), the functions reach their inflection point τ^{ip}. It denotes the income at which the material use function changes from being convex to being concave. The estimated inflections points are slightly higher than the average GDP per capita in our sample.

Material use rises further in income after the inflection points, but at a declining rate. Domestic Material Consumption reaches its maximum τ^{max} at a GDP per capita of 229,644 US$ (far out of sample). The Material Footprint is estimated to reach its maximum at 125,959 US$ which is higher than the maximum income in the sample as well.[8] The time trends are nonsignificant, which is unsurprising in view of opposite trends in OECD and non-OECD found above.

[8] The following formulae are used to compute the minimum (τ^{min}), the inflection point (τ^{ip}), and the maximum (τ^{max}) of the S-shaped curve:

$$\tau^{min} = exp\left(-\frac{1}{3}\frac{\beta_2}{\beta_3} - \sqrt{\left(\frac{\beta_2}{3\beta_3}\right)^2 - \frac{\beta_1}{3\beta_3}}\right)$$

$$\tau^{ip} = exp\left(-\frac{\beta_2}{3\beta_3}\right)$$

It follows from the minima and maxima that there exists an upward sloping relationship between income and material use over most of the income range. We therefore test the performance of a linear specification. We find a significant positive coefficient in this model, which amounts to 0.343 for DMC. Given the log-log specification, this coefficient represents the elasticity of DMC with respect to income: A 1-percent increase in per capita income goes along with an increase in per capita DMC by 0.343 percent. As in the cubic model, the time trend is non-significant. The coefficient of determination (R^2) is 0.271. In comparison with $R^2 = 0.305$ in the cubic model, the R^2 of the linear model indicates a moderate loss in explanatory power.

Similar to the case of DMC, there is an upward sloping relationship between income and MFP over most of the range, though that range is smaller than in the case of DMC. A linear model yields a significant elasticity coefficient of 0.276. Unlike in the case of DMC, the R^2 in the linear model (0.138) suggests a considerable loss in explanatory power in comparison with the cubic model ($R^2 = 0.183$).

Comparing DMC to MFP, the linear models suggest a greater income elasticity of DMC than of MFP, contrary to both theoretical reasoning and the descriptive results. This seems to be related to the fact that part of the increase in MFP is attributed to a positive time trend.

5.5 IV Estimation

Our results up to this point suggest the existence of an S-shaped relationship between income and both DMC and MFP. It is unclear, however, if this relationship is causal or if it just represents a correlation driven by other factors, such as institutional conditions.[9]

We employ the instrumental variable (IV) approach to circumvent this problem. The instrument is a variable which is correlated with income but which does not influence material use in other ways than through income. The two-stage least squares (2SLS) approach is used to estimate the instrumental variable specification. In the first stage, the log of GDP per capita is regressed on the instrument. In the second stage, the predicted values are used as explanatory variables for material use. Note that the standard errors have to be adjusted to account for the estimation errors in the first stage.

We choose infant mortality as our instrumental variable. It is defined as the number of infants dying before reaching one year of age, per 1,000 live births in a given year. Data is collected by the United Nations Inter-agency Group for Child Mortality Estimation (UN IGME) and presented as part of the World Bank's World Development Indicators. For details on data collection and estimation, see (UNICEF et al. 2015).

Infant mortality is highly correlated with income. The correlation coefficient between the log of GDP per capita and the log of infant mortality is -0.89. For the OECD countries, it is slightly lower but still at -0.79. We do not expect an immediate effect of child mortality on material use.[10]

$$\tau^{max} = exp\left(-\frac{1}{3}\frac{\beta_2}{\beta_3} + \sqrt{\left(\frac{\beta_2}{3\beta_3}\right)^2 - \frac{\beta_1}{3\beta_3}}\right)$$

[9] For instance, Welsch (2004) found that corruption affects both national income and, independently, pollution.

[10] Lin and Liscow (2013) use an instrumental variable approach to estimate the causal effect of income on the concentration of several water pollutants. They employ two instrumental variables: the total debt services in per cent of gross national income and the age dependency ratio (population under 15 and over 65 relative to the working age population). Both are taken from the World Development Indicators. The former indicator exhibits many gaps for the countries in our sample. With a correlation coefficient of -0.81, the log of the age dependence

Table 4 presents the results. The cubic specification suggests an S-shaped income-DMC relationship, but the linear term is non-significant. The time trend is significantly negative, at 1.1 percent per year. The inflection point occurs at 3,360 US$, the minimum at 76 US$, and the maximum at 148,666 US$ (out of sample).

The IV estimation suggests an upward-sloping income-DMC relationship over the range of incomes in the sample. Consistent with this result, the linear specification yields a significant elasticity coefficient of 0.866 which is more than twice as high as in the fixed effect estimation. This difference can be attributed to the significant negative time trend of 1.3 percent per year. The IV estimation indicates a higher impact of income on DMC combined an autonomous decline in DMC over time.

Regarding the Material Footprint, we find a non-significant N-shape and a significant negative time trend at 2.4 percent per year. The linear specification for the MFP yields a significant positive elasticity coefficient of 1.183 and a significant negative time trend of 2.2 percent per year.

Overall, the IV estimates suggest an upward-sloping relationship between income and both DMC and MFP over most of the income range. The income-elasticity of DMC from the linear model (0.866) suggests that DMC increases with income slightly less that proportionately, whereas the elasticity of MFP (1.183) suggests that MFP rises with income more than proportionately. The time trend is negative for both DMC and MFP, but larger for the latter (-0.022) than the former (-0.013).

The IV estimates differ from the standard FE estimates in several important ways. First, the S-shaped income-materials relationship becomes less significant (DMC) or nonsignificant (MFP) under IV. Second, there are significant negative time trends for both DMC and MFP, and the latter is stronger than the former. Third, in contrast to the standard FE, the income elasticity under IV is greater for MFP than DMC.

	logDMCpc		logMFpc	
	Cubic	Linear	Cubic	
logGDPpc	-3.376 (2.442)	0.866*** (0.092)	4.194 (4.019)	1.183*** (0.125)
$logGDPpc^2$	0.532* (0.275)		-0.421 (0.452)	
$logGDPpc^3$	-0.022** (0.010)		0.019 (0.017)	
trend	-0.011*** (0.003)	-0.013*** (0.003)	-0.024*** (0.005)	-0.022*** (0.004)
τ^{min}	76		-	
τ^{ip}	3,360		-	
τ^{max}	148,666		-	
N	2677	2677	2677	2677
F	88.963	172.339	90.336	102.003

Table4: Results with Instrumented Income

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

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ratio is highly correlated with the log of GDP per capita. For OECD countries, however, the correlation drops to -0.20.

5.6 Non-Stationarity of the Data

A potential econometric issue is non-stationarity of the data, which implies that results of classical regressions may be spurious. To tackle non-stationarity, Stern and Common (2001) use a first difference model to cancel out stochastic trends. Tests by Perman and Stern (2003) suggest that income and pollution variables are integrated. As noted by Wagner (2008), however, standard unit root tests for panel data are inappropriate in the presence of cross-sectional dependence and non-linear variables (such as polynomials of income). Stern (2010) addresses this criticism by using a between-estimator (BE). BE averages the data for each country over time. Therefore the estimates only exploit variation across countries and not within countries (across time), though they use the entire dataset. Following Pesaran and Smith (1995), Stern (2010) argues that BE is a consistent estimator of the long-run relationship between the variables even in the presence of powers of unit root variables under the standard assumption that there is no correlation between the regressors and the error term (exogeneity). Due to the averaging across time, cross-sectional dependence is not an issue either. The downside of BE is that it is unable to account for observed or unobserved time-invariant country characteristics, whose omission may create endogeneity problems. We will get back to this issue below.

Table 5 shows the results of the between estimation. In the cubic model, the between estimates are all nonsignificant, whereas the coefficients of the linear model are significant and positive. Both for DMC and MFP, the income elasticities are higher than in the fixed effect specification. Substantially higher R^2 than in the fixed effect specification indicate that income differences explain a large fraction of the long run between-country variation in material use.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-6.456 (4.578)	0.554*** (0.030)	-5.413 (4.267)	0.732*** (0.028)
$logGDPpc^2$	0.823 (0.545)		0.705 (0.508)	
$logGDPpc^3$	-0.032 (0.021)		-0.027 (0.020)	
N	2696	2696	2696	2696
R^2	0.713	0.708	0.833	0.829
F	116.075	344.526	232.776	689.424

Table 5: Results of Between-Estimation

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

As already mentioned, BE is unable to control for time-invariant country characteristics (such as geography, for instance). If those characteristics are correlated with the regressors, an omitted variable bias arises. Omission of correlated variables is one form of endogeneity (along with reverse causation and measurement error), and it can be addressed by using instrumental variables. We therefore combine IV estimation with a between estimator to simultaneously correct for panel non-stationarity and endogeneity.[11] The results reflect the causal long-run impact of income on material use.

[11] Since such a combination is not implemented in stata, we compute averages of DMCpc, MFPpc, GDPpc, and infant mortality (and their polynomials) across time for each country and ran a 2SLS IV regression.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-12.778 (15.217)	0.562*** (0.032)	-4.280 (13.152)	0.752*** (0.027)
$logGDPpc^2$	1.601 (1.810)		0.592 (1.569)	
$logGDPpc^3$	-0.063 (0.071)		-0.023 (0.062)	
N	143	143	143	143
R^2	0.703	0.704	0.834	0.830
F	101.670	299.651	277.462	750.772

Table 6: Results of the IV Regression of the Country Averages

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table 6 presents the results of the IV estimations of country averages. They do not differ much from the standard BE (Table 5): the cubic models yield S-shaped income-materials relationships for both DMC and MFP but the coefficients are nonsignificant. The linear specifications yield significant positive coefficients and the coefficient for MFP (0.752) is greater than that for DMC (0.562). Both coefficients are somewhat greater than their standard-BE counterparts, but the difference is not large. Omission of country characteristics (and other sources of endogeneity), thus, does not seem to have a big effect on the estimated income-materials elasticity.

We, furthermore, conduct IV estimations of country averages for the linear model on the OECD and non-OECD subsamples to reveal whether income elasticities of DMC and MFP differ between high-income and low-income nations. These checks aim at investigating whether high-income nations offshore material-intensive production, as indicated by previous results.

	logDMCpc		logMFPpc	
	OECD	nonOECD	OECD	nonOECD
logGDPpc	0.488** (0.207)	0.563*** (0.044)	0.785*** (0.130)	0.790*** (0.048)
N	33	110	33	110
R^2	0.076	0.638	0.528	0.756
F	5.553	167.068	36.324	267.839

Table 7: Results of the IV Regression of the Country Averages (OECD and non-OECD)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table 7 displays the IV estimates of the country averages in the OECD and non-OECD subsamples. With an income elasticity of 0.488 for DMC, the OECD countries' Domestic Material Consumption reacts less sensitive to GDP changes than the other countries' DMC, which exhibit an elasticity of 0.563. Furthermore, the R^2 is substantially lower in the OECD than in the non-OECD subsample, indicating that DMC is determined by factors other than GDP in these countries.

The income elasticity of MFP is almost identical in the OECD and the non-OECD subsample (0.785 and 0.790). Contradicting the S-shaped relationship between GDP and MFP found in the fixed effect specification, this result indicates that a linear function describes the impact of income changes on

Material Footprints well. High-income countries, thus, appear to offshore material-intensive production while their Material Footprints grow at a constant rate.

The Material Footprint data by Wiedmann et al. (2015) differentiates between four material groups: biomass, construction materials, fossil fuels, and metal ores and industrial minerals. We estimate the income elasticity of Material Footprints for these groups individually to reveal how their use reacts to GDP changes. Results for the IV estimation of country averages are presented.[12] Biomass, which contains essential goods such as food, exhibits the lowest income elasticity (0.430). The demand for biomass does not grow strongly in income. With an income elasticity of 0.927, the Material Footprint of metal ores and industrial minerals exhibits the second-lowest responsiveness to GDP changes. The income elasticity of construction materials almost equals unity (1.027), indicating a proportional relationship between income and the Material Footprint. With a value of 1.383, the Material Footprint of fossil fuels shows the highest income elasticity. Throughout the income range, the MFP of fossil fuels grows more than proportionally in income.

5.7 Robustness Checks

Previous research cautions that EKC estimations might be sensitive to the exclusion of countries or years (Harbaugh et al. 2002). We conduct a number of checks to scrutinize whether our results are robust to changes in the way how time trends are represented or to the exclusion of years and countries. The robustness checks are conducted for the cubic and linear models in four specifications: fixed effects (FE), instrumental variables (IV), between (BE), and IV of country averages. The detailed results are presented in section A of the online appendix.

The checks confirm that our results are generally robust. Replacing the linear time trend with year dummies or allowing the linear time trend to differ between OECD and non-OECD countries has no major impact. The same is the case if we drop the observations between 1990 and 1992, which might be biased by nonrecurring structural change after the fall of the Iron Curtain, or if we drop the year 2008, which might be affected by the financial crisis. Using a balanced panel also has minor impacts on our results.

Allowing for country-specific linear time trends, which represent political and technological developments in individual nations, turn the cubic relationship between income and DMC nonsignificant in the fixed effect specification. They, furthermore, lead to a higher income elasticity of MFP in the linear model. Country-specific political and technological developments appear to have moderate importance for material use.

After dropping the four countries with the highest GDP per capita in our sample (Brunei, Kuwait, Qatar, and Singapore), the cubic model for MFP in the fixed effect specification becomes partly nonsignificant. The cubic model for DMC becomes nonsignificant if we exclude the countries with a GDP per capita below 1,000 US$. We conclude that the cubic model reacts sensitively if the lower or the upper end of the income distribution is cut off.

The linear model in the IV estimation on country averages is highly robust across all checks, both qualitatively and quantitatively. Excluding individual years or nations does not affect the estimated long-

[12] We estimate the fixed effect specification for the cubic, linear, and quadratic models as well as the IV, between, and the IV of country averages specifications for the cubic and linear models. The results are usually inconclusive with the exception of the linear models, in particular in the IV of country averages specification. See section B of the online appendix for details.

run impact of income on material use. It is only affected notably if observations with a very low income are dropped.

5.8 Discussion

In contrast to most of the earlier literature on the relationship between economic development and material use, we analyze data from a large set of developing and developed economies, spanning a range of income from 225 US$ per capita to 124,558 US$ per capita. Consistent with earlier literature (Velmas 2007, Steinberger et al. 2013) we found an indication that the income-materials relationship may become negative at very high levels of per capita income. Besides mainly focusing on developed economies, however, the previous literature disregarded issues of endogeneity (due to reverse causation, omitted variables, and measurement error) and non-stationarity of the data.

While standard fixed-effects estimation suggest the existence of an S-shaped cubic income-materials relationship in our data, the coefficients of that specification turn out to be unstable and tend to become nonsignificant once endogeneity and non-stationarity are accounted for by means of instrumental variable and between estimators. In contrast to the cubic model, a linear specification yields a significant positive coefficient for the income elasticity of material use without a great loss in explanatory power. Except for the standard FE estimator, all estimation methods yield a greater income elasticity for the material footprint than for domestic material use. This result is consistent with the idea of outsourcing material-intensive production from richer to poorer countries as national income grows.

With respect to the various estimation methods, Pesaran and Smith (1995) argue that the averaged time series and between estimators are consistent estimators of the long-run coefficients, provided there are no omitted variables or other sources of endogeneity. This suggests that the combination of BE and IV may be the preferred method to deal with panel non-stationarity and endogeneity. This method, applied to a linear specification of the income-materials relationship, suggests an income elasticity of 0.562 for domestic material use and of 0.752 for the material footprint. These long-run relationships between income and material use remain robust in our sensitivity checks.

To put these figures in perspective, we note that Stern (2010) finds a between estimate of 1.509 for the global carbon-income elasticity. This value is slightly higher than our income elasticity for the MFP for fossil fuels (1.383), but substantially higher than the elasticities of MFP and DMC for all materials. Using data for 2008, Wiedmann et al. (2015) estimate an income elasticity of MFP of 0.60.

6 Conclusions

Many industrializing economies, from the former socialist nations in Eastern Europe to India and China, have exhibited rapid economic convergence to the high-income countries in Europe or North America in recent years. This development poses the question how economic growth in general and the convergence of industrializing countries in particular will affect the use of materials. The Environmental Kuznets Curve (EKC) hypothesis predicts that environmental pressures such as material use do not rise monotonically in income but that they follow an inverted U-shaped trajectory. There might be a point after which material use declines in income.

This study investigates whether there is evidence for the existence of an EKC for material use. We employ two indicators to quantify material use. Domestic Material Consumption (DMC) per capita is a production-based indicator. It denotes the apparent use of materials in a country. The Material Footprint (MFP) per capita measures the amount of materials extracted to produce a country's final demand. It is a consumption-based indicator.

Our study is the first to investigate whether there is evidence for an EKC for Material Footprints. Furthermore, it has the broadest country coverage of all EKC studies on material use. Our dataset is not limited to developed countries but also contains a large number of middle and low-income countries. Several econometric techniques are employed to analyze the data, including fixed effects, instrumental variables and between estimators.

Motivated by the EKC hypothesis, the income-materials relationship is first estimated in a quadratic model. This model yields an inverted U-shaped relationship between income and DMC only if we restrict our sample to high-income countries. For non-OECD members, the quadratic model yields a U-shaped relationship, in sharp contradiction to the EKC hypothesis. There is no statistically significant quadratic relationship between GDP per capita and MFP per capita.

The results from the quadratic specification for OECD and non-OECD members suggest an S-shaped relation for the overall sample. Implementing this idea through a cubic specification yields estimates consistent with this idea. The estimates suggest sharply increasing material use from very low income levels up to an inflection point at 11,400 US$ (DMC) and 11,075 US$ (MFP). After this point, material use rises concavely and reaches maxima of 229,644 US$ (DMC) and 125,959 US$ (MFP), both of which are beyond the maximum income in our sample.

These results are in line with the structural transformation paradigm of economic development which stipulates a three-phase model of development. After a first phase dominated by the agricultural sector, countries develop manufacturing industries and construct infrastructure. These activities are material-intensive and imply a substantial rise in material use. In the third phase, the role of manufacturing declines and services supersede them. Material use grows more slowly and, eventually, falls again.

Though the S-shaped pattern is robust to several robustness checks, the coefficients of the cubic model become nonsignificant once endogeneity (due to reverse causation, omitted variables or measurement error) as well as panel non-stationarity are accounted for. A linear specification fares better in this regard, as it yields significant positive coefficients across all estimation methods for both DMC and MFP without an appreciable loss in explanatory power.

We conduct an instrumental variable (IV) estimation, which uses infant mortality as an instrument for GDP per capita, on country averages to simultaneously cope with endogeneity and panel non-stationarity. Results from the linear model suggest long-run income elasticities of 0.562 for DMC and 0.752 for MFP. The elasticity is greater for MFP than for DMC under every estimation method except for the simple fixed effects estimator.

Our results are consistent with the presumption that developed countries have outsourced material-intensive production to developing countries. Though our elasticity estimates suggest a relative decoupling of income and DMC as well as MFP, GDP growth is associated with a higher increase in MFP than DMC. The long-run income elasticity of DMC is, furthermore, substantially lower in the OECD subsample than in the non-OECD subsample while the MFP exhibits the same elasticity in both country groups.

We conclude that economic growth under status-quo policies will not limit the use of materials. Policy intervention will be needed to slow down and restrict the use of materials. These interventions should focus on materials whose use implies particularly large environmental burdens and on Material Footprints rather than the apparent use of materials. But further research is needed to shape effective policies. We anticipate the existence of key factors with large influence on both economic growth and material use. These might include technological change, pro-growth policies, or infrastructure investments. Future research needs to isolate the contribution of these factors in order to inform policy makers to regulate material use effectively.

7 References

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Online Appendix

A Robustness Checks

The first section of the online appendix presents the results of a number of robustness checks. Altogether, we conduct eight sets of checks. The first three scrutinize the way how trends in material use over time are considered. Two robustness checks study whether our results are substantially influenced by structural change after the fall of the Iron Curtain or by the financial crisis. One check analyzes if our results are altered if we use a balanced panel. The last two robustness checks investigate how the estimates change if we drop outliers with very high or very low income.

All robustness checks are conducted for the cubic and linear models in four specifications: fixed effects (FE), instrumental variables (IV), the between (BE), and the IV estimation of country averages. The latter two are not conducted for the checks in which we model time trends differently because they are estimated on averages over time. We denote the results with a linear time trend based on the full sample (Tables 3 to 6) the baseline with which we compare the robustness checks.

A.1 Time dummies

This subsection investigates whether our results change if the linear time trend is replaced by year dummies. Table A.1.1 displays the results of estimating equation (1) with year dummies. We estimate the cubic and the linear model for DMC and MFP. The results are virtually unchanged compared to the baseline with a linear time trend.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.269*** (1.601)	0.338*** (0.064)	-6.535*** (1.835)	0.244*** (0.072)
$logGDPpc^2$	0.509** (0.197)		0.750*** (0.216)	
$logGDPpc^3$	-0.018** (0.008)		-0.027*** (0.008)	
N	2696	2696	2696	2696
R^2	0.307	0.274	0.255	0.215
F	9.754	8.690	18.922	16.999

Table A.1.1: Results with Time Dummies (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.1.2 reports the results of the IV estimation with time dummies instead of a linear time trend. As for the fixed effect specification, the results are very similar to the baseline.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-2.858 (2.559)	0.895*** (0.100)	3.487 (4.050)	1.202*** (0.128)
$logGDPpc^2$	0.476* (0.287)		-0.340 (0.454)	
$logGDPpc^3$	-0.020* (0.011)		0.016 (0.017)	
N	2677	2677	2677	2677
F	18.124	19.074	27.444	21.812

Table A.1.2 Results with Time Dummies (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.2 Separate Time Trends for OECD and non-OECD countries

In a second robustness check concerning the specification of time trends, we allow them to vary between OECD and non-OECD members. This check reflects the differences between OECD and non-OECD countries suggested by the quadratic model.

Table A.2.1 presents the results for the fixed effect specification of the cubic and linear models. They are almost indistinguishable from the estimates with one time trend (Table 2).

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.073** (1.447)	0.342*** (0.062)	-7.171*** (1.706)	0.278*** (0.069)
$logGDPpc^2$	0.475*** (0.177)		0.838*** (0.199)	
$logGDPpc^3$	-0.016** (0.007)		-0.031*** (0.008)	
N	2696	2696	2696	2696
R^2	0.317	0.276	0.190	0.150
F	21.771	25.521	30.107	37.284

Table A.2.1: Results with Separate Time Trends for OECD and non-OECD countries (baseline)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The results of the IV estimation with separate time trends for OECD and non-OECD countries are presented in Table A.2.2. The estimated impact of income on DMC and MFP in the linear models remained unchanged. The point estimates in the cubic model are closer to zero and less significant.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-2.003 (2.245)	0.915*** (0.093)	-1.322 (3.222)	1.069*** (0.121)
$logGDPpc^2$	0.361 (0.256)		0.262 (0.363)	
$logGDPpc^3$	-0.015 (0.010)		-0.009 (0.014)	
N	2677	2677	2677	2677
F	75.014	120.625	132.022	209.571

Table A.2.2 Results with Separate Time Trends for OECD and non-OECD countries (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.3 Country-specific time trends

In the estimations presented in subsection A.3, we allow the linear time trend to vary between nations. These robustness checks investigate whether country-specific policy or technology trends, which are independent of economic growth, have a large impact on the income-material use relationship.

Table A.3.1 reveals that the fixed effect estimates are largely robust to allowing for country-specific time trends. In the cubic model for DMC, the parameter estimates are not significant any more. The income elasticity of MFP per capita rises from 0.276 to 0.331 in the linear model.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-3.497 (2.266)	0.337*** (0.069)	-7.932*** (2.207)	0.331*** (0.074)
$logGDPpc^2$	0.392 (0.281)		0.941*** (0.259)	
$logGDPpc^3$	-0.013 (0.011)		-0.035*** (0.010)	
N	2696	2696	2696	2696
R^2	0.608	0.593	0.501	0.485
F	.	.	.	.

Table A.3.1: Results with Country-specific Time Trends (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.3.2 shows the results of the IV estimation with country-specific time trends. Compared to the estimations with a joint time trend for all countries, the income elasticities of material use in the linear models are lower. They fall from 0.866 to 0.645 (DMC) and from 1.183 to 0.781 (MFP). Allowing for country-specific time trends, thus, brings them closer to the elasticities found in the between estimations as well as the IV estimations of country averages.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-8.705 (5.562)	0.645*** (0.083)	3.809 (9.766)	0.781*** (0.140)
logGDPpc²	0.976 (0.737)		-0.579 (1.296)	
logGDPpc³	-0.031 (0.033)		0.033 (0.057)	
N	2677	2677	2677	2677
F	55.677	74.932	27.128	48.988

Table A.3.2 Results with Country-specific Time Trends (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.4 Results without 1990 to 1992

In this robustness check, we drop the observations from 1990 to 1992 because they might be affected by structural change following the fall of the Iron Curtain. This structural change is unlikely to be replicable in the future and might bias our results.

The results from the fixed effect estimations, presented in Table A.4.1, are qualitatively unchanged compared to the baseline. In the linear models, the income elasticities are smaller than in Table 3.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.540** (1.796)	0.285*** (0.063)	-6.700*** (1.879)	0.219*** (0.069)
logGDPpc²	0.544** (0.225)		0.771*** (0.218)	
logGDPpc³	-0.020** (0.009)		-0.028*** (0.008)	
Trend	0.003 (0.002)	0.005** (0.002)	0.004* (0.002)	0.007*** (0.003)
N	2303	2303	2303	2303
R²	0.300	0.262	0.193	0.138
F	23.873	34.340	16.808	20.427

Table A.4.1: Results without 1990-1992 (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

If we exclude the years 1990 to 1992 from the IV estimations (Table A.4.2), their results do not change substantially. The coefficients and significance levels in the cubic model are very similar to the baseline. Unlike in the fixed effect estimations, the income elasticities of DMC and MFP are higher than in the baseline.

	logDMCpc	logMFPpc

	Cubic	Linear	Cubic	Linear
logGDPpc	-3.103 (2.546)	0.968*** (0.126)	4.710 (3.865)	1.234*** (0.150)
logGDPpc²	0.491* (0.287)		-0.506 (0.441)	
logGDPpc³	-0.020* (0.011)		0.024 (0.017)	
Trend	-0.015*** (0.005)	-0.018*** (0.004)	-0.032*** (0.006)	-0.027*** (0.005)
N	2287	2287	2287	2287
F	72.594	127.886	59.266	75.191

Table A.4.2: Results without 1990-1992 (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.4.3 shows the results of the between estimation without the observations from 1990, 1991, and 1992. In both the cubic and the linear models, the estimates as well as the significance levels remain unaltered compared to the baseline (Table 5).

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-5.711 (4.445)	0.555*** (0.029)	-5.608 (4.209)	0.737*** (0.028)
logGDPpc²	0.730 (0.527)		0.724 (0.499)	
logGDPpc³	-0.028 (0.021)		-0.027 (0.019)	
N	2303	2303	2303	2303
R^2	0.719	0.714	0.833	0.829
F	119.129	354.697	233.584	689.954

Table A.4.3: Results without 1990-1992 (between)

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The IV estimation on the country averages excluding 1990 to 1992 (Table A.4.4) yield very similar results than the one with the full sample (Table 6). Parameter estimates and significance levels do not change. Together with the results from the between estimation (Table A.4.3), we conclude that the long-run relationship between income and material use is not effected by the structural change in the aftermath of the fall of the Iron curtain.

	logDMCpc		logMFPpc	

	Cubic	Linear	Cubic	Linear
logGDPpc	-13.513 (16.080)	0.560*** (0.032)	-4.023 (13.830)	0.757*** (0.027)
logGDPpc²	1.691 (1.907)		0.562 (1.644)	
logGDPpc³	-0.067 (0.074)		-0.022 (0.064)	
N	143	143	143	143
R²	0.706	0.712	0.835	0.831
F	103.130	307.248	275.991	760.401

Table A.4.4: Results without 1990-1992 (IV of country averages)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for $p<0.10$, ** for $p<0.05$, and *** for $p<0.01$.

A.5 Results without 2008

The following robustness checks investigate whether the financial crisis had an influence on our results. Therefore, we exclude all observations in 2008. The fixed effect estimates presented in Table A.5.1 indicate that this concern is unsubstantiated. The results with and without 2008 are very similar. At least in its early phase, the financial crisis appears to affect material use predominantly through changes in GDP per capita.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.468*** (1.458)	0.335*** (0.061)	-7.198*** (2.033)	0.265*** (0.071)
logGDPpc²	0.535*** (0.178)		0.832*** (0.239)	
logGDPpc³	-0.019*** (0.007)		-0.030*** (0.009)	
Trend	0.001 (0.002)	0.003 (0.002)	0.002 (0.003)	0.004 (0.003)
N	2552	2552	2552	2552
R²	0.286	0.252	0.149	0.104
F	21.640	33.389	16.854	16.378

Table A.5.1: Results without 2008 (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for $p<0.10$, ** for $p<0.05$, and *** for $p<0.01$.

Dropping the observations from 2008 has no major impact on the results of the IV estimation either. As Table A.5.2 shows, only the income elasticity for DMC per capita falls notably, from 0.866 in the baseline to 0.809.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-3.299 (2.675)	0.809*** (0.089)	4.507 (4.456)	1.158*** (0.132)
logGDPpc²	0.522* (0.301)		-0.457 (0.501)	
logGDPpc³	-0.022* (0.011)		0.020 (0.019)	
Trend	-0.009*** (0.003)	-0.011*** (0.003)	-0.023*** (0.005)	-0.022*** (0.004)
N	2534	2534	2534	2534
F	77.393	155.716	67.377	75.723

Table A.5.2: Results without 2008 (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.5.3 shows the results for the between estimations excluding 2008. We do not observe noteworthy changes compared to the baseline.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-6.935 (4.591)	0.555*** (0.030)	-5.429 (4.279)	0.730*** (0.028)
logGDPpc²	0.881 (0.548)		0.705 (0.511)	
logGDPpc³	-0.034 (0.022)		-0.027 (0.020)	
N	2552	2552	2552	2552
R²	0.713	0.707	0.832	0.827
F	115.799	342.463	230.457	681.061

Table A.5.3: Results without 2008 (between)

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The IV estimations of country averages excluding 2008 (Table A.5.4) also do not change compared to the baseline. As in case of dropping 1990 to 1992 (subsection A.4), our results are robust to the influences of the financial crisis.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-12.501 (14.349)	0.562*** (0.033)	-4.365 (12.507)	0.749*** (0.027)
logGDPpc²	1.569 (1.709)		0.601 (1.495)	
logGDPpc³	-0.062 (0.067)		-0.023 (0.059)	
N	143	143	143	143
R²	0.703	0.703	0.832	0.828
F	102.107	298.834	277.420	742.424

Table A.5.3: Results without 2008 (IV of country averages)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.6 Results with a Balanced Panel

Some countries which only became independent after the fall of the Iron Curtain do not have observations for all years. Therefore, our panel is slightly imbalanced. The following robustness checks analyze if our estimates change if we employ a balanced panel.

The fixed effect estimates presented in Table A.6.1 indicate that using the balanced panel leads to qualitatively similar results than in the baseline. The impacts of income on DMC and MF are, however, quantitatively smaller than in the baseline for both the cubic and the linear model.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-3.835** (1.888)	0.309*** (0.073)	-6.799*** (1.827)	0.245*** (0.082)
$logGDPpc^2$	0.462** (0.232)		0.793*** (0.218)	
$logGDPpc^3$	-0.017* (0.009)		-0.029*** (0.008)	
Trend	0.001 (0.002)	0.003 (0.002)	0.003 (0.003)	0.006** (0.003)
N	2356	2356	2356	2356
R^2	0.297	0.263	0.175	0.130
F	16.441	25.723	14.449	16.685

Table A.6.1: Results with a Balanced Panel (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.6.2 displays the results of the IV estimations on a balanced panel. The results are qualitatively unaltered compared to the baseline. Unlike in Table A.6.1, however, the parameter estimates indicate a stronger reaction of DMC and MFP to income.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-3.803 (2.466)	0.950*** (0.116)	3.006 (4.296)	1.374*** (0.158)
$logGDPpc^2$	0.589** (0.278)		-0.248 (0.483)	
$logGDPpc^3$	-0.024** (0.010)		0.012 (0.018)	
Trend	-0.015*** (0.004)	-0.016*** (0.003)	-0.028*** (0.005)	-0.028*** (0.005)
N	2337	2337	2337	2337
F	75.933	135.145	66.843	88.001

Table A.6.2: Results with a Balanced Panel (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The results of the between estimation on the balanced panel are presented in Table A.6.3. The cubic models yield somewhat different parameter estimates than the baseline. In both cases, they are not statistically significant. The linear models, however, indicate very similar elasticities of DMC and MFP with respect to GDP.

	logDMCpc	logMFPpc

	Cubic	Linear	Cubic	Linear
logGDPpc	-6.829 (4.883)	0.556*** (0.031)	-6.090 (4.487)	0.733*** (0.029)
$logGDPpc^2$	0.870 (0.582)		0.783 (0.535)	
$logGDPpc^3$	-0.034 (0.023)		-0.030 (0.021)	
N	2356	2356	2356	2356
R^2	0.726	0.721	0.845	0.840
F	105.969	314.506	217.877	641.801

Table A.6.3: Results with a Balanced Panel (between)

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Showing the IV estimates of country averages, Table A.6.4 indicates the same conclusion as Table A.6.3: the linear models' results remain unchanged when using a balanced panel.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-20.528 (18.791)	0.563*** (0.034)	-5.638 (15.392)	0.752*** (0.028)
$logGDPpc^2$	2.539 (2.238)		0.754 (1.838)	
$logGDPpc^3$	-0.100 (0.088)		-0.029 (0.072)	
N	123	123	123	123
R^2	0.701	0.718	0.846	0.842
F	89.202	277.153	263.879	720.848

Table A.6.4: Results with a Balanced Panel (IV of country averages)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.7 Results without Brunei, Kuwait, Qatar, and Singapore

The next robustness checks scrutinize the importance of countries with very high income for our results. We exclude the four richest nations in our sample to check whether these outliers drive the relationship between income and material use: Brunei, Kuwait, Qatar, and Singapore.

A.7.1 presents results of the fixed effect estimations. In the case of DMC per capita, results are qualitatively unchanged. Note that the point estimates have higher absolute values than in the baseline for the cubic model, but a lower one for the linear model. For MFP per capita in the linear model, we find a higher income elasticity than in the baseline. The parameter estimates of the cubic model are smaller than in the full sample and the significance levels drop. We suspect that this effect is caused by a lack of high-income observations to identify the right side of the cubic function.

	logDMCpc		logMFPpc	

	Cubic	Linear	Cubic	Linear
logGDPpc	-5.517*** (1.516)	0.310*** (0.058)	-4.627** (2.162)	0.295*** (0.080)
$logGDPpc^2$	0.673*** (0.191)		0.500* (0.268)	
$logGDPpc^3$	-0.025*** (0.008)		-0.016 (0.011)	
Trend	0.003 (0.002)	0.004** (0.002)	0.001 (0.003)	0.005* (0.003)
N	2620	2620	2620	2620
R^2	0.293	0.258	0.199	0.144
F	22.434	33.050	20.444	20.566

Table A.7.1: Results without Brunei, Kuwait, Qatar, and Singapore (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The results of the IV estimations without Brunei, Kuwait, Qatar, and Singapore are shown in Table A.7.2. The point estimates in the linear models are affected mildly by dropping the richest nations in our sample. The cubic models are impacted quantitatively more than the linear ones.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-2.446 (2.321)	0.849*** (0.091)	2.478 (3.547)	1.136*** (0.122)
$logGDPpc^2$	0.422 (0.263)		-0.262 (0.403)	
$logGDPpc^3$	-0.018* (0.010)		0.014 (0.015)	
Trend	-0.011*** (0.003)	-0.012*** (0.003)	-0.019*** (0.004)	-0.020*** (0.004)
N	2601	2601	2601	2601
F	81.467	158.874	107.052	99.488

Table A.7.2: Results without Brunei, Kuwait, Qatar, and Singapore (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The between estimation excluding the four richest countries in our sample (Table A.7.3) does not yield substantial changes compared to the baseline (Table 5). The cubic model for DMC is, however, an exception. Its parameter estimates have higher absolute values than in the baseline, and they are statistically significant.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-9.861* (5.104)	0.548*** (0.031)	-5.321 (4.718)	0.729*** (0.029)
$logGDPpc^2$	1.243** (0.612)		0.696 (0.566)	
$logGDPpc^3$	-0.049** (0.024)		-0.026 (0.022)	
N	2620	2620	2620	2620
R^2	0.700	0.690	0.827	0.823
F	105.630	307.861	216.457	642.651

Table A.7.3: Results without Brunei, Kuwait, Qatar, and Singapore (between)

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.7.4 displays the results for the IV estimations of country averages excluding Brunei, Kuwait, Qatar, and Singapore. The linear model yield results which are very similar to the baseline. The cubic models exhibit greater differences in the point estimates. Note that the estimates in the cubic model for DMC are not significant. The significant cubic relationship found in Table A.7.3 could not be confirmed in the IV estimation of country averages.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-10.054 (12.541)	0.559*** (0.034)	-8.740 (9.754)	0.747*** (0.028)
$logGDPpc^2$	1.275 (1.488)		1.130 (1.158)	
$logGDPpc^3$	-0.050 (0.058)		-0.044 (0.045)	
N	139	139	139	139
R^2	0.694	0.685	0.828	0.824
F	93.561	269.275	320.858	733.348

Table A.7.4: Results without Brunei, Kuwait, Qatar, and Singapore (IV of country averages)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

A.8 Results without Low-Income Countries

The last robustness check is conducted to evaluate how the results change if we exclude low income countries. Therefore, we restrict the sample to observations with a GDP per capita of at least 1,000 US$. The number of observations is reduced by 267 in this check.

The fixed effect estimates are presented in Table A.8.1. In the linear models, the income elasticity of material use rises after excluding low-income nations, from 0.343 to 0.408 (DMC) and from 0.276 to 0.398 (MFP). The cubic models also exhibit higher absolute parameter estimates for GDP per capita than in the baseline. In case of DMC per capita, the cubic model, furthermore, loses its significance.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-7.548 (4.733)	0.408*** (0.059)	-8.281** (3.741)	0.398*** (0.060)
$logGDPpc^2$	0.870 (0.534)		0.957** (0.410)	
$logGDPpc^3$	-0.031 (0.020)		-0.035** (0.015)	
Trend	0.001 (0.002)	0.002 (0.002)	0.003 (0.002)	0.004 (0.002)
N	2429	2429	2429	2429
R^2	0.311	0.295	0.213	0.201
F	22.641	43.737	21.086	36.266

Table A.8.1: Results without Low-Income Countries (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The IV estimations restricted to observations with a GDP of 1,000 US$ or more (Table A.8.2) show a similar pattern than the fixed effect estimations (Table A.8.1). The parameter estimates for GDP per capita are higher than in the baseline, in particular in the cubic models.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	25.058 (20.823)	0.897*** (0.098)	44.843* (26.776)	1.234*** (0.130)
$logGDPpc^2$	-2.551 (2.265)		-4.833* (2.917)	
$logGDPpc^3$	0.089 (0.082)		0.178* (0.106)	
Trend	-0.016** (0.007)	-0.012*** (0.003)	-0.032*** (0.009)	-0.022*** (0.004)
N	2410	2410	2410	2410
F	57.759	172.915	47.950	118.712

Table A.8.2: Results without Low-Income Countries (IV)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table A.8.3 displays the results of the between estimation excluding all observations with a GDP per capita of less than 1,000 US$. As in the baseline, the cubic models are nonsignificant. Furthermore, the income elasticities are higher than in the baseline. They rise from 0.554 to 0.588 (DMC) and from 0.732 to 0.759 (MFP).

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-4.170 (8.550)	0.588*** (0.034)	-12.601 (7.830)	0.759*** (0.032)
$logGDPpc^2$	0.574 (0.981)		1.519* (0.898)	
$logGDPpc^3$	-0.023 (0.037)		-0.057* (0.034)	
N	2429	2429	2429	2429
R^2	0.689	0.687	0.815	0.811
F	98.276	296.155	195.832	579.889

Table A.8.3: Results without Low-Income Countries (between)

Standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The results of the IV estimations of country averages when restricting the sample to nations with a GDP per capita of at least 1,000 US$ are displayed in Table A.8.4. In the linear models, the income elasticities are, again, higher than in the baseline. This result is consistent throughout all robustness checks in this section.

	logDMCpc		logMFPpc	
	Cubic	Linear	Cubic	Linear
logGDPpc	-6.479 (61.324)	0.594*** (0.039)	28.345 (54.047)	0.786*** (0.031)
$logGDPpc^2$	0.892 (7.035)		-3.120 (6.203)	
$logGDPpc^3$	-0.037 (0.267)		0.117 (0.235)	
N	136	136	136	136
R^2	0.679	0.683	0.769	0.811
F	87.578	237.180	195.632	641.085

Table A.8.3: Results without Low-Income Countries (between)

Robust standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

B Results for Individual Material Groups

Wiedmann et al. (2015) provide data on Material Footprints of four material groups: biomass, construction materials, fossil fuels, and metal ores and industrial minerals. We conduct a number of estimations for Material Footprints by material group to investigate whether they react differently to income changes. This section of the online appendix presents the results.

For each material group, we conduct fixed effect estimations for the cubic, linear, and quadratic model. Furthermore, the cubic and linear models are estimated for the IV, between, and IV of country averages specification. All estimations are run on the full sample.

B.1 Biomass

Table B.1.1 presents the results of the fixed effect estimations of the MFP per capita for biomass. Neither the cubic nor the linear models show significant relationships between income and MFP of biomass. The quadratic model, however, indicates a U-shaped influence of GDP per capita. Note that the R^2 is very low for all three models.

	logMFPpc		
	Cubic	Linear	Quadratic
logGDPpc	1.689 (2.102)	-0.080 (0.101)	-1.018*** (0.320)
$logGDPpc^2$	-0.269 (0.262)		0.057*** (0.017)
$logGDPpc^3$	0.013 (0.010)		
Trend	0.011** (0.005)	0.013*** (0.005)	0.011** (0.005)
N	2964	2964	2964
R^2	0.059	0.041	0.056
F	7.162	7.941	10.673

Table B.1.1: Results for biomass (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The three remaining specifications are presented in Table B.1.2. The cubic model is nonsignificant in all specifications, whereas the linear model is highly significant. In our preferred specification (IV of country averages), we find an income elasticity of 0.430. For all materials, for comparison, the corresponding number is 0.752. These numbers suggest that the material footprint for biomass is substantially less responsive to income changes than the total material footprint.

	logMFPpc					
	IV		Between		IV of country averages	
	Cubic	Linear	Cubic	Linear	Cubic	Linear
logGDPpc	1.866 (3.631)	0.935*** (0.141)	1.428 (4.457)	0.444*** (0.034)	4.551 (11.977)	0.430*** (0.036)
$logGDPpc^2$	-0.261 (0.407)		-0.168 (0.534)		-0.527 (1.421)	
$logGDPpc^3$	0.016 (0.015)		0.008 (0.021)		0.022 (0.055)	
Trend	-0.017*** (0.004)	-0.015*** (0.004)				
N	2888	2888	2964	2964	152	152
R^2			0.536	0.526	0.534	0.530
F	47.620	45.566	58.476	171.035	70.749	138.988

Table B.1.2: Results for biomass (IV, between, and IV of country averages)

Standard errors are shown in parentheses. Clustered standard errors in the IV estimation, robust standard errors in the IV estimation of country averages. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

B.2 Construction Materials

This subsection displays the estimates for the Material Footprint for construction materials. Table B.2.1 shows the results of the fixed effect estimations of the cubic, linear, and quadratic models. The results of the first two models are similar to those for all materials (Table 3). This result is not surprising: construction materials constitute a large share of the overall material use in most nations. Note, however, that the quadratic model exhibits substantially different point estimates than for all materials and that it is not significant.

	logMFPpc		
	Cubic	Linear	Quadratic
logGDPpc	-4.041* (2.195)	0.288*** (0.095)	0.187 (0.477)
$logGDPpc^2$	0.514* (0.261)		0.006 (0.027)
$logGDPpc^3$	-0.020** (0.010)		
Trend	0.027*** (0.004)	0.028*** (0.004)	0.027*** (0.004)
N	2964	2964	2964
R^2	0.253	0.249	0.249
F	46.273	76.761	57.094

Table B.2.1: Results for construction materials (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The three other specifications' results are presented in Table B.2.2. In the IV estimations, both the cubic and linear models are significant. As in the estimations for all materials, the cubic model is nonsignificant in the between as well as in the IV of country averages specification. The income elasticity of the Material Footprint for construction materials is higher than for all materials. In our preferred specification, it is very close to unity.

	logMFPpc					
	IV		Between		IV of country averages	
	Cubic	Linear	Cubic	Linear	Cubic	Linear
logGDPpc	9.007** (3.789)	0.828*** (0.153)	5.738 (5.707)	0.988*** (0.043)	7.561 (15.165)	1.027*** (0.042)
logGDPpc²	-0.901** (0.428)		-0.539 (0.684)		-0.643 (1.815)	
logGDPpc³	0.033** (0.016)		0.020 (0.027)		0.020 (0.071)	
Trend	0.012** (0.005)	0.013*** (0.005)				
N	2888	2888	2964	2964	152	152
R^2			0.774	0.772	0.761	0.771
F	153.121	263.384	173.831	522.300	179.755	607.049

Table B.2.2: Results for construction materials (IV, between, and IV of country averages)

Standard errors are shown in parentheses. Clustered standard errors in the IV estimation, robust standard errors in the IV estimation of country averages. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

B.3 Fossil Fuels

Section B.3 of the online appendix presents the estimates for the Material Footprint for fossil fuels. Table B.3.1 presents the results of the fixed effect specification. We find a significant relationship between MFC and GDP only in the linear model. The income elasticity of MFP is larger for fossil fuels (0.388) than for all materials (0.276).

	logMFPpc		
	Cubic	Linear	Quadratic
logGDPpc	-2.461 (1.937)	0.388*** (0.081)	-0.084 (0.430)
logGDPpc²	0.314 (0.225)		0.028 (0.024)
logGDPpc³	-0.011 (0.009)		
Trend	-0.004 (0.003)	-0.003 (0.003)	-0.004 (0.003)
N	2964	2964	2964
R^2	0.087	0.082	0.085
F	13.076	15.033	15.505

Table B.3.1: Results for fossil fuels (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

Table B.3.2 displays the results for the three remaining specifications. The linear models indicate income elasticities of material footprints for fossil fuels greater than one. It equals 1.383 in our preferred specification, which is the highest among all material groups. Interestingly, the cubic model becomes significant in the between specification. This significant relationship between income and MFPpc disappears again in the IV estimation of country averages.

	logMFPpc					
	IV		Between		IV of country averages	
	Cubic	Linear	Cubic	Linear	Cubic	Linear
logGDPpc	14.586*** (4.162)	1.244*** (0.126)	-12.528** (5.588)	1.322*** (0.043)	5.319 (16.118)	1.383*** (0.046)
logGDPpc²	-1.480*** (0.466)		1.725** (0.670)		-0.377 (1.920)	
logGDPpc³	0.054*** (0.017)		-0.070*** (0.026)		0.011 (0.075)	
Trend	-0.028*** (0.004)	-0.027*** (0.004)				
N	2888	2888	2964	2964	152	152
R^2			0.866	0.857	0.852	0.854
F	36.183	64.933	327.231	925.632	319.910	922.614

Table B.3.2: Results for fossil fuels (IV, between, and IV of country averages)

Standard errors are shown in parentheses. Clustered standard errors in the IV estimation, robust standard errors in the IV estimation of country averages. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

B.4 Metal Ores and Industrial Minerals

The last material group in our data encompasses metal ores and industrial minerals. Table B.4.1 displays the estimates for the fixed effect specification. Only the linear model is significant, and the point estimate for logGDPpc is greater than for all materials.

	logMFPpc		
	Cubic	Linear	Quadratic
logGDPpc	-5.635* (3.348)	0.297** (0.132)	-0.425 (0.750)
logGDPpc²	0.670 (0.407)		0.043 (0.046)
logGDPpc³	-0.024 (0.016)		
Trend	0.004 (0.005)	0.005 (0.005)	0.004 (0.006)
N	2947	2947	2947
R^2	0.059	0.048	0.053
F	7.110	9.659	6.646

Table B.4.1: Results for ores (fixed effects)

Clustered standard errors are shown in parentheses. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

The three other specifications' results are presented in Table B.4.2. Only the linear relationship between income and Material Footprints is significant for metal ores and industrial minerals. The estimated income elasticities are higher than for all materials but below unity, at least for the baseline and IV of country averages specifications.

	logMFPpc					
	IV		Between		IV of country averages	
	Cubic	Linear	Cubic	Linear	Cubic	Linear
logGDPpc	6.504 (4.762)	1.728*** (0.167)	-8.280 (7.157)	0.951*** (0.054)	7.270 (17.326)	0.927*** (0.058)
$logGDPpc^2$	-0.649 (0.539)		1.122 (0.858)		-0.724 (2.064)	
$logGDPpc^3$	0.028 (0.020)		-0.045 (0.034)		0.027 (0.081)	
Trend	-0.036*** (0.005)	-0.035*** (0.005)				
N	2871	2871	2947	2947	152	152
R^2			0.671	0.667	0.650	0.657
F	59.046	83.518	103.130	307.959	94.518	255.423

Table B.4.2: Results for ores (IV, between, and IV of country averages)

Standard errors are shown in parentheses. Clustered standard errors in the IV estimation, robust standard errors in the IV estimation of country averages. Stars correspond to the p-value: * for p<0.10, ** for p<0.05, and *** for p<0.01.

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