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The Role of Income and Substitution in Commodity Demand

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Abstract

This paper presents estimates of time-varying income elasticities of demand for energy and metal commodities. The analysis finds that the elasticities are close to unity, evaluated at world median per capita income levels. Furthermore, the estimates confirm that as income rises, demand growth for industrial commodities slows and eventually plateaus. Indeed, estimates for aggregate metals and energy differ by an order of magnitude throughout the income spectrum: from a low of 0.2 for advanced economies to nearly 2 for low-income countries. The analysis, which accounts for substitutability by estimating group aggregates as well as individual commodities with cross-price effects, is based on a panel autoregressive distributed lag model covering 1965–2018, for up to 63 countries.

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1. Introduction

Demand for industrial commodities surged over the past two decades, notably as a result of strong growth in emerging markets and developing economies (EMDEs). The surge in demand was most pronounced in metals, which grew more than 150 percent during this period. This increase was driven by China, whose share of world metals demand reached 50 percent in 2015, up from 10 percent two decades earlier. Commensurate increases took place in coal consumption, driven by both China and India (World Bank 2018).

The overall increase in demand was associated with a price boom; between 2000 and their 2011 peak, real prices of metals nearly doubled while those of energy rose almost 150 percent. Although prices of most commodities have since come down in real terms (as of 2020), they have remained much higher than their average in 1985-2000, a period of relatively low and stable prices (Figure 1).

The commodity demand boom provoked discussions of whether global commodity markets had entered a period of scarcity: whether global metal reserves would be adequate to meet the infrastructure needs of fast-growing EMDEs; and whether global energy and food supplies could keep up with population and income growth. References to "peak oil" (the time when the maximum extraction rate of crude oil is attained) reached record highs along with the peak in oil prices (IMF 2011; Lutz et al. 2012; Kerschner et al. 2013). Discussions intensified about whether metal prices had entered a super-cycle like those experienced during the industrial revolution and the westward expansion of the United States. (Radetzki 2006; Cuddington and Jerrett 2008; Erten and Ocampo 2013). In addition, food security concerns prompted the agriculture ministers of the G20 to launch an inter-agency platform to ensure appropriate policy measures (AMIS 2011).

However, the post-2011 commodity price declines, and especially the 2014 oil price collapse, ushered in a sharp reversal of views. Scarcity concerns were replaced by worries about the challenges posed by low commodity prices for commodity exporting countries, and about suitable policies for addressing them (Baffes et al. 2015; Christensen 2016). In a similar vein, discussions of the "peak oil" hypothesis were pushed aside by discussions of "peak demand" (Dale and Fattouh 2018).

The sharp reversal in views reflects three key principles that shape the evolution of commodity consumption. First, the relationship between consumption and income is non-linear in the sense that, as income increases, commodity consumption initially rises at an accelerated pace, but after a certain level growth slows and begins to plateau. Second, consumption surges, which are often associated with price booms, induce substitution among commodities in the short term, if substitute products are readily available, and in the long term, as new products become available through innovation. Third, a period of higher prices with demand outstripping supply leads to induced innovation in the production of commodities. These three trends were observed throughout the events of the past twenty years. The dramatic changes in commodity demand were driven by China, which experienced rapid growth at the start of the 1990s, but has slowed more recently, and also saw a shift from being a lower-income country to a middle-income country over this period (World Bank 2018). As such, its income per capita growth, and income elasticity of demand, both slowed, from a high level. The period of strong commodity demand (which was also associated with high prices) induced innovation and substitution in the use and production of commodities—the most notable example of innovation being the development of the U.S. shale oil industry.

The objective of this paper is to shed light on the first two principles by estimating income elasticities of energy and metal commodities at the individual and aggregate level and incorporating cross-price effects to test for substitution between commodities. Our approach, which takes into consideration both non-linearities as well as short- and long-term substitution effects, extends the literature of commodity demand in four ways.[1]

First, it utilizes a comprehensive data set and applies a common framework to three energy and six metal commodities for up to 63 countries over more than half a century (1965-2017). The broad and long data coverage, which encompasses the two post-WWII price cycles (1970s and 2000s), enables us to obtain a consistent picture across the full spectrum of industrial commodities. This is especially pertinent in the context of EMDEs, for which the literature is not as rich as that of high-income countries, even though EMDEs account for two-thirds of world metals demand and nearly half of world energy demand (Focacci 2005; Canas et al. 2003; Roberts 1996; Rogich 1996; Radetzki and Tilton 1990).

Second, the demand equations provide estimates of income elasticities of demand that vary by income level. We find that while income elasticities of demand for energy and metal are close to one at median income levels, they are substantially higher at low income levels (close to 2) but drop rapidly (approaching 0.2) at high income levels. These results complement the existing literature which typically provides single estimates for the income elasticity of demand for commodities.

Third, the paper accounts for substitutability among commodities—in the short term by including cross-price effects and in the long-term by estimating commodity

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[1] This paper builds on earlier work which estimated income elasticities of demand for three energy (coal, natural gas, and oil) and three metal (aluminum, copper, and zinc) commodities (Baffes et al. 2018).

aggregates.[2] Substitutability among commodities is an area of research that has not received adequate attention from a modeling perspective.

Fourth, the model includes control variables designed to capture the countries' growth orientation (represented by the ratio of investment to GDP), rate of urbanization, and population density, hence yielding a deeper understanding of how these factors interact with commodity consumption as well as providing consistent and unbiased estimates of income elasticities.

The rest of the paper proceeds as follows. The next section sets the stage by reviewing the underpinnings of the relationship between economic development and commodity consumption. Section 3 describes the model, estimation procedure, and data. Section 4 discusses results based on aggregate and commodity-specific demand equations, including various extensions and robustness checks. The last section concludes with policy implications and directions for further research. Appendices discuss examples of substitution episodes among commodities and provide a detailed data description, comprehensive parameter estimates, and various robustness checks.

2. The income-commodity consumption relationship

The way in which commodity consumption responds to income is, perhaps, one of the earliest empirically-verified relationships in economic analysis. In the mid-nineteenth century, Engel (1857) observed that poor families spend a larger proportion of their income on food than wealthier families; this observation was later coined Engel's Law. Almost a century later, Kindleberger (1943) argued that, as a direct consequence of Engel's Law, the terms of trade (ToT) faced by developing countries (typically commodity-exporting) relative to industrialized economies (mostly commodity-importing) would be subjected to downward pressures. Hence, commodity-dependent countries should reduce their reliance on their resource base and, instead, embrace industrialization policies in order to mimic the growth paths of industrialized economies. Prebisch (1950) and Singer (1950) confirmed Kindleberger's conjecture, which later became the Prebisch–Singer hypothesis. Engel's Law, Kindleberger's views, and the Prebisch-Singer hypothesis set the stage for the post-WWII development agenda, which promoted industrialization policies, particularly in Latin America but also in some Sub-Saharan African countries (Baer 1982).

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[2] The distinction between short- and long-term substitutability used in this paper is different than the distinction between short- and long-term adjustment used in the model. The former captures whether substitutability is price- or innovation-driven. The latter captures the time it takes for shocks to be dissipated.

These views on economic development contained implicit assumptions that the relationship between commodity consumption and income was stable over time and invariant across commodities and countries. But these assumptions came to be questioned on several grounds. First, most commodity prices have experienced long boom and bust periods (in addition to short-term cycles). For example, since the collapse of the Bretton Woods fixed-exchange-rate regime in the early 1970s, commodity prices have experienced two large and broad-based boom-bust episodes: a supply- and geopolitically-driven episode during 1972-85, and a demand-driven episode during 2000–14 (Cooper and Lawrence 1975; Radetzki 2006; Baffes and Haniotis 2010). Such cyclicality renders the declining ToT hypothesis somewhat invalid, at least from a longer-term perspective.

Second, consumption patterns with respect to income have differed across commodities (Evans and Lewis 2005; Fernandez 2018a). Over the past 55 years, energy intensity (i.e., energy consumption relative to GDP) at the global level has declined smoothly, while metal intensity has both been more volatile than energy, and it reversed its downward trend and began to rise in the early 1990s (Figure 2). Consumption paths have also differed across individual commodities (see figures in Appendix B).

Third, both theoretical perspectives and empirical observations have increasingly shown that, as economies grow, per capita demand for commodities rises rapidly initially (even at an accelerating pace) but then slows and plateaus, and may eventually decline. This occurs as the economy becomes increasingly dominated by the less-commodity intensive service sector at the expense of the more commodity-intensive agricultural and manufacturing sectors (Clark 1940; Kuznets 1972; Malenbaum 1978; Larson et al. 1986). In addition, resource requirements lessen as economies develop and infrastructure needs are fulfilled, and as technological developments lead to efficiency gains. The idea that the commodity consumption–income relationship is non-linear throughout the development process has led to a strand of literature that comes under various names: The material or environmental Kuznets curve (an extension to the Kuznets curve which links economic growth and inequality); *S*-shaped curve; inverted *U*-shaped curve; dematerialization hypothesis; intensity of material use hypothesis; and plateauing hypothesis (Herman, Ardekani, and Ausubel 1990; Tilton 1990; Cleveland and Ruth 1998; Radetzki et al. 2008).

The empirical literature on the commodity consumption-income relationship is rich. At a primary commodity level, for example, Lahoni and Tilton (1993), Stuermer (2017), and Fernandez (2018b) among others, examined base metals; Jaunky (2012) looked at aluminum; while Guzman et al. (2005) and Bailliu et al. (2019) studied copper. For energy, several papers look at demand for energy (Burke and Csereklyei 2016; Csereklyei and Stern 2015; Dahl and Roman 2004; Jakob, Haller, and Marschinski 2012), while others look at individual energy commodities, including oil (Hamilton 2009; Gately and Huntington 2002), natural gas (Krichene 2002; Erdogdu 2010), and coal (Shealy and Dorian 2010; Chan and Lee 1996).[3] Demand for final products has also been studied extensively—see Kamerschen and Porter (2004) for electricity; Dahl (2012), Gately and Streifel (1997), and Drollas (1984) for gasoline and diesel, and Crompton (2015) and Wårrel (2014) for steel. Various authors have summarized the literature, including Cleveland and Ruth (1998) who looked at 42 empirical studies on dematerialization and the intensity of use hypothesis and Huntington, Barrios, and Arora (2017) who provided a review of 48 studies of energy demand elasticities for large EMDEs. Both these reviews highlight the large variation of results across studies. Crowson (2017) attributed such variation to structural changes in trading relationships and technological change, as well as inaccurate data and inconsistent methodologies.

The present analysis is novel in that it estimates aggregate demand equations (energy and metal), in addition to individual commodity equations, thereby addressing the complex nature of substitutability among commodities. The complexity arises from the fact that substitution can occur from a change in relative prices in the short term (if alternative materials are available) or with some lag (when the development of new material entails significant costs). More importantly, it can also occur in the longer term in response to new technologies and innovation not necessarily in response to price changes (Tilton and Guzmán 2016). Long term substitution is often irreversible and could entail substitution across commodity groups—so-called functional substitution (Wellmer 2012; Renner and Wellmer 2019). Furthermore, the factors leading to substitution (regardless of source) are often accompanied or triggered by policies such as taxes, subsidies, trade restrictions, ore environmental regulations that can permanently alter the consumption paths of individual commodities.

3. Model, estimation, and data

3.1. Econometric model

Two broad frameworks offer suitable features for analyzing the commodity consumption–income relationship (Charfeddine and Barkat 2020): The vector autoregressive (VAR) approach, which yields impulse responses and variance decompositions (Kilian 2009; Kilian and Murphy 2014; Baumeister and Peersman 2013; Baumeister and Hamilton 2019), and the autoregressive distributed lag (ARDL) framework, which combines long-

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[3] The energy consumption–income relationship has been examined from a causality perspective as well (Apergis and Payne 2009; Costantini and Martini 2010).

run dynamics with short-run movements and gives point estimates of elasticities (Pesaran and Smith 1995; Pesaran 1997; Fernandez 2018a). While VAR models, typically utilizing data at quarterly (or higher) frequency, account for endogeneity, they are seldom used in a panel-data framework with large cross-sectional dimensions. The ARDL approach is more appropriate for the data set used in this paper, where both the cross-sectional and the time dimension are moderate to large (with the latter being larger than the former) and the available data frequency is annual.

We begin with a standard demand equation:[4]

$$c_t = \mu + \theta_1 y_t + \theta_2 y_t^2 + \theta_3 p_t + \varphi' X_t + \varepsilon_t, \tag{1}$$

where c_t denotes per capita commodity consumption at year t; y_t is real per capita income, p_t is the real price of the commodity; and X_t is a $h \times 1$ vector of control variables, such as fixed effects, cross-price impacts, and various country-specific characteristics; ε_t is the stochastic error term; μ, θ_1, θ_2, θ_3 denote parameters and φ' a vector, all to be estimated. This approach is common in the literature (Adeyemi and Hunt 2007; Baffes *et al.* 2018; Crompton 2015; Burke and Csereklyei 2016; Stuermer 2017). The quadratic income term, y_t^2, which captures the nonlinearities discussed earlier, allows the calculation of income elasticities that vary across income levels. Most variables are expressed in logarithmic terms. For notational simplicity, we do not use country and commodity subscripts.

Because consumption is likely to depend on both current and lagged income, prices, and control variables, (1) is extended as follows:

$$\begin{aligned} c_t = {} & \sum_{i=1}^{p} \beta_i \, c_{t-i} + \sum_{j=0}^{q} \gamma_j \, y_{t-j} + \sum_{k=0}^{q} \delta_k \, y_{t-k}^2 + \sum_{l=0}^{r} \zeta_l \, p_{t-l} \\ & + \sum_{m=0}^{s} \pi_m' \, X_{t-m} + \varepsilon_t. \end{aligned} \tag{2}$$

Relationship (2) is an ARDL (*p*, *q*, *r*, *s*) model where *p*, *q*, *r*, and *s* denote the lag lengths. Its parameters— β_i, γ_j, δ_k, and ζ_l—are related to (1) as follows: $\theta_1 = \sum_{j=0}^{q} \gamma_j / \left(1 - \sum_{i=1}^{p} \beta_i\right)$; $\theta_2 = \sum_{k=0}^{q} \delta_k / \left(1 - \sum_{i=1}^{p} \beta_i\right)$; and $\theta_3 = \sum_{l=0}^{r} \zeta_l / \left(1 - \sum_{i=1}^{p} \beta_i\right)$.

To account for non-stationarity, (1) and (2) are combined in the following error-correction representation:

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[4] Early research on commodity demand was based on duality theory (Halvorsen 1977; Pindyck 1979). However, Deaton and Muellbauer (1980) who also analyzed consumer behavior in the context of duality, questioned the plausibility of Engel's model due to heterogeneity concerns and introduced a generalized Engel curve. They credited Sydenstricker and King (1921) and Prais and Houthakker (1955) for recognizing heterogeneity of demand across commodities and households.

$$\Delta c_t = \rho(c_{t-1} - \theta_1 y_t - \theta_2 y_t^2 - \theta_3 p_t - \varphi' X_t) + \alpha + \sum\nolimits_{i=1}^{p-1} \beta_i^* \Delta c_{t-i}$$

$$+ \sum\nolimits_{j=0}^{q-1} \gamma_j^* \Delta y_{t-j} + \sum\nolimits_{k=0}^{q-1} \delta_k^* \Delta y_{k-1}^2 + \sum\nolimits_{l=0}^{r-1} \zeta_l^* \Delta p_{t-l} + \sum\nolimits_{m=0}^{s-1} \pi_m^{*\prime} \Delta X_{t-m} + \epsilon_t. \quad (3)$$

The parameters β^*, γ^*, δ^*, and ζ^* in (3) capture short-term relationships and are related to (2) as: $\beta^* = -\sum_{n=k+1}^{p} \beta_n$, $\gamma^* = -\sum_{n=k+1}^{q} \gamma_n$, and $\delta^* = -\sum_{n=l+1}^{q} \delta_n$, $\zeta^* = -\sum_{n=m+1}^{r} \zeta_n$. Lastly, $\rho = \sum_{n=i+1}^{p} \lambda_n - 1$ denotes the speed of adjustment towards the long run equilibrium.

Income elasticities of demand can be derived by differentiating (1) with respect to income as follows:

$$\eta_t = \frac{\partial c_t}{\partial y_t} = \theta_1 + 2\theta_2 y_t, \quad (4)$$

where η_t denotes the long-run income elasticity for the given commodity. A key characteristic of η_t is that it varies with income, thereby establishing when consumption of a commodity plateaus as income rises.

3.2. Estimation

The model is estimated by a pool mean group (PMG) estimation procedure (Pesaran, Shin, and Smith 1999). The PMG ARDL procedure assumes homogeneity across all long-run estimators but allows for differences across countries in the short term—an appropriate assumption because commodity demand tends to be more similar across countries over the longer term than in the short term, where it may be heterogeneous. The Hausman test is used to assess the performance of the long-run homogeneity assumption. Lastly, following Pesaran and Shin (1999), the Bayesian information criterion (BIC) is used to determine the lag structure.

3.3. Data

The model is applied to three energy commodities (coal, natural gas, and oil) and six metals (aluminum, copper, lead, nickel, tin, and zinc), both individually and as group aggregates. For the energy group aggregate, coal, oil and natural gas were summed according to their energy content, while for metals, the six base metals were aggregated according to their weight. An alternative weighting method based on value was also tested for metals and is included in the robustness checks.

Annual data for 1965–2017 for up to 63 countries (depending on the commodity) were used. The number of countries, which varies depending on data availability, ranges from 57 (coal) to 63 (oil) for energy and from 36 (nickel) to 55 (zinc) for metals. The number of observations per demand equation fluctuates between 1,555 and 3,235. Data on per capita income were obtained from the World Bank's World Development Indicators (WDI); data on population were taken from the United Nations; data on commodity consumption were taken from the BP Statistical Review (energy) and the World Bureau of Metal Statistics (metals); world commodity prices were taken from the World Bank's Commodity Price Data and converted into real terms by using country-specific GDP deflators. Exchange rates were taken from both the WDI and the St. Louis Federal Reserve Bank's database. Appendix B gives a detailed description of data, sources, and summary statistics.

4. Results

This section presents results from the ARDL model, which include long-run parameter estimates, adjustment coefficients, Hausman test statistics, and log-likelihood values (short-run parameter estimates are not reported). The BIC suggests an optimal lag of one in all specifications; hence the use of ARDL (1,1,1,1). In most cases the Hausman test suggests that the pool mean group specification is a more suitable choice than the mean group approach, as the p-values exceed the 5 percent level in nearly all model specifications.

Results for commodity-specific demand equations are reported in Table 1. Of the nine equations, only four (oil, aluminum, copper, and zinc) yielded parameter estimates for the two income and price variables that were both significantly different from zero at the 1 percent level as well as consistent with *a priori* expectations—positive y_t and negative y_t^2 and p_t. Income elasticities, which were calculated at the median income of our sample according to (4), differ considerably among the four commodities, from a low of 0.3 for zinc to a high of 0.8 for aluminum. Indeed, the estimates exhibited a high degree of heterogeneity across commodities, a finding that is consistent with the literature as noted earlier. In order to examine the source of heterogeneity and also account for short- and log-term substitutability, the next two sections discuss results from two extensions of the model: Aggregate demand equations and the inclusion of cross-price effects in the commodity-specific equations.

4.1 Aggregate demand equations

The three energy and six metal commodities were combined into two group aggregates. Thus, the demand equation for each country features energy (instead of, say, oil) and metals (instead of, say, copper).[5] Results for the aggregate demand equations are reported in the first columns of Tables 2 (energy) and 3 (metals). In both equations, all four parameter estimates have the expected sign, and are different from zero at the 1 percent level of significance. Moreover, all four parameter estimates for the metals aggregate are greater than those for energy, implying that metal consumption exhibits a stronger response to income and price changes and it also adjusts to long-run equilibrium much faster than energy. This is consistent with the higher variability of metal intensity, compared to that of energy (Figure 2). Indeed, consumption volatility of aggregate metals is nearly three times as high compared to energy (5.21 versus 2.09 as reported in Table B2, Appendix B).

As noted earlier, the parameter estimates on the income variables enable us to calculate implied income elasticities of demand that vary by income level. Figure 3 presents income elasticity estimates for both entire per capita income spectrum while Figure 4 give the 1997 and 2017 point estimates for three EMDEs (India, China, and Turkey) and three advanced economies (Korea, U.S., and Japan).

Income elasticities are high at low income levels but decline rapidly as income rises. For metals, they reach unity at about \$9,000 per capita, and are 0.2 at the current level of U.S. income per capita. For energy, elasticity begins declining at a lower income level compared to metals, reaching unity at \$3,800 per capita, but it declines less rapidly, and like metals, it reaches 0.2 at the current level of U.S. income per capita. At China's current per capita income level, the elasticity of metals demand is 1.1, while for energy demand it is 0.8. This indicates that China's energy demand is closer to the plateau stage, but that its demand for metals is still rising faster than growth in GDP per capita. These results help explain the diverging trends we have seen in metals and energy demand over the past two decades: at China's level of development over the past 20 years, the estimated income elasticity of demand for metals has ranged from 1.9 to 1.1, while for energy it has ranged from 1.3 to 0.8.

The subsequent five columns of Tables 2 and 3 report estimates by including five control variables. These variables, which were considered sequentially (for better interpretation and to avoid collinearity issues) represent the country's growth orientation and distribution of population. The former is captured by the country's investment-to-GDP ratio and the latter by the rate of urbanization and population density. We also run two additional specifications, by including a time trend and by splitting the real domestic

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[5] By combining individual commodities, we can avoid much of the issue of substitutability within commodity group, although substitution still occurs between commodity groups (e.g. when oil is used for plastic packaging in place of aluminum). Section A2 of Appendix A elaborates on various sustainability episodes, both within and across commodity groups.

price into a nominal dollar-based price and a real exchange rate. A time trend is often used as a proxy of technological change; the price decomposition permits us to distinguish the influence of the world price from that of the exchange rate.

A number of important results emerge from this extension of the model. First, regardless of which control variable is included in the demand equation, all four parameter estimates retain their sign and significance (1 percent level). Second, the coefficient on the time trend is not significantly different from zero in metals but is significantly different from zero in energy. Its inclusion noticeably affects the coefficient on the income variables, and therefore the implied income elasticities (see below). Third, in both equations, the coefficients on urbanization and population density are highly significant with alternate signs (positive and negative, respectively), implying that, while urbanization is a commodity-intensive process, countries with higher population density use fewer commodities per capita than their sparsely populated counterparts. Fourth, the coefficient on investment share was positive and significant for energy, but insignificant and negative for metals (it was significant at the 5 percent level). Finally, when the domestic real price is split into its nominal world counterpart (dollar-based) and the real exchange rate, we find that for both the energy and metals groups the world price matters much more than the exchange rate.

As with the baseline model, we estimated the income-varying elasticities of demand for energy and metals for each of the specifications (see left hand side panel of Figure 5 for energy and Figure 6 for metals). The estimated elasticities do not change substantially when the control variables are added, with high elasticities at low income levels and low elasticities at high income levels, consistent with the robustness of the model specification.

An important exception is the result from including the time trend in the energy model. Here we find that the coefficient on y_t^2 becomes much smaller, in turn leading to a smaller decline in elasticity as income rises; even at the top quartile of income, the elasticity remains at unity, indicating no plateauing. This suggests that the plateauing in energy use observed in the data may reflect consumption-saving efficiency improvements.

The aggregate demand equations were also subjected to a number of robustness checks. Detailed parameter estimates are reported in Appendix C (Table C1 for energy and Table C2 for metals). For comparison, the first column of each table reports the results from the base model as well. The corresponding elasticities are shown in the right hand side panels of Figures 5 and 6.

The first robustness check involved splitting the sample into two periods of equal length, 1965-97 and 1998-2017. The break allowed us to have one boom-bust price episode in each sub-sample, the second of which coincides with China's dominance in commodity demand. The results using the split remain unchanged from a qualitative perspective, as all parameter estimates for both aggregates retain their signs and levels of significance. More importantly, the elasticity estimates (evaluated at sample median per capita income) are lower in the second sub-period—0.8 versus 0.5 in energy and 1.1 versus 0.9 for metals. This finding is consistent with the fact that the per capita income and commodity consumption increased in most countries from the first to the second subperiod.

As a second robustness check, we excluded large countries (China and the U.S., the world's largest commodity consumers) and groups of countries (the G7, and low-income countries). The results, reported in the fourth and fifth columns of Tables C1 and C2, are nearly identical (including the magnitude of the parameter estimates) to those of the base specification. As expected, the country composition adjustments did not have a material impact on the values of the elasticity estimates depicted in Figures 5 and 6.

The third robustness check involved sample adjustments to address data concerns, including coverage, reliability, and weighting techniques. In the case of energy, we replaced the aggregate (sum of coal, natural gas, and oil) with total energy, which includes renewables and nuclear power. The results are little different, which is unsurprising given the relatively small share of these latter components in total energy demand (around 15 percent in 2017). In the case of metals, several authors, including Crowson (2017), have raised valid concerns about the way in which data are used. As a rough control, we excluded countries with potentially questionable consumption statistics, by dropping observations with a commodity demand growth rate that either exceeded 50 percent or was below 50 percent in three or more years or was zero in three or more consecutive years. Applying this rule reduced the number of countries to 29 (from 43 in the base specification). This adjustment did not change the results for either energy or metals.[6] Lastly, we replaced the volumetric aggregation of metals by a value-based aggregation. Following Considine (1987) and Humphreys (1987), we weighted the six base metals according to their average prices over the entire sample period (1965-2017). This substantially reduced the dominance of aluminum in the sample. But, as before, the results did not differ noticeably from those in the baseline.[7]

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[6] We also applied the adjusted sample for metals to the individual equations (Table C3); the results were similar to the ones of the base specification.

[7] We also replaced the BIC by the Akaike Information Criterion (AIC) for the choice of optimal lag. As in the case of other robustness checks, the results were very similar to the base specification.

To summarize, two key results emerge from the robustness checks. First, the estimated elasticities from splitting the sample are consistent with the plateauing hypothesis—in a rough sense, this change in elasticity can be viewed as an approximate measure of the speed at which plateauing materializes. Second, adjusting the sample and country composition did not have a discernable impact on the value of the elasticity estimates, implying that the nature of the data may not be a reason behind the heterogeneity of the results found in the literature (the next section elaborates further on this).

4.2 Cross-price effects

The second extension of the base model accounted for cross-price effects in the commodity-specific equations. As in the case of the control variables for aggregate equations, to avoid collinearity issues and make the results easier to interpret, prices of other commodities were considered sequentially. A negative sign on the price of another commodity is consistent with substitutability, while a positive sign is consistent with complementarity. Detailed results are reported in Appendix D (Tables D1-D3 for energy and Tables D4-D9 for metals).

The inclusion of cross-price effects improves the performance of the models on several occasions. In the case of coal, for example, not only are the parameter estimates of oil and natural gas prices highly significant, but the parameter estimates of income (linear and quadratic) and own-price elasticity become highly significant. It is worth emphasizing that the magnitudes of the oil and natural gas price parameter estimates are similar (0.46 and 0.52) to one another—not a surprising outcome since in most countries natural gas pricing has typically been based on oil prices (though this is gradually changing).

In the natural gas equation, the effect of including the price of coal is not significantly different from zero, leaving the results largely unchanged. When the price of oil is included, it gives a negative parameter estimate while the own-price elasticity becomes positive, with both estimates having roughly similar magnitudes. As noted above, this is likely due to natural gas pricing being based on the oil price in most countries. To confirm this, we replaced the price of natural gas by the price of oil in the natural gas model, and the results were remarkably similar (-0.16 versus -0.14). Lastly, in the oil equation, both natural gas and coal prices have the expected sign (positive) and they are significantly different from zero at the 1 percent level, consistent with a strong degree of substitutability between oil and coal or natural gas—notably coal whose price elasticity is four times as high as that of natural gas (-0.63 versus -0.15).

The strong substitutability that we find between oil and coal is unsurprising given the trend toward replacement of oil by coal for electricity generation in the early years of the sample. While in recent years natural gas has increasingly been replacing coal in electricity generation, the duration of this development is much shorter (and applicable to a smaller number of countries), and so we may have too few observations for this trend to be reflected in our results.

In the case of aluminum, by far the most important metal by volume of consumption, only zinc shows a (marginal) cross-price effect. The sign, however, is negative, which potentially implies that aluminum and zinc may be complements.[8] For copper demand, the price of aluminum is highly significant, with a negative sign and the same magnitude as the own-price effect, implying a high degree of substitutability between aluminum and copper.[9] There is some degree of substitutability between copper and nickel (as well as potentially complementarity with tin, consistent with their joint use in alloys). Lead shows no signs of substitutability or complementarity with any other metal. In the case of nickel, when lead or tin are included in the demand equation, their respective prices are negative and highly significant, but the own price become insignificant, a result similar to that for natural gas. Tin turns out to be a close substitute with aluminum, as expected (see discussion in Appendix A). Interestingly, the tin model improves considerably when it includes the price of aluminum (as was the case with coal). Tin appears to be substitutable with nickel as well (and potentially a complement with copper and lead). Lastly, zinc appears to be a complement with copper.

To summarize, the performance of most commodity-specific demand equations improves when cross-price effects are taken into consideration. Specifically, three results emerge from the cross-price analysis. First, there is a high degree of substitutability for several commodity pairs, including oil–coal, aluminum–copper, and aluminum–tin. These commodities are also the most important ones in terms of volume of consumption. Second, there is complementarity between a few of the metals, consistent with patterns

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[8] The methodology used here is not designed to explicitly test for complementarity, which is why we are cautious in over-interpreting this result. A more formal examination of complementarity would require a different approach such as estimating demand functions in the context of flexible functional forms (Deaton and Muellbauer 1980; Chambers 1988).

[9] The asymmetry between aluminum and copper (aluminum influences copper but not vice versa) is likely due to the greater volume of aluminum consumption, and its greater number of uses. Aluminum can replace copper in industries such as electricity, but copper is less able to replace aluminum in many uses e.g. in construction.

of use for some metals, such as in alloys. Third, in several cases, especially coal and tin, the results of the model improve considerably when cross-prices are included.

As a final extension and check, the control variables were included in the commodity-specific demand equations. A key result emerging from this extension is that unlike those from the aggregate equations, the results for individual commodities are sensitive to the inclusion of control variables. Detailed parameter estimates are reported in Appendix E (Tables E1-E9). Even in the cases of oil and copper (two of the four equations that performed well in the base specification), the inclusion of population density or trend in the former, and the inclusion of urbanization in the latter, weakens the performance of the model. This implies that estimating the demand functions for group aggregates may capture substitutabilities and complementarities that are not accounted for by simply including cross prices.

5. Conclusions

This paper has examined the relationship between commodity demand and per capita income level for energy and metal commodities both at the aggregate and commodity-specific levels. Three energy commodities (oil, coal, and natural gas) and six metals (aluminum, copper, lead, nickel, tin, and zinc) were featured in the analysis. These commodities account for more than 85 percent of global energy consumption and for nearly all base metal use as measured by volume. The analysis was based on an autoregressive distributed lag model utilizing annual data for 1965-2018 for up to 63 countries.

Several findings emerged. First, the estimation of demand equations for individual commodities gave highly heterogeneous results, consistent with most of the literature; only four of the nine commodities showed significant results consistent with theory (i.e. that demand increases as income rises and prices decline) and *a priori* expectations (i.e. that demand increases at a decelerating pace). Second, the group aggregates gave results that are consistent with theory and *a priori* expectations, i.e., income elasticities are inversely proportional to income levels. Elasticities for both energy and metals were close to unitary at the median income level, but close to 2 for low-income countries and as little as 0.2 for advanced economies. Third, the inclusion of cross-price effects confirmed substitutability for several commodities (and, for some metals, complementarity), which is consistent with the superior performance of the aggregate estimates compared to the individual ones. Fourth, the size of the elasticities at current median income levels (based on the sample) is close to unity for both commodity groups and around 0.2 for advanced economies, implying the plateau stage is reached at a very slow pace.

Two of the paper's findings are relevant from a policy perspective. First, inter-commodity substitution—a result of technological developments and innovation—suggests that scarcity in one resource that results in higher prices either boosts new investment in the exploration and production of that resource, or it encourages the use of substitutes. In other words, scarcity stimulates technological advancements that lead to "new" substitution of commodities, as postulated by the induced innovation hypothesis (Hicks 1932).

Second, given expected trends in population and income growth, commodity consumption is likely to continue to grow for several decades before it plateaus. For example, the world's population is expected to reach 9.8 billion by 2050 (from its current level of 7.6 billion), according to United Nations projections. Almost all of the population growth will take place in EMDEs, especially in low-income regions such as Sub-Saharan Africa, which currently have very low levels of commodity consumption. Furthermore, income growth is projected to continue, especially in EMDSs, albeit at a slower pace compared to the past two decades. On the other hand, as China continues to develop, its elasticity for metals will soon fall below one, suggesting a slowdown in growth in its demand for commodities—a major change in the pattern of global demand over the past 20 years. As such, commodity demand is likely to continue to grow, but potentially at a slower pace than seen over the past 20 years.

If history is any guide, the expected growth in demand is likely to be met by commensurate production increases as technology advancements will induce innovation and substitution (Schwerhoff and Stuermer 2019). Such increase of production and consumption of commodities however, gives rise to an important policy question. Can resources be produced and consumed in an environmentally sustainable manner in view of their environmental externalities, both at the local and global level? Local externalities are typically easier to address since they frequently require policy actions by a single policymaker (such as a national government), although they can still prove controversial and be politically difficult to implement. For example, China has implemented a range of policies to improve air pollution in cities, including restrictions on metal smelting (as discussed in the metals section of this report). Similarly, many countries implement recycling policies to reduce the amount of waste going to landfills. For regional or global externalities, however, such as increased CO_2, ocean plastic waste, or water pollution, regional or global policy actions are required. Because externalities extend beyond country boundaries, a key policy concern should be how to guarantee that the production and consumption of commodities is environmentally sustainable, rather than ensuring commodity production meets growing demand.

There are a number of ways in which this research could be extended. First, expanding coverage by including agricultural (especially food) commodities or other industrial commodities (such as cement and sand) would test whether Engel's Law indeed applies to all types of commodities, albeit at different turning points. Second, seeking a deeper understanding of how much of China's commodity consumption has been associated with its domestic economy, and how much with export-driven demand. That line of enquiry could contribute to a third extension, which would consider whether other EMDEs (either individually, such as India, whose population is similar to China's, or as a group, such as Sub-Saharan Africa, which is expected to experience the highest population and urbanization growth during the next three decades) might mimic China's consumption patterns in future. Lastly, estimating an aggregate commodity demand that includes the aggregates considered here and (potentially) agriculture, could shed more light on the nature of substitution across commodity groups.

Table 1: Parameter estimates for individual commodities

	------------------ ENERGY ------------------			-- METALS --					
	Coal	**N. Gas**	**Oil**	**Aluminum**	**Copper**	**Lead**	**Nickel**	**Tin**	**Zinc**
Parameter estimates									
y_t	-0.87	1.49*	1.81***	3.98***	3.67***	1.40*	1.88*	0.72	2.89***
	(0.64)	(0.80)	(0.37)	(0.39)	(0.67)	(0.76)	(1.03)	(0.79)	(0.24)
y_t^2	0.08**	-0.04	-0.07***	-0.17***	-0.18***	-0.07*	-0.07	-0.04	-0.14***
	(0.03)	(0.04)	(0.02)	(0.02)	(0.03)	(0.04)	(0.05)	(0.04)	(0.01)
p_t	0.01	-0.20***	-0.41***	-0.21***	-0.27***	-0.07*	-0.11***	0.00	-0.22***
	(0.06)	(0.02)	(0.03)	(0.03)	(0.04)	(0.03)	(0.04)	(0.02)	(0.03)
ρ	-0.09***	-0.16***	-0.07***	-0.26***	-0.13***	-0.18***	-0.30***	-0.21***	-0.25***
	(0.02)	(0.02)	(0.01)	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)
Key statistics									
Hausman test	4.81	3.21	4.15	2.40	1.25	2.12	2.28	2.21	10.35
p-value	0.19	0.36	0.25	0.49	0.74	0.55	0.52	0.55	0.02
Log-likelihood	1,930	1,917	5,195	964	472	516	-140	-204	844
Observations	2,898	2,779	3,235	2,525	2,300	2,355	1,555	2,165	2,637
Countries	57	60	63	52	49	52	36	49	55

Notes: The dependent variable is the logarithm of consumption of the respective commodity. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table 2: Parameter estimates for aggregate energy

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**
Parameter estimates						
y_t	3.47*** (0.23)	2.84*** (0.22)	3.83*** (0.18)	3.96*** (0.27)	2.84*** (0.20)	3.50*** (0.21)
y_t^2	-0.15*** (0.02)	-0.12*** (0.02)	-0.17*** (0.01)	-0.16*** (0.01)	-0.09*** (0.01)	-0.14*** (0.01)
p_t	-0.17*** (0.02)	-0.16*** (0.01)	-0.15*** (0.01)	-0.10*** (0.01)	-0.12*** (0.01)	—
Inv. share	—	0.19*** (0.04)	—	—	—	—
Urbanization	—	—	0.32*** (0.01)	—	—	—
Pop. density	—	—	—	-0.28*** (0.07)	—	—
Trend	—	—	—	—	-0.01*** (0.00)	—
Nom. price	—	—	—	—	—	-0.15*** (0.01)
RER	—	—	—	—	—	-0.06*** (0.01)
ρ	-0.08*** (0.01)	-0.09*** (0.01)	-0.11*** (0.01)	-0.12*** (0.01)	-0.10*** (0.01)	-0.09*** (0.01)
Key statistics						
Hausman test	13.44	20.10	14.76	11.45	20.04	43.83
p-value	0.00	0.00	0.01	0.02	0.00	0.00
Log-likelihood	6,086	6,043	6,087	5,798	6,105	6,093
Observations	3,235	3,170	3,183	2,940	3,235	3,235
Countries	63	63	62	63	63	63

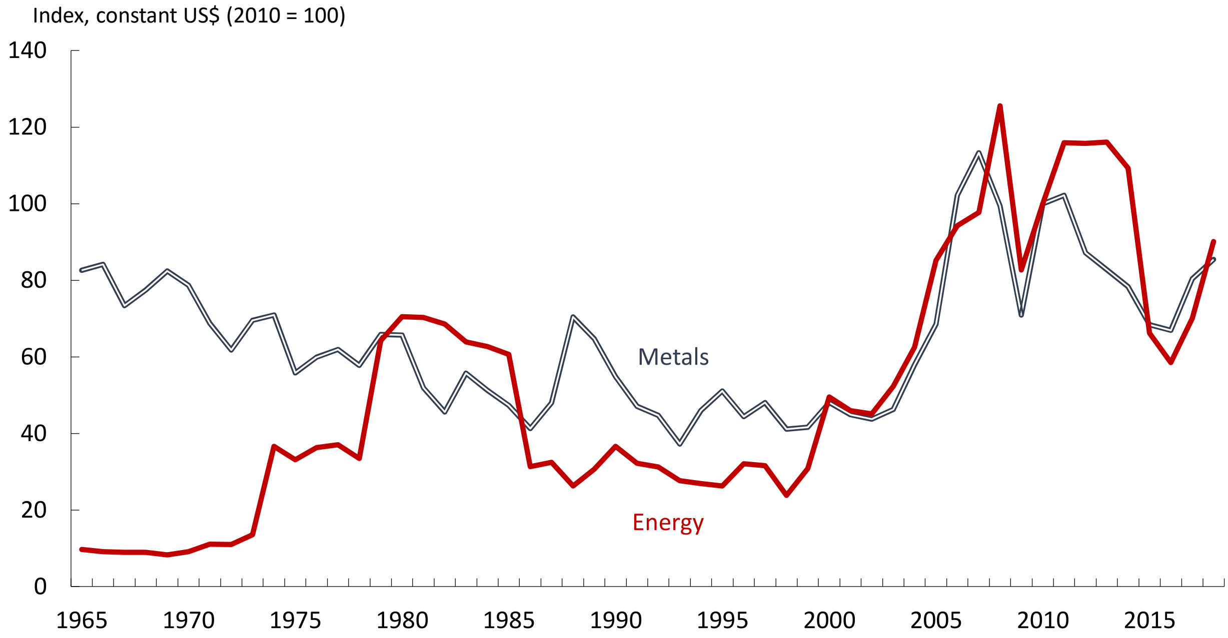
Notes: The dependent variable is the logarithm of aggregate energy consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table 3: Parameter estimates for aggregate metals

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	5.01*** (0.30)	5.24*** (0.29)	4.78*** (0.33)	2.45*** (0.57)	4.96*** (0.32)	4.42*** (0.32)
y_t^2	-0.22*** (0.02)	-0.24*** (0.02)	-0.22*** (0.02)	-0.09*** (0.03)	-0.22*** (0.02)	-0.18*** (0.02)
p_t	-0.26*** (0.03)	-0.28*** (0.03)	-0.25*** (0.04)	-0.12*** (0.03)	-0.27*** (0.03)	—
Inv. share	—	-0.14** (0.07)	—	—	—	—
Urbanization	—	—	0.39** (0.18)	—	—	—
Pop. density	—	—	—	-0.24** (0.14)	—	—
Trend	—	—	—	—	0.00 (0.00)	—
Nom. price	—	—	—	—	—	-0.18*** (0.04)
RER	—	—	—	—	—	0.01** (0.00)
ρ	-0.19*** (0.02)	-0.20*** (0.02)	-0.21*** (0.02)	-0.29*** (0.02)	-0.19*** (0.02)	-0.19*** (0.02)
Key statistics						
Hausman test	2.26	6.98	5.06	0.88	7.07	4.96
p-value	0.52	0.14	0.28	0.93	0.13	0.29
Log-likelihood	1,853	1,880	1,835	1,857	1,853	1,887
Observations	2,165	2,137	2,113	2,001	2,165	2,165
Countries	43	43	42	43	43	43

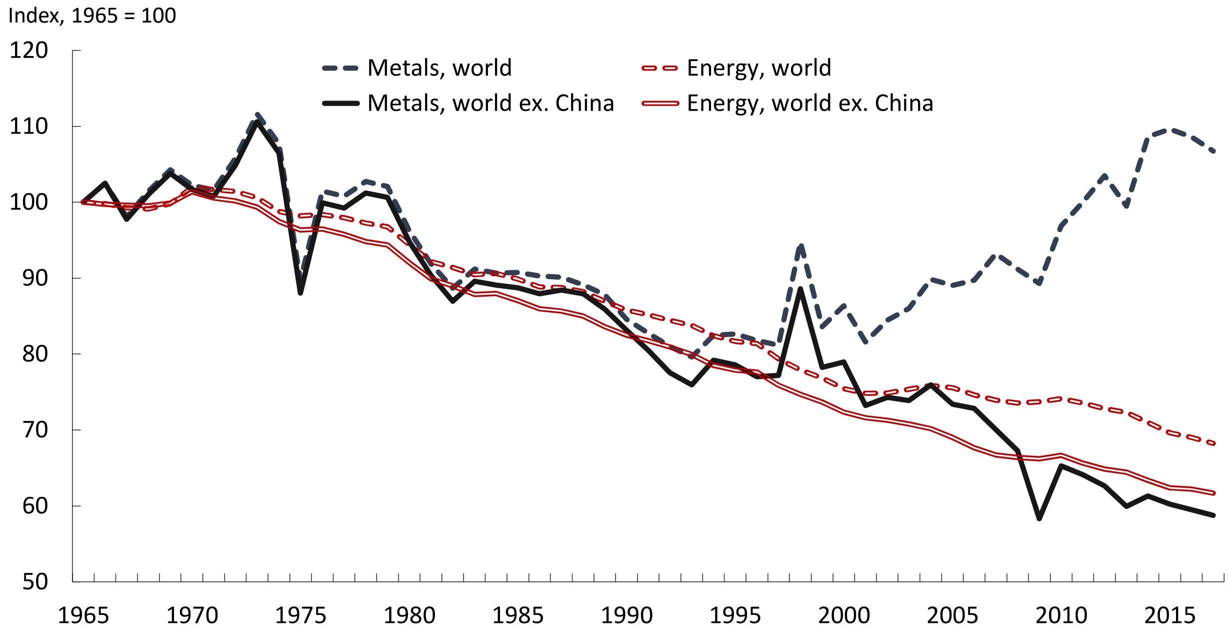
Notes: The dependent variable is the logarithm of aggregate metal consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Figure 1: Commodity price indices



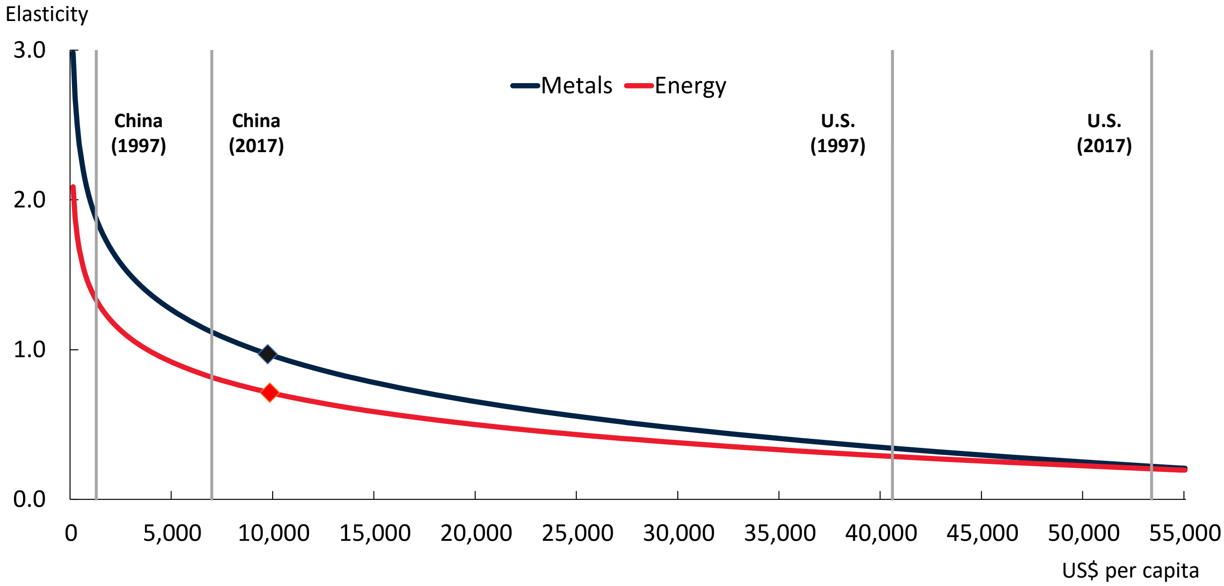
Source: World Bank

Figure 2: Commodity consumption per unit of GDP



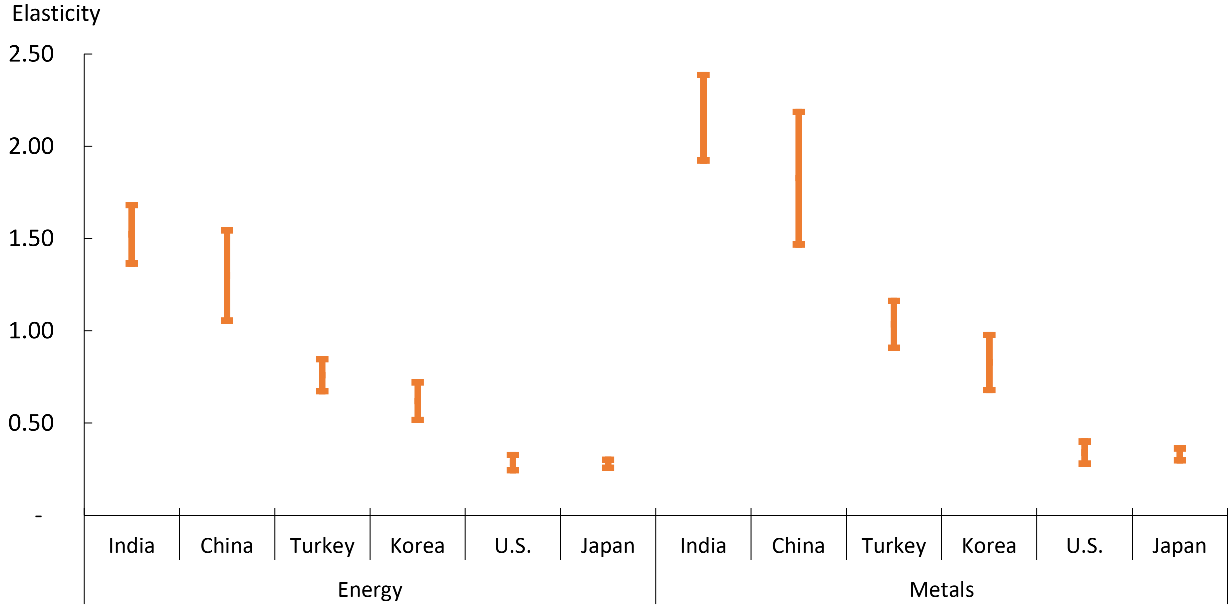
Source: BP Statistical Review, World Bureau of Metal Statistics, and World Bank.

Figure 3: Income elasticity estimates at various income levels



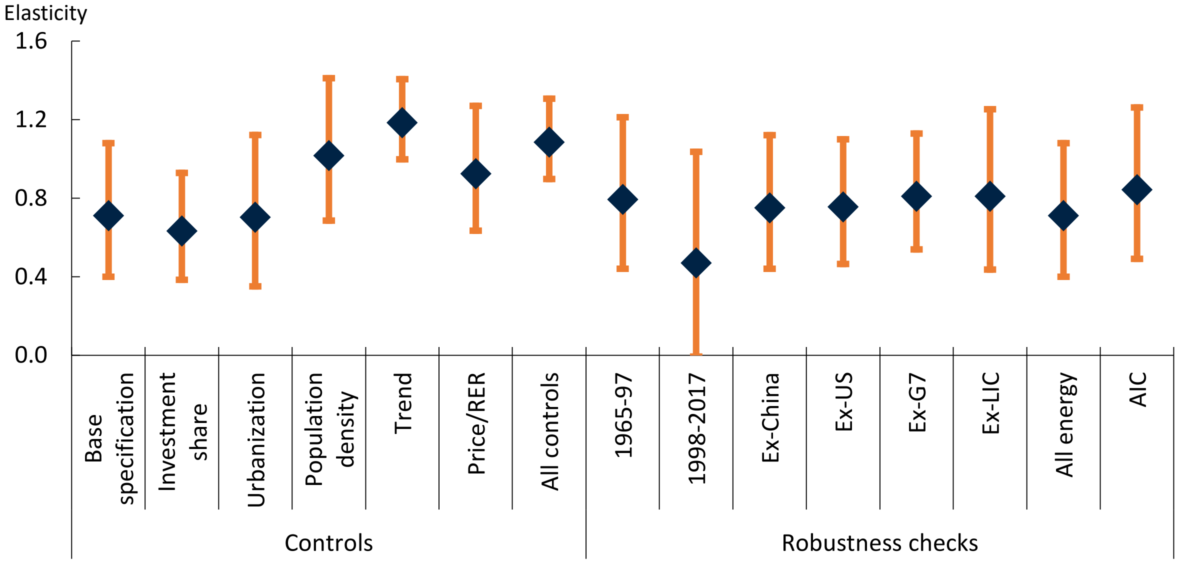
Source: Authors' calculations based on model's parameter estimates.
Notes: The vertical lines denote the level of per capita income of the respective countries and years. Diamonds mark elasticities at $ 9,900 per capita income (sample median).

Figure 4: Income elasticity estimates for various countries for 1997 and 2017



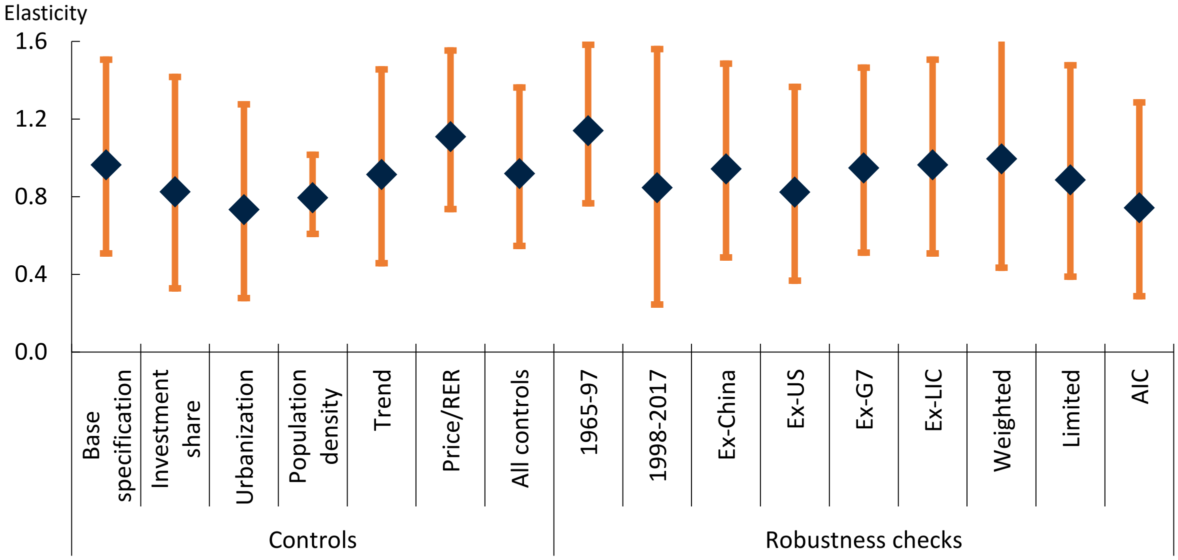
Source: Authors' calculations based on model's parameter estimates.
Notes: The upper and lower ends of the bars denote elasticity estimates for 1997 and 2017, respectively.

Figure 5: Energy income elasticity estimates using controls and robustness checks



Source: Authors' calculations based on model's parameter estimates.
Notes: Diamonds denote elasticities at $ 9,900 per capita income (sample median). The lower and upper ends denote elasticities at $ 28,000 and $ 9,900 per capita income, respectively. Definitions of Controls and Robustness checks can be found in Table C1 (Appendix C).

Figure 6: Metals income elasticity estimates using controls and robustness checks



Source: Authors' calculations based on model's parameter estimates.
Notes: Diamonds denote elasticities at $ 9,900 per capita income (sample median). The lower and upper ends denote elasticities at $ 28,000 and $ 9,900 per capita income, respectively. Definitions of Controls and Robustness checks can be found in Table C2 (Appendix C).

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Appendix A
Commodity consumption and substitutability

The relationship between commodity consumption and income, one of the earliest empirically-verified relationships in economics, has been studied from two extreme perspectives: as a Malthusian process, whereby population and income growth eventually strain resources, with catastrophic consequences, and as a process under which competitive markets, aided by innovation and substitution, always ensure adequate supplies of resources. This appendix summarizes the historical development of thinking about the relationship between commodity consumption and income, including the post-2000 price cycle, and then elaborates on the complex nature of substitutability in commodity consumption.

A1. Commodity consumption and resource constraints

The commodity consumption–income relationship goes back to Engel who, in the mid-nineteenth century, observed that poorer families spend a larger proportion of income than their wealthier counterparts. In particular, Engel (1857, quoted in Stigler 1954, p. 98) wrote that: "[t]he poorer a family, the greater the proportion of its total expenditure that must be devoted to the provision of food" and concluded that "… the wealthier a nation, the smaller the proportion of food to total expenditure." This observation, which is consistent with less than unitary income elasticity, was later coined Engel's Law.

Almost a century later Kindleberger (1943) conjectured that, as a direct consequence of Engel's Law, the terms-of-trade (ToT) of developing countries (typically commodity exporting) relative to industrialized economies (generally commodity importing) will be subjected to downward pressures. Therefore, he argued, commodity-dependent countries should reduce their reliance on primary resources and, instead, embrace industrialization policies. Contrary to Engel's Law, which pertained to food commodities only, Kindleberger's conjecture applied to all commodities (p. 349):

> A comparative advantage in natural silk, nitrates, or rubber, or an economy founded on coal and steam may be of fleeting profitability. Inexorably, too, the terms of trade move against agricultural and raw material countries as the world's standard of living increases (except in time of war) and as Engel's law of consumption operates. The elasticity of demand for wheat, cotton, sugar, coffee, and bananas is low with respect to income. If the agricultural and raw material countries of the world want to share the increase in the world's productivity, including that in their own products, they must join the transfer of resources from agricultural, pastoral pursuits, and mining to industry."

The declining ToT hypothesis was revisited by Prebisch (1950) and Singer (1950) and later became the Prebisch-Singer hypothesis (Baffes and Etienne 2016). Engel's Law, Kindleberger's conjecture, and the Prebisch-Singer hypothesis influenced the post-WWII development policy agenda in favor of the industrialization policies that many countries pursued during the 1960s and 1970s (Balassa 1982).

A1.1. Challenges to the declining ToT hypothesis

The declining ToT hypothesis and its implications were subsequently challenged in at least two ways. First, from a policy perspective, several authors noted that commodity sectors should not be treated differently from the rest of the economy (see Akiyama et al. (2003) for a review of the literature). For example, Johnson (1947) argued that the agricultural sector should not be subjected to interventions. Friedman (1954) disputed the benefits for commodity producers of managing income variability. Johnston and Mellor (1961) criticized the pro-urban policies pursued by many developing countries. Bates (1981) called for a reconsideration of policies on commodity markets to promote economic development in rural communities. Lal (1985) criticized pricing policies and marketing arrangements in commodity-dependent developing countries. The tide took a definite turn against industrialization policies with the publication of two influential reports: the 1986 *World Development Report*, which highlighted the problems associated with policy interventions in agricultural commodity markets (World Bank 1986) and a detailed assessment of macroeconomic and sector-specific distortions associated with policy intervention in primary commodity sectors (Krueger et al. 1992).

The second challenge came from a resource-availability perspective and arose mostly in response to the commodity price boom of the 1970s, which numerous scholars believed marked the start of an era of resource scarcity. The highlight of this view was encapsulated by the "Club of Rome" publication entitled *Limits to Growth* (Meadows et al. 1972, p. 23), as follows:

> If the present growth trends in world population, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable results will be a rather sudden and uncontrollable decline in both population and industrial capacity.

The ensuing oil crises of 1973 and 1979 sparked a debate on the long-run sustainability of energy supplies, with frequent references made to the "peak oil" hypothesis—the time when the maximum extraction rate of crude oil is reached (Campbell and Laherrère 1998). The "peak oil" hypothesis was originally proposed by Hubbert (1962, p. 90), who argued that "… the culmination in the world production of petroleum is expected to occur by about the end of the present [20th] century. In the United States the culmination in the production of crude oil is expected to occur before 1970, and that of natural gas before 1980." Similar assessments were made in food commodities. Brown (1995), for example, conjectured that when China begins importing food, there may not be enough grain in the world to meet that demand, which will inevitably lead to high prices of agricultural commodities.

Among numerous critiques of the "Club of Rome" views and the "peak oil" hypothesis, perhaps the sharpest came from Goeller and Weinberg (1978, p. 4) who argued that technology and substitutability effectively transform non-renewable to renewable resources: "With three notable exceptions—phosphorus, a few trace elements needed in agriculture, and energy producing fossil fuels (CH_x)—society can subsist on inexhaustible or near-inexhaustible minerals with relatively little loss of living standards."

A1.2. Renewed scarcity concerns

Following the post-2000 commodity price boom, resource scarcity concerns reemerged, this time with a focus on the demand pressures coming from EMDEs—especially China and India, which together account for nearly 40 percent of the world's population. Rogers (2004, p. 3), for example, argued that "A new bull market is under way, and it is in commodities—the 'raw materials,' 'natural resources,' 'hard assets,' and 'real things' that are the essentials of not just your life but the lives of everyone in the world." Similarly Heap (2005), noted that China's high rates of urbanization, industrialization, and capital formation set the stage for a super cycle, similar to the ones experienced during the late 1800s and early 1900s (driven mainly by growth in the United States) and the years following the Second World War (prompted by reconstruction in Europe and the Japanese expansion.) Several papers focused on super cycles, especially for metals (Radetzki 2006; Cuddington and Jarrett 2008; Erten and Ocampo 2013).

Concerns were heightened about energy during 2011-13 when oil prices averaged above $100/bbl. References to the "peak oil" hypothesis intensified as oil prices peaked.[10]

Income growth in China and India was cited as the main factor behind the price increases of food commodities, especially following the 2007-08 food price spike. Indeed, the June 2009 issue of the *National Geographic* noted that "… as countries like China and

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[10] In May 2008, for example, "peak oil" appeared 100 times in the news—the crude oil price averaged $123/bbl that month (in January 2016, it appeared only 3 times and the crude oil price averaged $30/bbl). The average monthly appearance of "peak oil" dropped from 42 times during 2008-11 to 3 times during 2017-18 (based on Google Trends, "worldwide", "all categories", "news search").

India prosper and their people move up the food ladder, demand for grains has increased.” Similar arguments were advanced by noted scholars. Krugman (2008) argued that “… there’s the march of the meat-eating Chinese—that is the growing number of people in emerging economies who are, for the first time rich enough to start eating like Westerners” (*New York Times* editorial, April 7, 2008). Likewise, Wolf (2008) wrote: “So why have prices of food risen so strongly? … On the demand side, strong rises in incomes per head in China, India and other emerging countries have raised demand for food, notably meat and the related animal feeds” (*Financial Times*, April 29, 2008). In response to such concerns, the agriculture ministers of the G20 launched an interagency platform, the Agricultural Market Information System (AMIS) in order to enhance food market transparency and increase food security.

But following the post-2011 commodity price declines and, especially, the 2014 oil price collapse, concerns about whether metal reserves could meet global infrastructure needs, or whether global energy and food supplies could keep up with population and income growth, gave way to concerns about low commodity prices and suitable policies to respond to them for commodity exporting countries. Similarly, the “peak oil” hypothesis was replaced by “peak demand” discussions. Part of the reason for the overall decline in prices (and hence the reversal of views) was that persistently high prices had led to investment and innovation which eventually led to substitution among commodities, as well as increased production. The next section discusses several examples and episodes of substitution among commodities.

A2. The complex nature of substitutability

Substitutability has been a key feature of commodity markets. Theoretical discussions of substitutability go back to Hicks (1932), who wrote (pp. 124): “… a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind—directed to economizing the use of a factor which has become relatively expensive.” Hicks’ view, which was later coined the induced innovation hypothesis, has been discussed extensively, including Hayami and Ruttan 1970; Olmstead and Rhode 1993; Hanlon 2015; Newell, Jaffe, and Stavins 1999. Substitutability among commodities has been cited as the antidote to resource scarcity (Goeller and Weinberg 1978; Pei and Tilton 1999). The rest of this section first offers some examples of substitution and then discusses three episodes that have had longer-term consequences.

Substitution can occur from a change in relative prices in the short term is alternative materials are available (or with some lag if it entails significant costs). It can also occur in the longer term from development of new technologies and innovation (Tilton and Guzmán 2016). Substitution could also emerge from innovation not necessarily in response to price changes. Long term substitutability is often irreversible (Wellmer 2012; Renner and Wellmer 2019). Often the factors leading to substitution (regardless of source) are accompanied or triggered by policies such as taxes, subsidies, trade restrictions, ore environmental regulations that can permanently alter the consumption paths of individual commodities.

Substitution takes place both within the same commodity group and across groups.[11] Straightforward cases of substitution can be found in food commodities (e.g., substitution of palm oil by soybean oil for human consumption or maize by soybean meal for animal use); in electricity generation where one energy source (e.g., coal) is substituted by another (e.g., natural gas); and in metals, where two commodities can be used for the same application (e.g., copper and aluminum in electrical grids, Djukanovic 2016).

Substitution can take also place in complex and, often, unexpected ways. Two cases that have had profound implications for commodity consumption came as the transport and petrochemical industries responded to technical innovations. Substitutability in transport goes back to the industrial revolution; with the invention of the steam engine, animal traction was replaced by trains, and as a consequence the agricultural commodities used to feed the animals were replaced by coal to fuel the steam engines. The wooden frames of sailing ships were replaced steel and iron ore frames and steam engines in the late nineteenth century (Lundgren 1996), implying substitution between agriculture (timber) and metals (iron ore) and between renewable energy (wind) and fossil fuels (coal). In the early twentieth century, further substitution between food and energy commodities resulted from the introduction of electric cars and the use of biofuels in the internal combustion engine. Initially, animal traction was replaced by electric cars, which meant that food commodities were substituted by electricity. Then, the first-generation internal combustion engines substituted electric cars by cars that used biofuels (Kovarik 2013). Later, cars powered by gasoline and diesel dominated the transport industry. The use of products derived from crude oil was expanded in sea (diesel) and air transport (kerosene) during the second half of the twentieth century.

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[11] As Wellmer (2012, p. 11) noted, "… we do not consume resources *per se* but their inherent functions or their physical and chemical properties. We do not need one tonne of copper: we need its electrical conductivity for transmitting power supply or transferring messages *via* electric pulses in telephone wires. This latter function can be ensured *via* fiber cables, directional antennae or mobile phone. So, we have substitution in the narrow sense (glass fibre *vs*. copper) and functional substitution to obtain the same function. Every technical solution has its own raw-material profile."

Innovation in the chemical industry, notably petrochemicals, led to substitution of both agricultural and metal commodities by energy products. Synthetic fibers, mostly derived from crude oil and natural gas, now account for nearly two thirds of global fiber consumption, but before the 1950s cotton was the dominant fiber (Baffes and Gohou 2006). Synthetic rubber, a key input to tire manufacturing and derived from crude oil, currently accounts for more than half of global rubber consumption. Copper has been increasingly replaced by plastic tubing in plumbing and other applications in residential and commercial structures while plastics have penetrated a vast number of consumer products. In the beverage and food packaging sectors, there is great competition between aluminum, composites, glass, paper, plastic, tin, and other materials. Recent advances in information technology have also led to substitution of other kinds: paper (made from timber), which was used for information storage in books, is being gradually replaced by digital storage (which uses energy and metals in its process). In the telecommunications industry, cables (made mostly from copper) are being replaced by fiber optic lines (made from petrochemicals) and, more recently, by wireless communication devises and satellites, which use rare-earth metals and composite materials.

The rest of this section discusses the roles of technology, policies, and prices in three episodes of substitution.

A2.1. Beverage can and bottle industries

Until the 1960s, glass, tin, and steel were the dominant materials used for the manufacturing of beverage containers (principally soft drinks and beer). The can industry moved to tin-free metals during the war years, however, the emergence of aluminum in the 1960s, with its superior light-weight properties, ease of recycling, and technological developments (pull-up and crimp can) significantly changed the beer industry, and to a lesser extent the soft drink sector (Nappi 1990). For the latter, the dramatic rise of plastic bottles since their introduction in 1978 have kept the share of aluminum cans for soft drinks much lower. Innovation continues today, particularly for soft drinks. Recyclable glass and plastics (and increasingly paper) dominate the bottle market while aluminum is the key input in the can industry. Thus, what initially began as substitution among metals turned into substitution between metals and energy (plastics) and, recently, between metals/energy and agriculture (paper).

Aluminum's expanded use at the expense of tin was also aided by the International Tin Agreement which kept tin prices artificially high through the management of buffer stocks. First negotiated in 1954 with the objective of maintaining tin prices within a desired range through the management of buffer stocks, the International Tin

Agreement (ITA) collapsed in 1985 following several years of insufficient funds to maintain stocks (Chandrasekhar 1989). Thus, tin lost market share both from technological advances of its competitors, but also by its own pricing decisions. Notice that commodity agreements were common throughout the twentieth century for both metals (Tilton and Guzman 2016) and agricultural commodities (Gilbert 1996), all of which have ceased operations.

A2.2. The energy crises of the 1970s

Geopolitical developments have significantly altered energy consumption patterns in both the short- and long term. In the decade prior to 1972, global oil consumption was growing at almost 8 percent a year in response to the rapid post-war expansion of transport and surging electricity consumption; the surge was also aided by low oil prices (during 1945-72 oil prices averaged about $16/bbl in 2017 constant terms). The 1973 and 1979 energy crises, which resulted in a seven-fold increase in oil prices, set in motion powerful market forces, policies, and efficiency gains in the use of fuel in transport and encouraged the substitution of oil for electricity generation by coal, nuclear power, and other renewable energy sources. Global oil consumption, which peaked at nearly 64 mb/d in 1979, declined by a cumulative 10 percent (or 6.3 mb/d) in the subsequent four years. Meanwhile the share of coal in global energy consumption increased by 8 percent (the equivalent of 2.9 mb/d) while nuclear energy consumption was up 60 percent (the equivalent of 1.8 mb/d). Thus, the oil shocks induced an equivalent of 4.7 mb/d substitution for oil by other energy sources, plus a net decline of 1.6 mb/d in crude oil consumption.

Coal’s increasing use in electricity generation was encouraged by the International Energy Agency’s decision to ban its member countries from building new oil-fired electricity plants. The IEA’s ban was introduced under the “Principles for IEA Action on Coal” directive and was justified as follows (IEA 1979, pp. 1 and 4):

> The Principles are based on the conclusion that greatly increased coal use is required to meet growing energy demand in the medium and long term, and that this is both desirable and possible in light of the world's abundant coal reserves and the economic advantages which coal already has over oil in many energy markets … [T]he world is still confronted with the serious risk that within the decade of the 1980's it will not have sufficient oil and other forms of energy available at reasonable prices unless present energy policies are strengthened.

Coal’s use was further aided by domestic policies, such as the U.S. Powerplant and Industrial Fuel Use Act of 1978, which provided that no new baseload electric power plant may be constructed or operated without the capability to use coal or another non-oil/gas alternate fuel as a primary energy source—the Act was repealed in 1987.

A2.3. Cleaner fuels and electric car technology

Substitutability among commodities is also driven by environmental concerns. First, the fuel mix for electricity generation is changing in response to preference for cleaner fuels such as natural gas and renewable sources over coal and other polluting sources such as firewood (Burke and Csereklyei 2016). Such preference is not surprising given that natural gas generates 53 kgs of CO_2 per mmbtu, compared to 71 kgs from oil and 93 kgs from coal (EIA 2016). In transport, numerous countries legislated biofuel policies, mostly in the form of mandates. Such policies promoted maize-based ethanol in the United States, edible oil-based biodiesel in the European Union, and sugarcane-based ethanol in Brazil. About 4 percent of global grain and oilseed supplies have been diverted to fuel production (Cassidy et al. 2013). They account for 1.6 percent of global liquid energy consumption.

Second, transitioning toward a lower carbon energy environment, which is expected to significantly impact the transportation industry, especially through the gradual replacement of the internal combustion engine (ICE) vehicles by electric vehicles (EVs) either fully battery-powered or some form of hybrids. Not only will EVs induce substitution of oil by other sources of energy (for electricity generation), they will also induce substitution among metals.

Initially, EVs faced numerous headwinds, including high prices, long charging times, and limited range. However, aided by improvements in battery technology and charging infrastructure along with government incentives, EVs have enjoyed impressive demand growth. For example, in 2018, the global electric car fleet exceeded 5 million units, up 2 million from the previous year. China is currently the world's largest electric car market, followed by the Europe and the United States, with Norway having the highest market share at 46 percent. Numerous countries (and car companies) have set high targets for EV penetration.

In addition to the fuel mix, the rapid expansion of EV technology is changing the composition of the metal consumption. An EV contains five-times more copper (battery, electric motor, and wiring) than an ICE vehicle, and large volumes of copper will also be needed for power grid extensions and EV charging infrastructure. For a standard battery pack with the most common battery chemistry, the main materials are aluminum, copper, cobalt, graphite/carbon, lithium, nickel and manganese. The chemistry of lithium-ion EV batteries is moving towards higher nickel content to generate higher energy density.

Appendix B

Data: Description, sources, and summary statistics

The paper utilized country-specific data (up to 63 countries, depending on the commodity) and commodity-specific data for three energy and six metal commodities for the 1965-2017 period. The energy commodities account for 85 percent of global energy consumption, including crude oil (34 percent share), coal (28 percent), and natural gas (23 percent). Oil is primarily used for transport and, to a lesser degree, petrochemicals while most coal and natural gas are used for electricity generation and less for industrial purposes. The metals (aluminum, copper, lead, nickel, tin, and zinc) are widely used in commercial and industrial applications. Aluminum's largest uses are in transport, followed by construction, packaging, and electrical grids. Copper's main application is in the electrical sector, including power cables, generators and motors, as well as in construction and electronics. Nickel is one of the main components of stainless steel, while zinc is mostly used as an anti-corrosion agent to galvanize iron and steel while some is alloyed with other metals (e.g., combined with copper to produce brass). Tin is heavily used in electronics in the form of solder. Lead, which was once used in various chemical applications (most of which have been banned) is still widely used in car batteries, ammunition, and in storage of corrosive liquids. Detailed descriptions and notes on sources follow.

Commodity consumption

Data on commodity consumption was taken from the BP Statistical Review for the three energy commodities and World Bureau of Metal Statistics for the six base metals.

Commodity prices

Commodity prices were taken from the World Bank's Commodity Price Data and converted into real terms by using country-specific GDP deflators.

Per capita income

Data on per capita income were obtained from the World Bank's World Development Indicators (WDI).

Investment to GDP ratio

The investment to GDP ratio was calculated by dividing nominal investment, obtained from the IMF WEO, by nominal GDP, obtained from the World Bank's World Development Indicators (WDI).

Urbanization

Data on urbanization were obtained from the United Nations Population Division, World Urbanization Prospects, 2018 revision.

Population density

The population density ratio was calculated by dividing population, obtained from the United Nations, by land size, obtained from the Food and Agriculture Organization of the United Nations.

Exchange rate

Exchange rates were taken from both the World Bank's WDIs, and the St. Louis Federal Reserve Bank's database.

The rest of this appendix summarizes the data in various ways. Table B1 reports commodity consumption and characteristics for China, Republic of Korea, and the G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States). The selection of these entities reflected the desire to include the largest and fastest growing EMDE (China) whose consumption of some commodities surged during the past two decades; Republic of Korea, which was a low-income country in the early part of the sample period, went through the industrialization process, and became a high-income country; and the G7 countries, whose incomes have been high throughout the sample period and, thus, their commodity consumption paths have plateaued. Table B2 reports summary statistics for all nine commodities. Figures B1-B3 depict the global consumption of the nine commodities studied in this paper. Lastly, Figures B4-B14 show scatter-diagrams of the relationship between per capita commodity consumption and per capita income for the three energy and six commodities as well as the two aggregates for China, Republic of Korea, and the G7 countries during 1965-2017.

Table B1: Summary statistics for China, Korea, and G7

	-------- China -------		----- Korea, Rep. -----		---------- G7 ----------	
	1970-75	**2010-15**	**1970-75**	**2010-15**	**1970-75**	**2010-15**
Per capita commodity consumption per annum						
Coal (bbl equivalent)	1.67	10.12	1.45	12.02	7.84	6.97
Natural gas (bbl equivalent)	0.04	0.72	—	6.22	7.64	9.96
Oil (bbl)	0.41	2.70	2.42	16.66	19.71	15.08
Energy, aggregate (bbl equivalent)	2.19	14.94	3.94	40.25	37.56	38.77
Aluminum (kilograms)	0.37	17.44	0.73	25.48	13.20	14.72
Copper (kilograms)	0.28	6.84	0.50	15.14	8.52	6.64
Lead (kilograms)	0.20	3.31	0.31	9.95	4.69	3.56
Nickel (kilograms)	0.02	0.53	0.01	2.01	0.71	0.65
Tin (kilograms)	0.02	0.13	0.02	0.30	0.24	0.12
Zinc (kilograms)	0.20	4.23	0.65	11.46	5.26	3.53
Metals, aggregate (kilograms)	1.01	32.48	2.11	64.34	30.74	29.23
Share of global consumption (percent)						
Coal	13.30	50.36	0.45	2.17	41.85	18.80
Natural gas	0.52	4.75	—	1.48	65.23	35.43
Oil	1.90	11.73	0.43	2.63	60.40	35.45
Energy, aggregate	5.03	23.21	0.35	2.17	55.79	29.71
Aluminum	2.75	48.54	0.21	2.57	64.71	22.16
Copper	3.15	44.95	0.22	3.61	63.77	23.62
Lead	3.61	42.96	0.22	4.69	57.24	25.00
Nickel	3.01	44.05	0.04	6.04	66.71	29.34
Tin	5.99	47.18	0.31	4.03	61.35	24.48
Zinc	3.01	45.06	0.39	4.43	54.11	20.35
Metals, aggregate	2.98	45.83	0.25	3.24	60.63	22.17
Key statistics						
Per capita income ($ 2010 constant)	242	5,341	2,222	23,587	21,907	43,706
Investment share (percent of GDP)	3.23	3.82	3.21	3.39	3.27	3.01
Urbanization ratio (percent)	17.29	52.38	44.40	81.81	72.87	80.07
Population density (persons per)	93.12	146.86	350.63	514.17	151.38	172.66

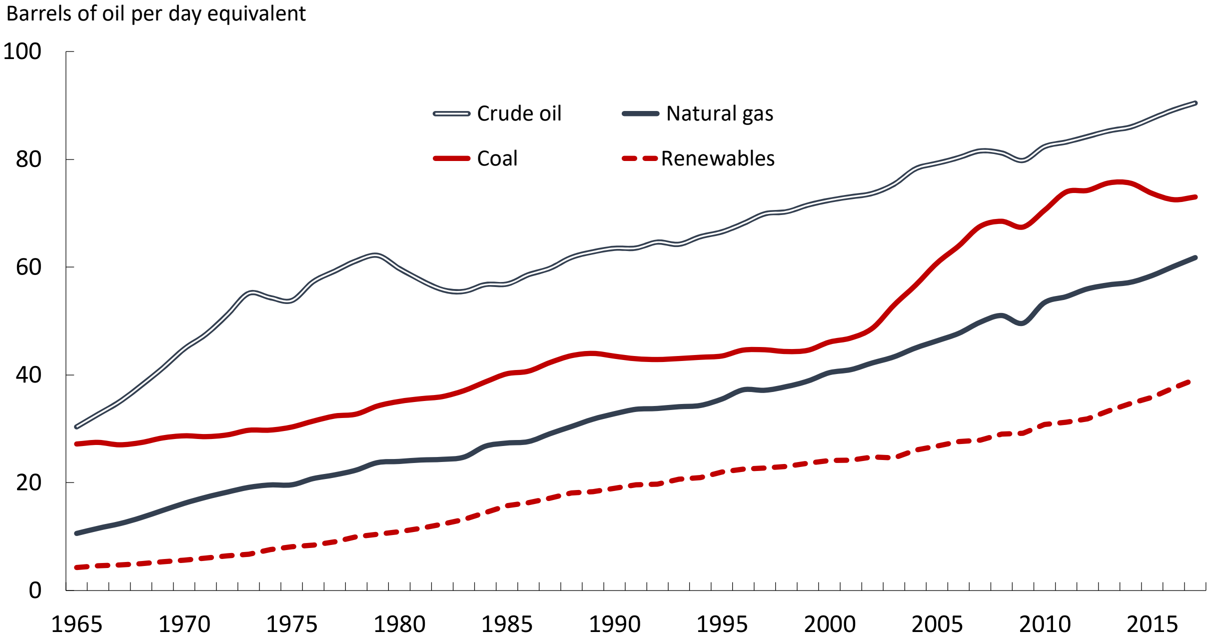
Notes: xxx.

Table B2: Summary commodity statistics

	ENERGY				METALS						
Period	**Coal**	**N. gas**	**Oil**	**Energy**	**Alumin.**	**Copper**	**Lead**	**Nickel**	**Tin**	**Zinc**	**Metals**
Consumption, global (energy: mb/d equivalent; metals: million metric tons)											
1965-67	27.23	11.53	32.72	71.48	7.35	6.28	3.28	0.46	0.21	4.22	21.80
2015-17	73.08	58.83	89.08	220.98	58.56	23.12	11.24	1.95	0.38	13.94	109.18
Change (%)	168.32	410.21	172.27	209.15	697.04	268.38	242.62	326.11	78.26	229.89	4.01
Consumption, per capita (energy: barrels per year; metals: kgs per year)											
1965-67	3.02	1.28	3.63	7.92	2.23	1.91	1.00	0.14	0.06	1.28	3.02
2015-17	3.73	3.00	4.55	11.28	8.19	3.23	1.57	0.27	0.05	1.95	3.73
Change (%)	23.48	135.04	25.40	42.34	267.12	69.51	57.66	96.08	-17.98	51.84	23.48
Consumption, volatility (standard deviation of logarithmic changes)											
1965-97	1.65	2.88	3.57	2.28	7.30	5.04	4.22	8.26	5.58	5.71	5.27
1998-2017	3.16	2.35	1.14	1.73	6.67	5.74	3.57	6.38	6.47	6.15	5.11
1965-2017	2.36	2.79	2.94	2.09	7.03	5.28	4.00	7.56	5.94	5.86	5.21
Average price ratios with respect to oil (energy) and aluminum (metals)											
1965-74	1.12	1.06	1.00	—	1.00	2.27	0.53	4.38	6.91	0.73	—
1975-84	0.42	0.66	1.00	—	1.00	1.27	0.50	4.23	10.08	0.61	—
1985-94	0.44	0.83	1.00	—	1.00	1.49	0.38	4.95	4.13	0.74	—
1995-2004	0.37	0.84	1.00	—	1.00	1.36	0.40	5.44	3.76	0.69	—
2005-14	0.24	0.59	1.00	—	1.00	3.18	0.91	9.38	8.26	1.00	—
1965-2017	0.44	0.81	1.00	—	1.00	1.99	0.58	5.64	6.89	0.79	—

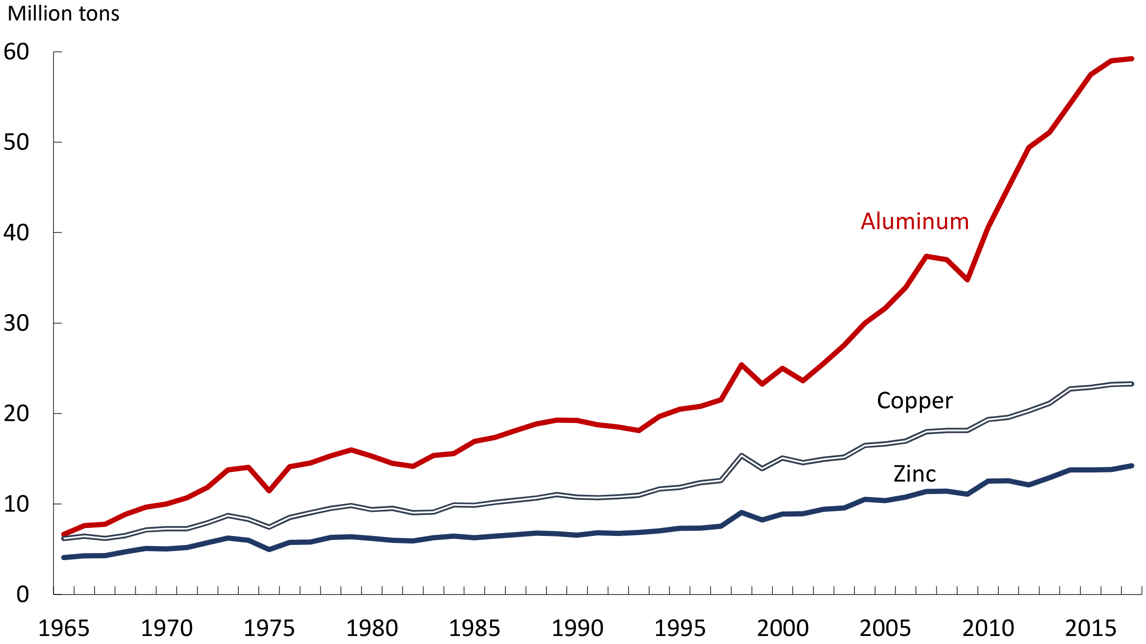
Notes: mb/d refers to million barrels per day; "—" indicates that the corresponding entry is not relevant. Energy prices were converted into barrels of oil equivalent in order to calculate the price ratios.

Figure B1: Global energy consumption



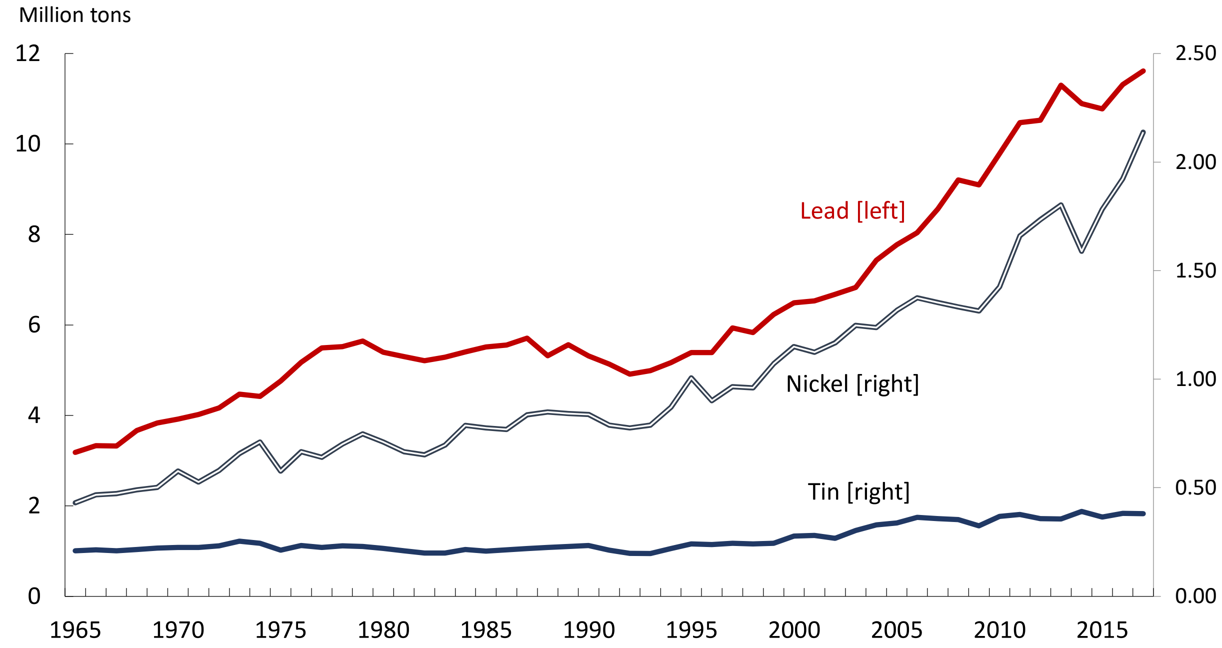
Source: BP Statistical Review and World Bank.

Figure B2: Global aluminum, copper, and zinc consumption



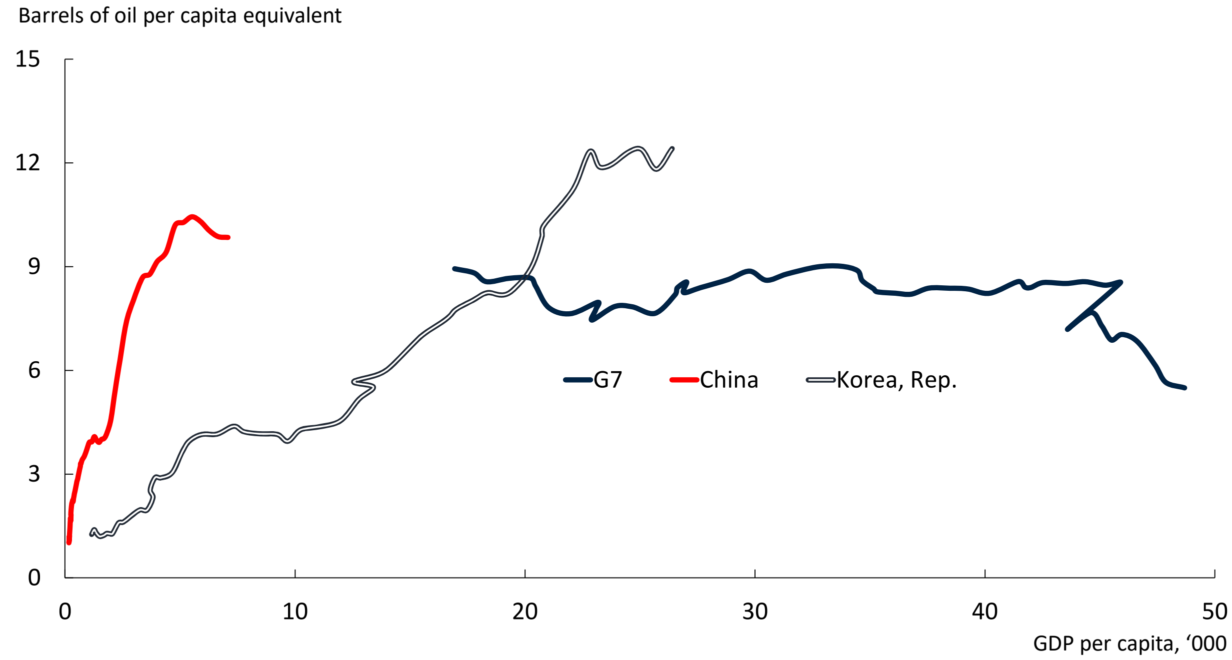
Source: World Bureau of Metal Statistics and World Bank

Figure B3: Global lead, nickel, and tin consumption



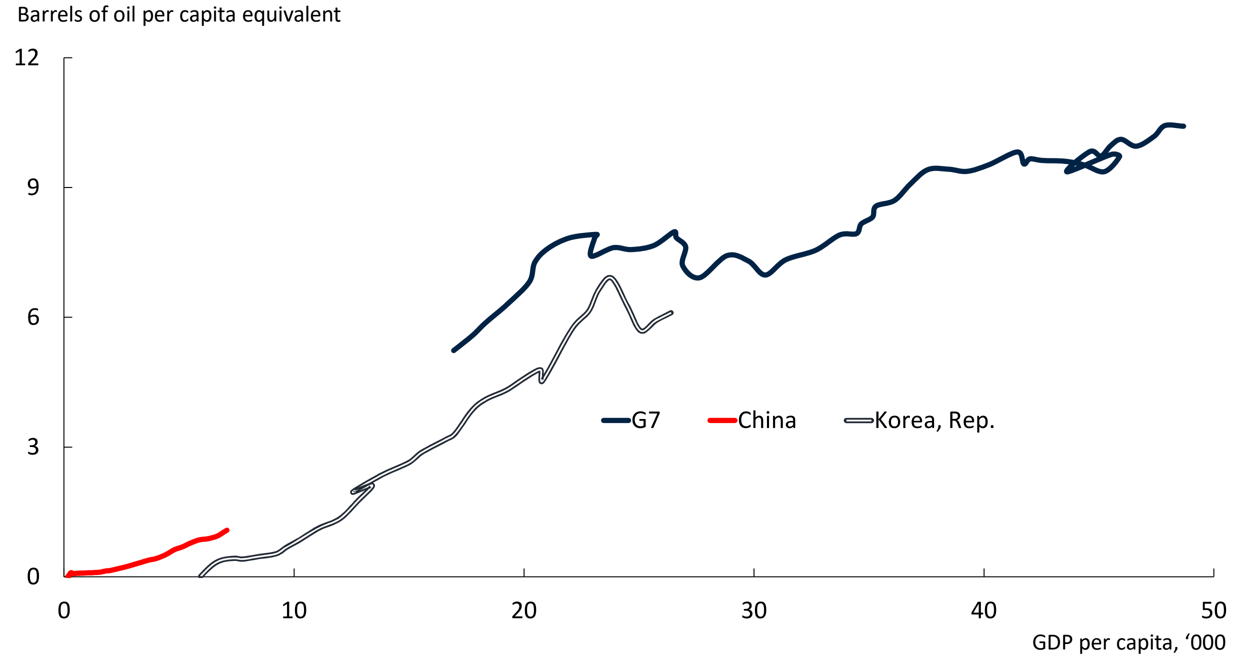
Source: Tilton (1990), World Bureau of Metal Statistics and World Bank

Figure B4: Per capita income and consumption of coal, 1965-2018



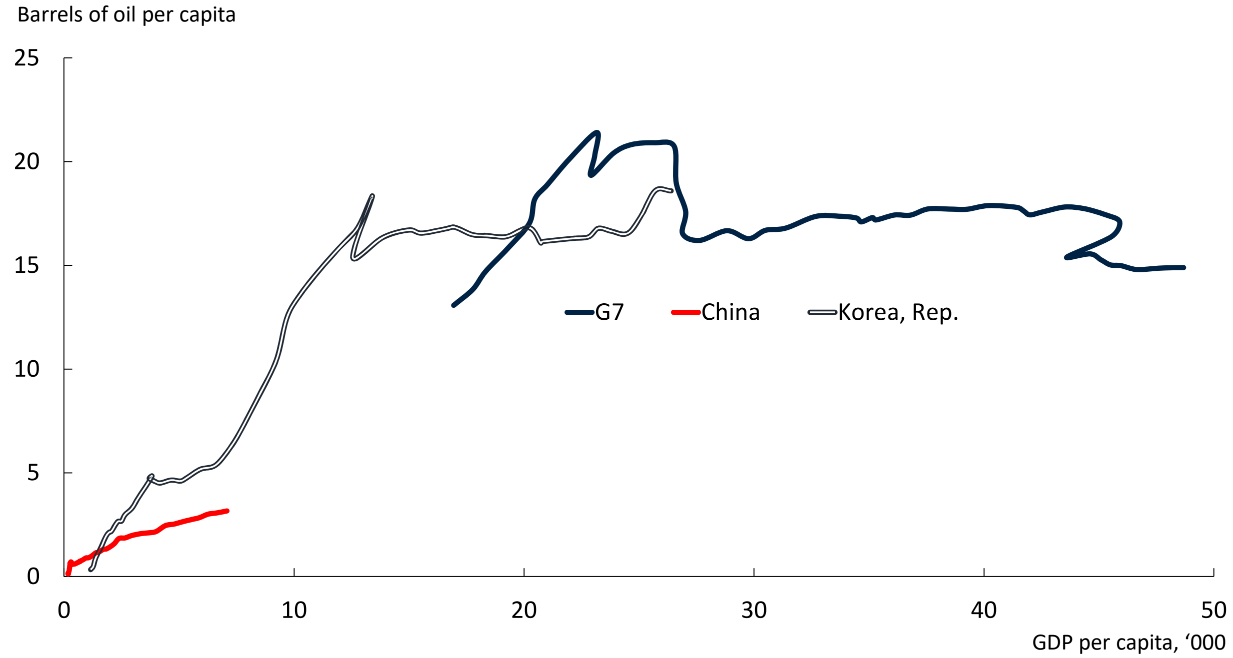
Source: BP Statistical Review and World Bank

Figure B5: Per capita income and consumption of natural gas, 1965-2018



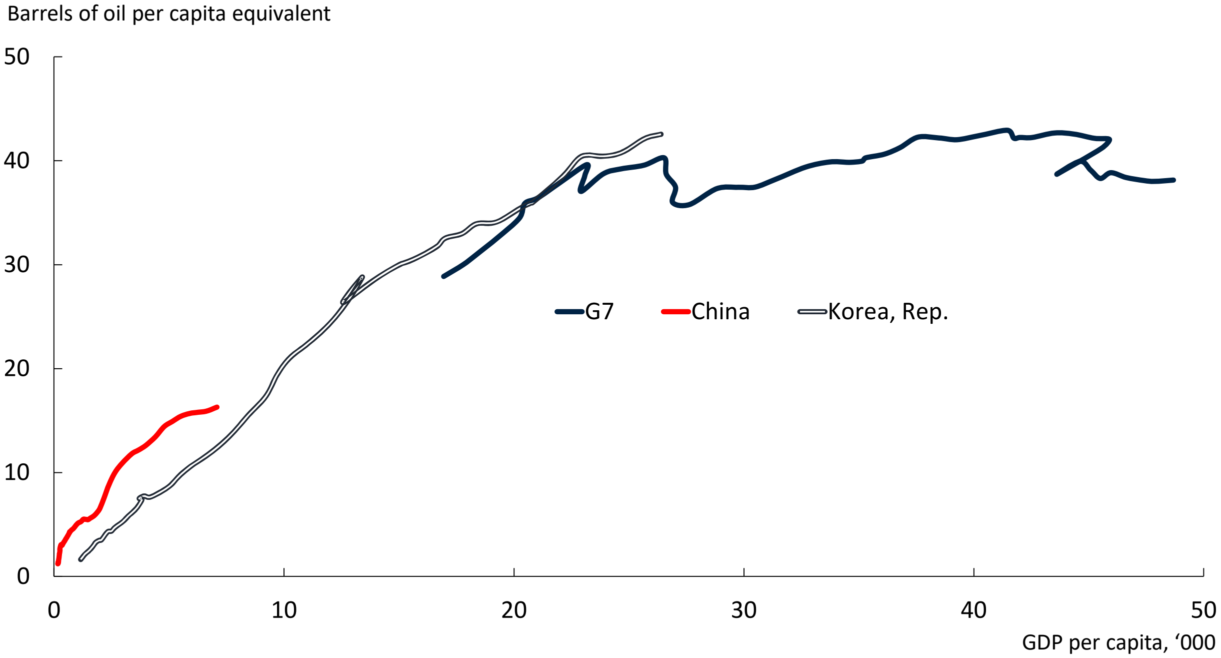
Source: BP Statistical Review and World Bank

Figure B6: Per capita income and consumption of crude oil, 1965-2018



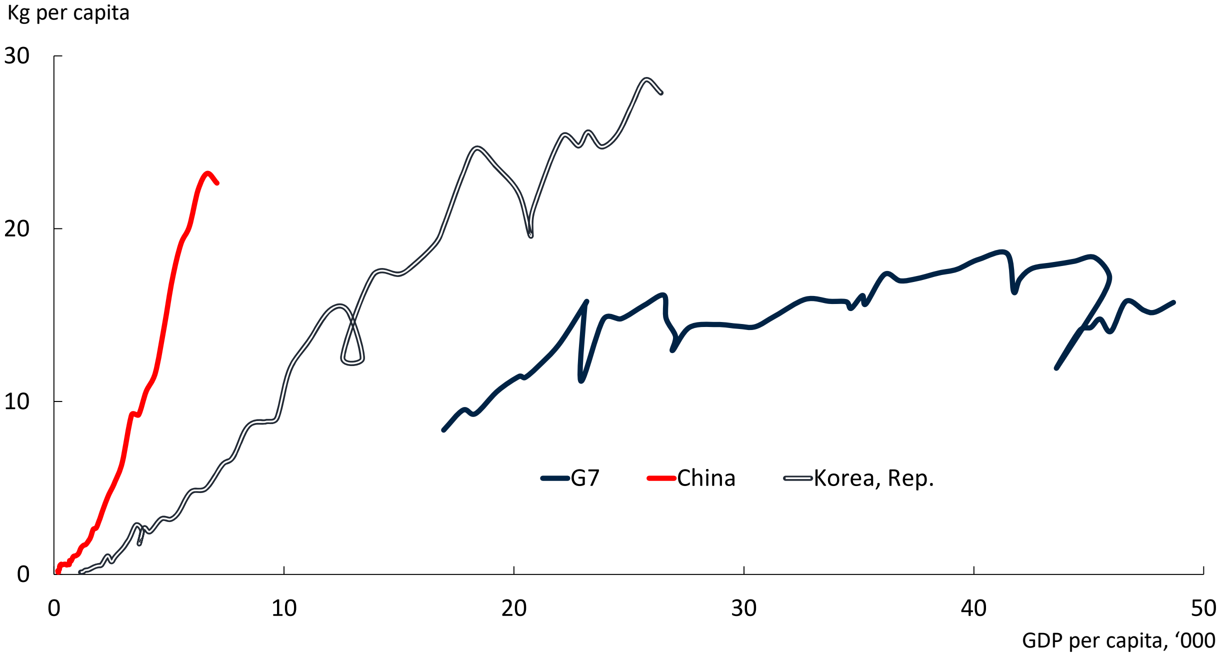
Source: BP Statistical Review and World Bank

Figure B7: Per capita income and consumption of aggregate energy, 1965-2018



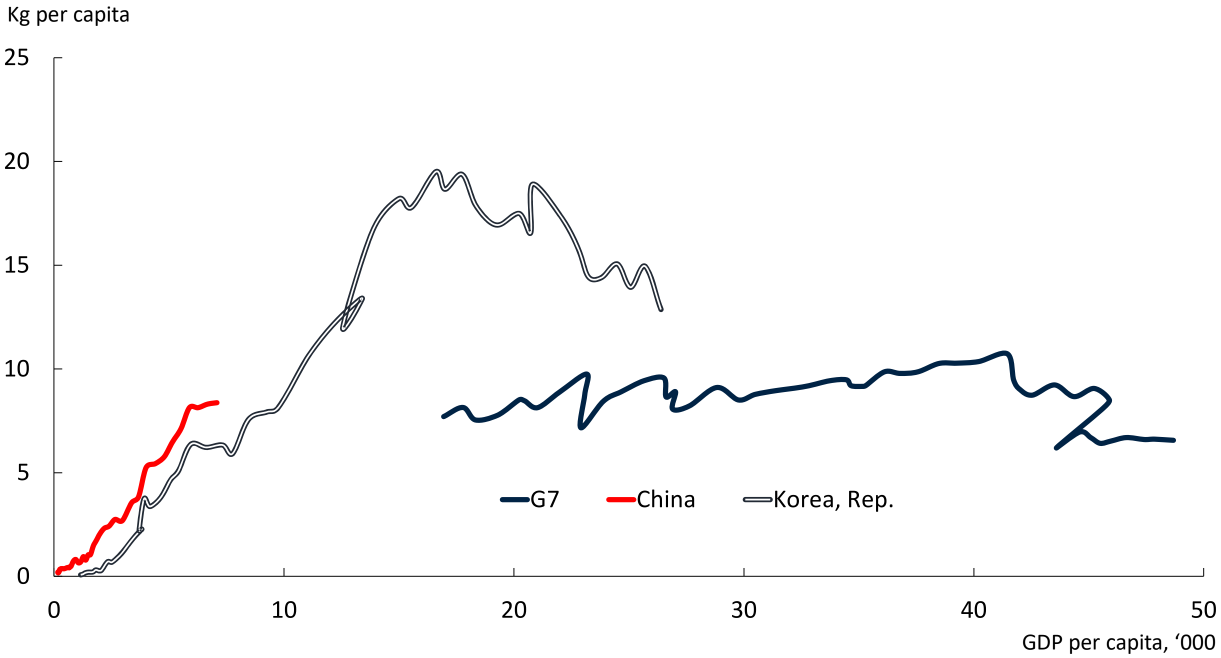
Source: BP Statistical Review and World Bank

Figure B8: Per capita income and consumption of aluminum, 1965-2018



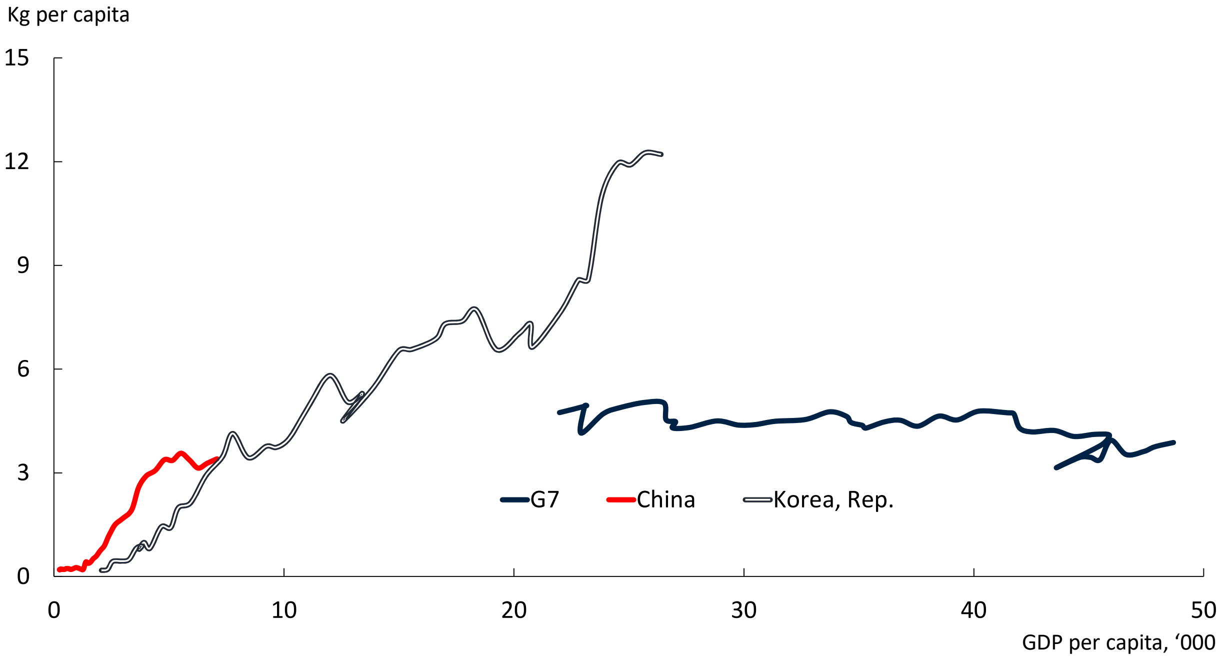
Source: World Bureau of Metal Statistics and World Bank

Figure B9: Per capita income and consumption of copper, 1965-2018



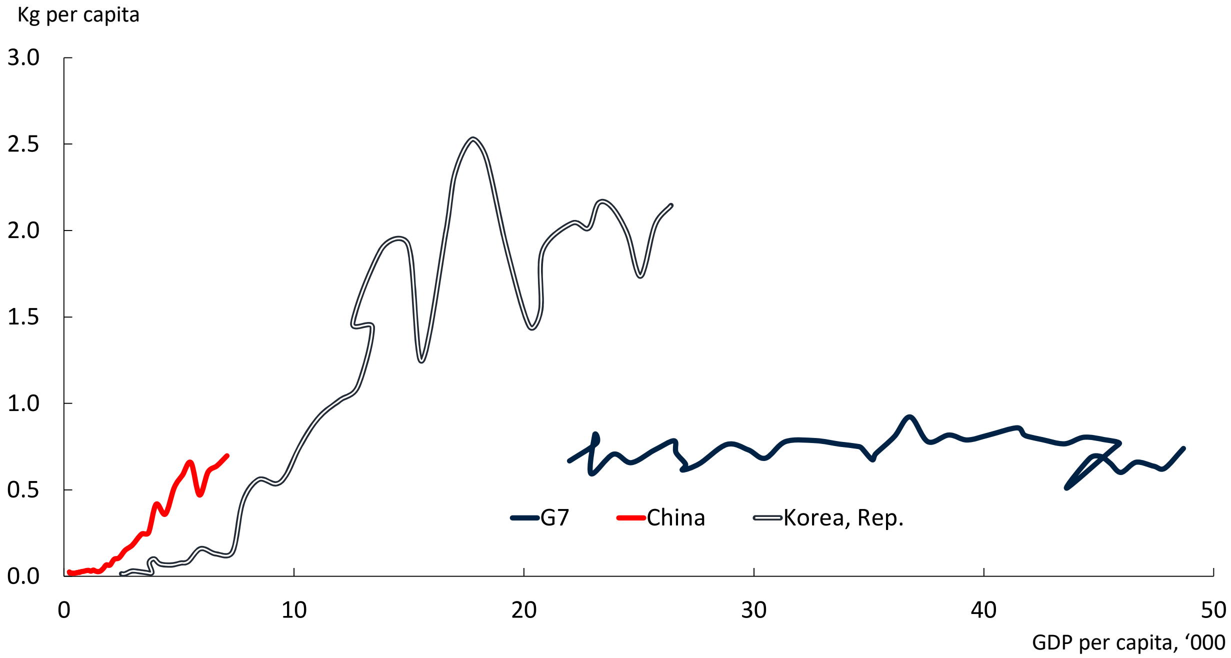
Source: World Bureau of Metal Statistics and World Bank

Figure B10: Per capita income and consumption of lead, 1965-2018



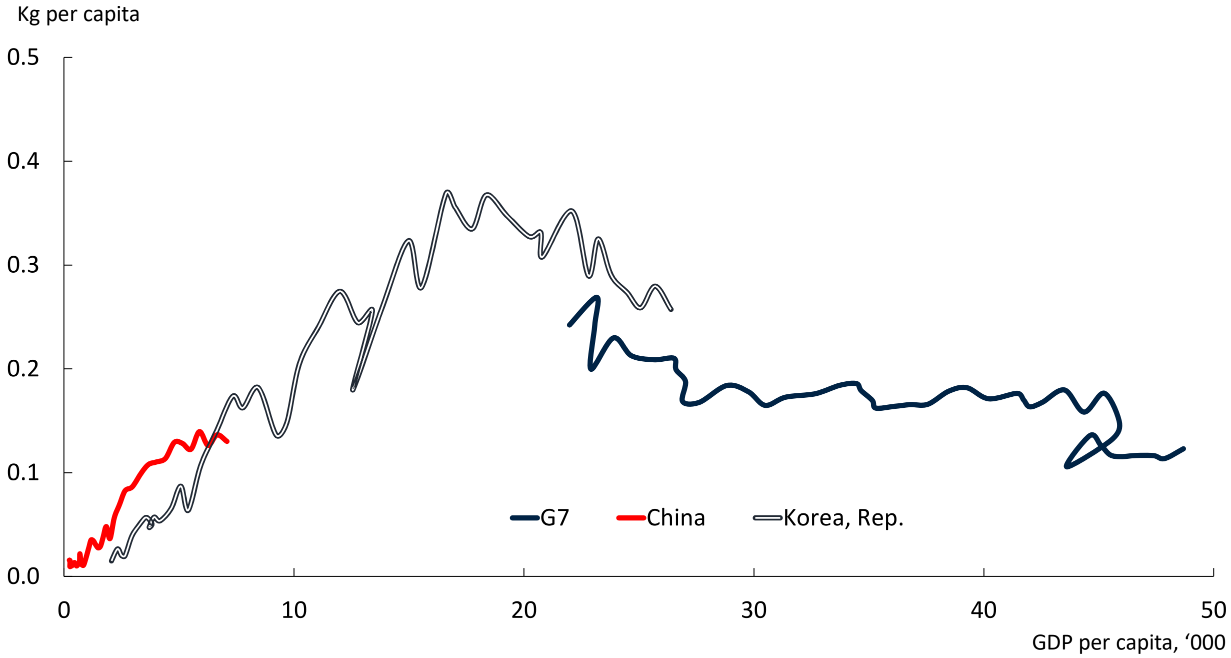
Source: BP Statistical Review and World Bank

Figure B11: Per capita income and consumption of nickel, 1965-2018



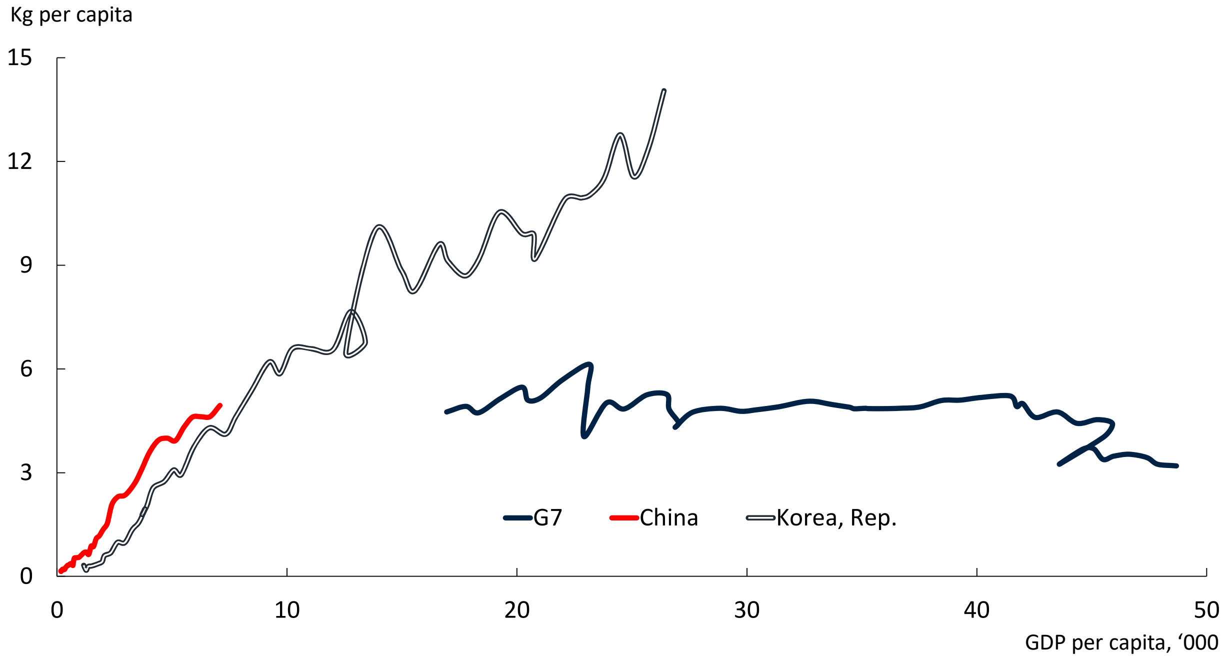
Source: World Bureau of Metal Statistics and World Bank

Figure B12: Per capita income and consumption of tin, 1965-2018



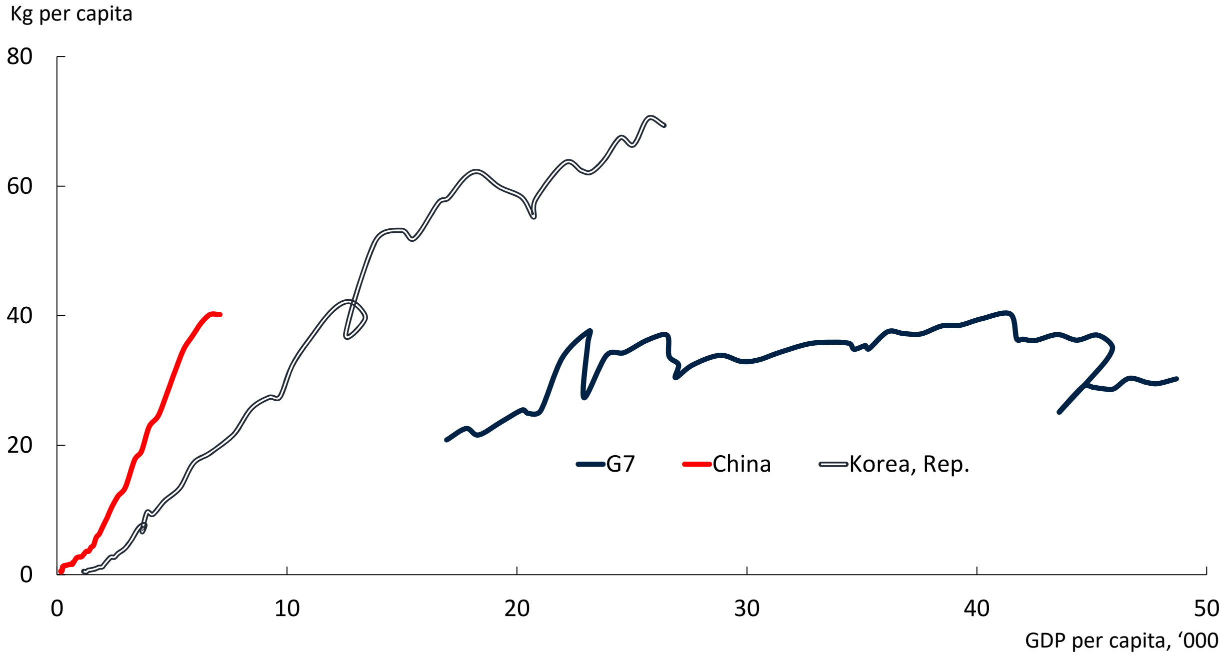
Source: World Bureau of Metal Statistics and World Bank

Figure B13: Per capita income and consumption of zinc, 1965-2018



Source: World Bureau of Metal Statistics and World Bank

Figure B14: Per capita income and consumption of aggregate metals, 1965-2018



Source: World Bureau of Metal Statistics and World Bank

Appendix C: Robustness checks

Table C1: Parameter estimates for aggregate energy with sample adjustments

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Base	**1965-97**	**1998-2017**	**Ex-China**	**Ex-US**	**Ex-G7**	**Ex-LIC**	**Energy**	**Controls**	**AIC**
Parameter estimates										
y_t	3.47***	3.92***	4.70***	3.51***	3.33***	3.20***	4.61***	3.47***	2.74***	3.97***
	(0.23)	(0.28)	(0.33)	(0.23)	(0.23)	(0.23)	(0.42)	(0.30)	(0.26)	(0.25)
y_t^2	-0.15***	-0.17***	-0.23***	-0.15***	-0.14***	-0.13***	-0.20***	-0.15***	-0.09***	-0.17***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
p_t	-0.17***	-0.15***	-0.04***	-0.17***	0.16***	-0.15***	-0.16***	-0.24***	-0.08***	-0.18***
	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
ρ	-0.08***	-0.14***	-0.26***	-0.09***	-0.09***	-0.09***	-0.09***	-0.07***	-0.15***	-0.08***
	(0.01)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Key statistics										
Hausman test	13.44	8.34	0.51	13.55	11.95	12.38	13.12	13.55	8.42	3.96
p-value	0.00	0.04	0.92	0.00	0.01	0.01	0.00	0.00	0.21	0.27
Log-likelihood	6,086	3,735	2,741	5,992	5,938	5,160	4,729	5,136	5,800	3,175
Observations	3,235	1,975	1,197	3,183	3,183	2,871	2,424	2,787	2,895	2,871
Countries	63	63	63	62	62	56	47	54	63	63

Notes: The dependent variable is the logarithm of aggregate commodity consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. The parameter estimates of the Base model (column [1]) are the ones reported in the first column of Table 2. Columns [2] and [3] report pre- and post-1998 results. Columns [4] though [7] report results excluding China, the U.S., the G7, and 16 low income EMDEs. Column [8] reports all energy, which includes renewables and nuclear power (in addition to the components of the base model: coal, natural gas, and oil). Column [9] reports estimates based on all controls reported in Table 2 (excluding trend). Column [10] reports results based on the Akaike Information Criterion, which gives an ARDL(2,1,1,1) specification.

Table C2: Parameter estimates for aggregate metals with sample adjustments

	[1]	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**	**[7]**	**[8]**	**[9]**	**[10]**	**[11]**
	Base	**1965-97**	**1998-2017**	**Ex-China**	**Ex-US**	**Ex-G7**	**Ex-LIC**	**Weighted**	**Limited**	**Controls**	**AIC**
Parameter estimates											
y_t	5.01***	4.45***	6.18***	4.99***	4.87***	4.81***	6.10***	5.96***	5.30***	4.23***	4.79***
	(0.30)	(0.38)	(0.70)	(0.30)	(0.30)	(0.32)	(0.46)	(0.29)	(0.32)	(0.66)	(0.35)
y_t^2	-0.22***	-0.18***	-0.29***	-0.22***	-0.22***	-0.21***	-0.28***	-0.27***	-0.24***	-0.18***	-0.22***
	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)
p_t	-0.26***	-0.10***	-0.13***	-0.26***	-0.26***	-0.28***	-0.26***	-0.29***	-0.24***	-0.18***	-0.30***
	(0.03)	(0.05)	(0.02)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)
ρ	-0.19***	-0.29***	-0.42***	-0.20***	-0.20***	-0.20***	-0.19***	-0.18***	-0.18***	-0.29***	-0.17***
	(0.02)	(0.03)	(0.04)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)
Key statistics											
Hausman test	2.26	2.90	0.52	2.50	2.21	1.90	7.43	3.26	5.63	13.18	4.42
p-value	0.52	0.49	0.91	0.48	0.53	0.59	0.06	0.35	0.58	0.04	0.22
Log-likelihood	1,853	1,162	1,000	1,792	1,780	1,392	1,526	1,785	1,434	1,883	1,909
Observations	2,165	1,305	817	2,113	2,113	1,801	1,636	2,165	1,472	1,983	2,122
Countries	43	43	43	42	42	36	32	43	29	43	43

Notes: The dependent variable is the logarithm of aggregate commodity consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. The parameter estimates of the Base model (column [1]) are the ones reported in the first column of Table 3. Columns [2] and [3] report pre- and post-1998 results. The next four columns ([4] through [7]) report results excluding China, the U.S., the G7, and 16 low income EMDEs. Column [8] reports a weighted consumption equation, based on weights reported in the lower panel of Table B2. Column [9] excludes countries which did not satisfy one or more of the following criteria: a growth rate of greater than 50 percent or less than -50 percent in three or more years; or a growth rate of zero in 3 or more years. Column [10] reports estimates based on all controls reported in Table 3 (excluding trend). Column [11] reports results based on the Akaike Information Criterion, which gives an ARDL(2,1,1,1) specification.

Table C3: Parameter estimates for individual metals, base *versus* sample-adjusted specification

	---- Aluminum ----		------- Copper ------		-------- Lead --------		------- Nickel -------		--------- Tin ---------		-------- Zinc --------	
	Base	**Limited**	**Base**	**Limited**	**Base**	**Limited**	**Base**	**Limited**	**Base**	**Limited**	**Base**	**Limited**
Parameter estimates												
y_t	3.98***	3.97***	3.67***	3.57***	1.40*	0.86	1.88*	1.54	0.72	1.81*	2.89***	2.71***
	(0.39)	(0.40)	(0.67)	(0.67)	(0.76)	(0.82)	(1.03)	(1.08)	(0.79)	(0.87)	(0.24)	(0.23)
y_t^2	-0.17***	-0.17***	-0.18***	-0.18***	-0.07*	-0.04	-0.07	-0.05	-0.04	-0.09*	-0.14***	-0.13***
	(0.02)	(0.02)	(0.03)	(0.03)	(0.04)	(0.04)	(0.05)	(0.05)	(0.04)	(0.04)	(0.01)	(0.01)
p_t	-0.21***	-0.24***	-0.27***	-0.24***	-0.07*	-0.07*	-0.11***	-0.10*	0.00	0.00	-0.22***	-0.22***
	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.04)	(0.04)	(0.02)	(0.02)	(0.03)	(0.03)
ρ	-0.26***	-0.25***	-0.13***	-0.14***	-0.18***	-0.18***	-0.30***	-0.28***	-0.21***	-0.24***	-0.25***	-0.24***
	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)
Key statistics												
Hausman test	2.40	1.11	1.25	7.71	2.12	14.82	2.28	0.75	2.21	1.50	10.35	7.63
p-value	0.49	0.89	0.74	0.36	0.55	0.01	0.52	0.99	0.55	0.96	0.02	0.27
Log-likelihood	964	1,049	472	871	516	569	-140	101	-204	187	844	884
Observations	2,525	2,088	2,300	1,571	2,355	1,933	1,555	1,062	2,165	1,253	2,637	2,398
Countries	52	42	49	32	52	43	36	24	49	28	55	50

Notes: The dependent variable is the logarithm of consumption of the respective commodity. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. The parameter estimates of the Base model are the ones reported in Table 1. The "Limited" sample model is discussed in Table C2.

Appendix D

Parameter estimates for individual commodities with cross-price effects

Table D1: Coal

	Base	**[1]**	**[2]**
Parameter estimates			
y_t	-0.87 (0.64)	6.54*** (1.02)	5.18*** (0.82)
y_t^2	0.08** (0.03)	-0.39*** (0.05)	-0.30*** (0.04)
p_t^{COAL}	0.01 (0.06)	-0.40*** (0.01)	-0.30*** (0.09)
p_t^{OIL}	—	0.46*** (0.07)	—
$p_t^{N.\ GAS}$	—	—	0.52*** (0.08)
ρ	-0.09*** (0.02)	-0.09*** (0.01)	-0.10*** (0.01)
Key statistics			
Hausman test	4.81	7.64	0.99
p-value	0.19	0.11	0.91
Log-likelihood	1,930	2,005	1,946
Observations	2,898	2,898	2,779
Countries	57	57	60

Notes: The dependent variable is the logarithm of consumption of the respective commodity. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D2: Natural gas

	Base	[1]	[2]	[3]
Parameter estimates				
y_t	1.49* (0.80)	1.63** (0.78)	2.20*** (0.77)	1.93** (0.76)
y_t^2	-0.04 (0.04)	-0.05 (0.04)	-0.07* (0.04)	-0.06* (0.04)
p_t^{COAL}	—	0.01 (0.04)	—	—
p_t^{OIL}	—	—	-0.46*** (0.10)	-0.14*** (0.02)
$p_t^{N.\ GAS}$	-0.20*** (0.02)	-0.21*** (0.03)	0.40*** (0.12)	—
ρ	-0.16*** (0.02)	-0.16*** (0.02)	-0.15*** (0.02)	-0.16*** (0.02)
Key statistics				
Hausman test	3.21	0.99	2.98	0.59
p-value	0.36	0.91	0.56	0.90
Log-likelihood	1,917	1,946	1,957	1,925
Observations	2,779	2,779	2,779	2,779
Countries	60	60	60	60

Notes: The dependent variable is the logarithm of consumption of the respective commodity. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D3: Oil

	Base	[1]	[2]
Parameter estimates			
y_t	1.81*** (0.37)	1.73*** (0.40)	1.40*** (0.39)
y_t^2	-0.07*** (0.02)	-0.06*** (0.02)	-0.04* (0.02)
p_t^{COAL}	—	—	0.42*** (0.06)
p_t^{OIL}	-0.41*** (0.03)	-0.53*** (0.07)	-0.63*** (0.05)
$p_t^{N.\ GAS}$	—	0.15** (0.08)	—
ρ	-0.07*** (0.01)	-0.07*** (0.01)	-0.07*** (0.00)
Key statistics			
Hausman test	4.15	8.21	8.65
p-value	0.25	0.08	0.07
Log-likelihood	5,195	5,229	5,248
Observations	3,235	3,235	3,235
Countries	63	63	63

Notes: The dependent variable is the logarithm of consumption of the respective commodity. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D4: Aluminum

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Parameter estimates							
y_t	3.98*** (0.39)	3.93*** (0.39)	3.59*** (0.39)	4.22*** (0.04)	3.80*** (0.38)	3.45*** (0.38)	3.37*** (0.40)
y_t^2	-0.17*** (0.02)	-0.17*** (0.02)	-0.15*** (0.02)	-0.19*** (0.02)	-0.16*** (0.02)	-0.14*** (0.02)	-0.14*** (0.02)
$p_t^{ALUMINUM}$	-0.21*** (0.03)	-0.20 (0.04)	-0.18** (0.04)	-0.26*** (0.05)	0.20*** (0.04)	-0.16*** (0.04)	-0.23*** (0.03)
p_t^{COPPER}	—	-0.04 (0.03)	—	—	—	—	-0.10 (0.06)
p_t^{LEAD}	—	—	-0.03 (0.03)	—	—	—	0.04 (0.11)
p_t^{NICKEL}	—	—	—	0.05 (0.04)	—	—	0.08 (0.07)
p_t^{TIN}	—	—	—	—	-0.03 (0.02)	—	-0.02 (0.04)
p_t^{ZINC}	—	—	—	—	—	-0.07* (0.04)	-0.02 (0.06)
ρ	-0.26*** (0.03)	-0.27*** (0.03)	-0.26*** (0.02)	-0.26*** (0.02)	-0.26*** (0.03)	-0.26*** (0.03)	-0.27*** (0.03)
Key statistics							
Hausman test	2.40	2.83	2.46	1.88	3.74	3.81	9.35
p-value	0.49	0.59	0.65	0.76	0.44	0.43	0.31
Log-likelihood	964	1,020	993	995	995	993	1150
Observations	2,525	2,525	2,525	2,525	2,525	2,525	2,525
Countries	52	52	52	52	52	52	52

Notes: The dependent variable is the logarithm of aluminum consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D5: Copper

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Parameter estimates							
y_t	3.67***	3.07***	9.77***	9.80***	10.29***	9.97***	3.41***
	(0.67)	(0.61)	(0.58)	(0.58)	(0.52)	(0.59)	(0.61)
y_t^2	-0.18***	-0.15***	-0.48***	-0.48***	-0.51***	-0.49***	-0.17***
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
$p_t^{ALUMINUM}$	—	0.26***	—	—	—	—	0.28
		(0.06)					(0.21)
p_t^{COPPER}	-0.27***	-0.29***	-0.23***	-0.30***	-0.17***	-0.22***	-0.23***
	(0.04)	(0.04)	(0.07)	(0.05)	(0.04)	(0.05)	(0.06)
p_t^{LEAD}	—	—	-0.03	—	—	—	0.33
			(0.07)				(0.36)
p_t^{NICKEL}	—	—	—	0.10*	—	—	0.10
				(0.06)			(0.14)
p_t^{TIN}	—	—	—	—	-0.12***	—	-0.13*
					(0.03)		(0.07)
p_t^{ZINC}	—	—	—	—	—	-0.04	-0.05
						(0.07)	(0.15)
ρ	-0.13***	-0.14***	-0.14***	-0.14***	-0.15***	-0.14***	-0.14***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Key statistics							
Hausman test	1.25	1.16	3.19	2.29	3.97	0.89	4.37
p-value	0.74	0.89	0.53	0.18	0.41	0.93	0.82
Log-likelihood	472	512	513	511	507	508	630
Observations	2,300	2,300	2,300	2,300	2,300	2,300	2,300
Countries	49	49	49	49	49	49	49

Notes: The dependent variable is the logarithm of copper consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D6: Lead

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Parameter estimates							
y_t	1.40* (0.76)	0.60 (0.78)	0.85 (0.73)	1.43* (0.76)	1.49* (0.77)	0.94 (0.74)	0.56 (0.73)
y_t^2	-0.07* (0.04)	-0.02 (0.04)	-0.04 (0.04)	-0.07* (0.04)	-0.07* (0.04)	-0.05 (0.04)	-0.03 (0.04)
$p_t^{ALUMINUM}$	—	0.09 (0.06)	—	—	—	—	0.16 (0.13)
p_t^{COPPER}	—	—	-0.10 (0.07)	—	—	—	-0.06 (0.14)
p_t^{LEAD}	-0.07** (0.03)	-0.09*** (0.03)	0.01 (0.06)	-0.06 (0.04)	-0.13** (0.06)	-0.06 (0.04)	-0.05 (0.05)
p_t^{NICKEL}	—	—	—	-0.02 (0.05)	—	—	-0.10 (0.08)
p_t^{TIN}	—	—	—	—	0.03 (0.05)	—	-0.01 (0.06)
p_t^{ZINC}	—	—	—	—	—	-0.04 (0.05)	0.01 (0.07)
ρ	-0.18*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)
Key statistics							
Hausman test	2.12	3.71	3.44	4.51	3.11	4.45	6.49
p-value	0.55	0.45	0.49	0.34	0.54	0.35	0.59
Log-likelihood	516	548	544	548	547	542	663
Observations	2,335	2,335	2,335	2,335	2,335	2,335	2,335
Countries	52	52	52	52	52	52	52

Notes: The dependent variable is the logarithm of lead consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D7: Nickel

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Parameter estimates							
y_t	1.88* (1.03)	0.87* (1.02)	3.35*** (1.16)	2.06** (1.02)	1.72 (1.06)	2.58** (1.10)	3.37*** (0.40)
y_t^2	-0.07 (0.05)	-0.07 (0.05)	-0.17*** (0.06)	-0.08* (0.05)	-0.07 (0.05)	-0.12** (0.06)	-0.14*** (0.02)
$p_t^{ALUMINUM}$	—	0.02 (0.10)	—	—	—	—	0.83*** (0.25)
p_t^{COPPER}	—	—	-0.03 (0.08)	—	—	—	0.50*** (0.16)
p_t^{LEAD}	—	—	—	-0.12*** (0.04)	—	—	0.70*** (0.28)
p_t^{NICKEL}	-0.11** (0.04)	-0.09 (0.06)	-0.27*** (0.09)	0.01 (0.05)	0.00 (0.04)	-0.20*** (0.07)	0.06 (0.05)
p_t^{TIN}	—	—	—	—	-0.11** (0.02)	—	0.05 (0.06)
p_t^{ZINC}	—	—	—	—	—	-0.05 (0.08)	0.34*** (0.12)
ρ	-0.30*** (0.03)	-0.29*** (0.03)	-0.28*** (0.03)	-0.30*** (0.03)	-0.31*** (0.04)	-0.29*** (0.03)	-0.30*** (0.04)
Key statistics							
Hausman test	2.28	6.60	1.79	3.97	4.04	2.27	26.06
p-value	0.52	0.16	0.77	0.41	0.40	0.59	0.00
Log-likelihood	-140	-106	-77	-113	-103	-103	36
Observations	1,550	1,550	1,550	1,550	1,550	1,550	1.550
Countries	36	36	36	36	36	36	36

Notes: The dependent variable is the logarithm of nickel consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D8: Tin

	Base	[1]	[2]	[3]	[4]	[5]	[6]
Parameter estimates							
y_t	0.72 (0.79)	0.34 (0.75)	0.45 (0.76)	0.61 (0.82)	0.81 (0.79)	0.07 (0.73)	0.37 (0.66)
y_t^2	-0.04 (0.04)	-0.01 (0.04)	-0.04 (0.04)	-0.04 (0.04)	-0.05 (0.04)	-0.01 (0.04)	-0.03 (0.03)
$p_t^{ALUMINUM}$	—	0.25** (0.05)	—	—	—	—	0.83*** (0.26)
p_t^{COPPER}	—	—	-0.17*** (0.04)	—	—	—	0.46*** (0.17)
p_t^{LEAD}	—	—	—	-0.13*** (0.06)	—	—	1.32*** (0.37)
p_t^{NICKEL}	—	—	—	—	0.13*** (0.04)	—	0.40*** (0.10)
p_t^{TIN}	0.00 (0.02)	-0.10*** (0.02)	-0.09** (0.03)	-0.09* (0.05)	-0.04 (0.03)	-0.05* (0.03)	0.13*** (0.04)
p_t^{ZINC}	—	—	—	—	—	-0.17*** (0.04)	0.67*** (0.14)
ρ	-0.21*** (0.03)	-0.22*** (0.03)	-0.21*** (0.03)	-0.21*** (0.03)	-0.21*** (0.03)	-0.21*** (0.03)	-0.21*** (0.03)
Key statistics							
Hausman test	2.21	4.41	4.11	5.74	2.07	3.37	14.57
p-value	0.55	0.35	0.39	0.22	0.72	0.50	0.07
Log-likelihood	-204	-165	-159	-173	-161	-171	-23
Observations	2,165	2,165	2,165	2,165	2,165	2,165	2,165
Countries	49	49	49	49	49	49	49

Notes: The dependent variable is the logarithm of tin consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table D9: Zinc

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**	**[6]**
Parameter estimates							
y_t	2.89*** (0.24)	2.70*** (0.24)	3.02*** (0.27)	2.80*** (0.24)	2.92*** (0.23)	2.99*** (0.23)	2.60*** (0.40)
y_t^2	-0.14*** (0.01)	-0.13*** (0.01)	-0.15*** (0.02)	-0.14*** (0.01)	-0.15*** (0.01)	-0.15*** (0.01)	-0.12*** (0.02)
$p_t^{ALUMINUM}$	—	0.06 (0.04)	—	—	—	—	0.15 (0.11)
p_t^{COPPER}	—	—	-0.12*** (0.03)	—	—	—	0.01 (0.07)
p_t^{LEAD}	—	—	—	-0.09*** (0.03)	—	—	-0.21 (0.13)
p_t^{NICKEL}	—	—	—	—	0.01 (0.03)	—	-0.05 (0.06)
p_t^{TIN}	—	—	—	—	—	-0.06*** (0.02)	0.00 (0.04)
p_t^{ZINC}	-0.22*** (0.03)	-0.23*** (0.03)	-0.11** (0.04)	-0.15** (0.04)	-0.23** (0.04)	-0.20*** (0.03)	-0.18*** (0.04)
ρ	-0.25*** (0.03)	-0.25*** (0.02)	-0.26*** (0.03)	-0.26*** (0.02)	-0.25*** (0.02)	-0.25*** (0.03)	-0.26*** (0.03)
Key statistics							
Hausman test	10.35	8.68	14.56	5.43	12.49	11.26	21.30
p-value	0.02	0.07	0.01	0.25	0.01	0.02	0.01
Log-likelihood	844	879	888	893	874	890	1026
Observations	2,637	2,637	2,637	2,637	2,637	2,637	2,637
Countries	55	55	55	55	55	55	55

Notes: The dependent variable is the logarithm of zinc consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Appendix E
Commodity-specific parameter estimates including control variables

Table E1: Coal

	Base	**[1]**	**[2]**	**[3]**	**[4]**	**[5]**
Parameter estimates						
y_t	-0.87 (0.64)	-5.31*** (0.98)	2.98*** (0.43)	6.04*** (0.69)	1.07* (0.64)	6.39*** (0.78)
y_t^2	0.08** (0.03)	0.30*** (0.05)	-0.18*** (0.02)	-0.32*** (0.04)	-0.02 (0.04)	-0.38*** (0.04)
p_t	-0.01 (0.06)	0.03 (0.05)	0.09** (0.03)	-0.04 (0.04)	0.15*** (0.03)	—
Inv. share	—	0.06 (0.09)	—	—	—	—
Urbanization	—	—	0.87** (0.33)	—	—	—
Pop. density	—	—	—	-0.46** (0.23)	—	—
Trend	—	—	—	—	-0.04*** (0.00)	—
Nom. price	—	—	—	—	—	0.22*** (0.04)
RER	—	—	—	—	—	-0.08*** (0.01)
ρ	-0.09*** (0.02)	-0.09*** (0.02)	-0.14*** (0.02)	-0.16*** (0.02)	-0.10*** (0.02)	-0.10*** (0.02)
Key statistics						
Hausman test	4.81	5.24	5.62	5.17	7.88	3.34
p-value	0.19	0.26	0.23	0.27	0.10	0.51
Log-likelihood	1,930	2,013	1,950	1,851	1,957	1,963
Observations	2,898	2,853	2,846	2,633	2,898	2,898
Countries	57	57	56	57	57	57

Notes: The dependent variable is the logarithm of coal consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E2: Natural gas

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	1.49* (0.80)	2.41*** (0.77)	3.93*** (0.64)	7.06*** (1.00)	1.12 (0.84)	2.07** (0.78)
y_t^2	-0.04 (0.04)	0.09** (0.04)	-0.16*** (0.03)	-0.31*** (0.05)	-0.02 (0.04)	-0.06* (0.04)
p_t	-0.20*** (0.02)	-0.22*** (0.02)	-0.13*** (0.02)	-0.13*** (0.01)	-0.21*** (0.02)	—
Inv. share	—	0.21** (0.09)	—	—	—	—
Urbanization	—	—	0.45* (0.25)	—	—	—
Pop. density	—	—	—	-0.16** (0.07)	—	—
Trend	—	—	—	—	-0.01** (0.00)	—
Nom. price	—	—	—	—	—	-0.17*** (0.03)
RER	—	—	—	—	—	-0.02 (0.01)
ρ	-0.16*** (0.02)	-0.16*** (0.02)	-0.19*** (0.03)	-0.19*** (0.03)	-0.15*** (0.02)	-0.16*** (0.02)
Key statistics						
Hausman test	3.21	0.76	1.71	1.76	2.56	1.14
p-value	0.36	0.94	0.79	0.78	0.63	0.89
Log-likelihood	1,917	1,986	1,988	2,178	1,918	1,920
Observations	2,779	2,714	2,727	2,596	2,779	2,779
Countries	60	60	59	60	60	60

Notes: The dependent variable is the logarithm of natural gas consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E3: Oil

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	1.81*** (0.37)	1.90*** (0.33)	3.19*** (0.38)	0.32 (0.31)	1.21*** (0.35)	1.38*** (0.39)
y_t^2	-0.07*** (0.02)	-0.07*** (0.02)	-0.14*** (0.02)	0.01 (0.02)	-0.01 (0.02)	-0.02 (0.02)
p_t	-0.41*** (0.03)	-0.37*** (0.03)	-0.29*** (0.02)	-0.26*** (0.02)	-0.31*** (0.03)	—
Inv. share	—	0.40*** (0.07)	—	—	—	—
Urbanization	—	—	-0.31 (0.21)	—	—	—
Pop. density	—	—	—	-0.14 (0.09)	—	—
Trend	—	—	—	—	-0.02*** (0.00)	—
Nom. price	—	—	—	—	—	-0.37** (0.03)
RER	—	—	—	—	—	-0.05*** (0.01)
ρ	-0.07*** (0.01)	-0.09*** (0.01)	-0.09*** (0.01)	-0.10*** (0.01)	-0.08*** (0.01)	-0.07*** (0.01)
Key statistics						
Hausman test	4.15	14.28	7.01	37.23	16.44	4.16
p-value	0.25	0.01	0.14	0.00	0.00	0.39
Log-likelihood	5,195	5,190	5,237	4,945	5,214	5,205
Observations	3,235	3,170	3,183	2,940	3,235	3,235
Countries	63	63	62	63	63	63

Notes: The dependent variable is the logarithm of crude oil consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E4: Aluminum

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	3.98*** (0.39)	4.22*** (0.46)	2.27*** (0.44)	4.71*** (0.51)	4.21*** (0.41)	1.21*** (0.41)
y_t^2	-0.17*** (0.02)	-0.19*** (0.02)	-0.08*** (0.02)	-0.20*** (0.03)	-0.19*** (0.02)	-0.05*** (0.02)
p_t	-0.21*** (0.03)	-0.24*** (0.03)	-0.07* (0.03)	-0.14*** (0.03)	-0.16*** (0.04)	—
Inv. share	—	-0.30*** (0.09)	—	—	—	—
Urbanization	—	—	-0.27 (0.20)	—	—	—
Pop. density	—	—	—	1.05*** (0.16)	—	—
Trend	—	—	—	—	0.01*** (0.00)	—
Nom. price	—	—	—	—	—	-0.08* (0.04)
RER	—	—	—	—	—	0.01*** (0.00)
ρ	-0.26*** (0.03)	-0.25*** (0.03)	-0.29*** (0.03)	-0.33*** (0.03)	-0.26*** (0.02)	-0.26*** (0.03)
Key statistics						
Hausman test	2.40	1.45	3.79	4.82	4.65	4.17
p-value	0.49	0.84	0.44	0.31	0.32	0.38
Log-likelihood	964	1,001	970	978	966	950
Observations	2,525	2,479	2,428	2,370	2,525	2,525
Countries	52	52	50	52	52	52

Notes: The dependent variable is the logarithm of aluminum consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E5: Copper

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	3.67*** (0.67)	4.43*** (0.75)	0.57 (0.82)	7.70*** (0.99)	9.60*** (0.66)	9.29*** (0.70)
y_t^2	-0.18*** (0.03)	-0.22*** (0.04)	-0.05 (0.04)	-0.36*** (0.05)	-0.47*** (0.04)	-0.44*** (0.04)
p_t	-0.27*** (0.04)	-0.28*** (0.04)	-0.31*** (0.04)	-0.22*** (0.04)	-0.24*** (0.04)	—
Inv. share	—	-0.36** (0.16)	—	—	—	—
Urbanization	—	—	3.89*** (0.35)	—	—	—
Pop. density	—	—	—	-0.55** (0.26)	—	—
Trend	—	—	—	—	0.00 (0.00)	—
Nom. price	—	—	—	—	—	-0.21*** (0.04)
RER	—	—	—	—	—	0.00 (0.00)
ρ	-0.13*** (0.02)	-0.14*** (0.02)	-0.18*** (0.02)	-0.19*** (0.02)	-0.14*** (0.02)	-0.14*** (0.02)
Key statistics						
Hausman test	1.25	0.56	14.06	4.38	4.05	3.52
p-value	0.74	0.97	0.01	0.36	0.40	0.47
Log-likelihood	472	509	580	485	482	572
Observations	2,300	2,257	2,126	2,155	2,300	2,300
Countries	49	49	45	49	49	49

Notes: The dependent variable is the logarithm of copper consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E6: Lead

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	1.40* (0.76)	4.93*** (0.64)	1.72** (0.75)	-1.94** (0.77)	1.03 (0.75)	1.61** (0.78)
y_t^2	-0.07* (0.04)	-0.24*** (0.03)	-0.09** (0.04)	0.10** (0.04)	-0.04 (0.04)	-0.07* (0.04)
p_t	-0.07** (0.03)	-0.09** (0.03)	-0.06** (0.03)	-0.05** (0.02)	-0.06** (0.03)	—
Inv. share	—	-0.45*** (0.12)	—	—	—	—
Urbanization	—	—	-0.09 (0.29)	—	—	—
Pop. density	—	—	—	-0.32* (0.18)	—	—
Trend	—	—	—	—	0.00* (0.00)	—
Nom. price	—	—	—	—	—	-0.09*** (0.03)
RER	—	—	—	—	—	0.02** (0.01)
ρ	-0.18*** (0.02)	-0.18*** (0.02)	-0.23*** (0.02)	-0.24*** (0.02)	-0.18*** (0.02)	-0.18*** (0.02)
Key statistics						
Hausman test	2.12	16.23	4.34	5.86	3.20	1.88
p-value	0.55	0.00	0.36	0.21	0.52	0.76
Log-likelihood	516	537	555	591	517	547
Observations	2,335	2,299	2,205	2,335	2,335	2,335
Countries	52	52	49	52	52	52

Notes: The dependent variable is the logarithm of lead consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E7: Nickel

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	1.88* (1.03)	3.12*** (1.01)	1.94* (1.12)	9.73*** (1.96)	1.22 (1.03)	1.59 (1.08)
y_t^2	-0.07 (0.05)	-0.14*** (0.05)	-0.08 (0.05)	-0.46*** (0.10)	-0.02 (0.05)	-0.05 (0.05)
p_t	-0.11*** (0.04)	-0.11*** (0.04)	-0.12*** (0.04)	-0.11** (0.04)	-0.05 (0.04)	—
Inv. share	—	-0.13 (0.13)	—	—	—	—
Urbanization	—	—	-0.39 (0.35)	—	—	—
Pop. density	—	—	—	-0.76 (0.48)	—	—
Trend	—	—	—	—	-0.01** (0.00)	—
Nom. price	—	—	—	—	—	-0.15*** (0.05)
RER	—	—	—	—	—	0.02*** (0.00)
ρ	-0.30*** (0.03)	-0.31*** (0.03)	-0.36*** (0.03)	-0.35*** (0.03)	-0.30*** (0.03)	-0.31*** (0.03)
Key statistics						
Hausman test	2.28	1.32	4.55	2.18	3.23	6.11
p-value	0.52	0.86	0.34	0.70	0.52	0.19
Log-likelihood	-140	-90	-81	-105	-139	-133
Observations	1,550	1,532	1,505	1,550	1,550	1,550
Countries	36	36	35	36	36	36

Notes: The dependent variable is the logarithm of nickel consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E8: Tin

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	0.72 (0.79)	0.01 (0.89)	1.78** (0.82)	1.91*** (0.64)	-0.88 (0.63)	1.50* (0.81)
y_t^2	-0.04 (0.04)	0.00 (0.04)	-0.09** (0.04)	-0.07** (0.03)	0.11** (0.04)	-0.07* (0.04)
p_t	-0.00 (0.02)	0.01 (0.02)	-0.04* (0.03)	-0.01 (0.02)	-0.02 (0.02)	—
Inv. share	—	-0.17 (0.12)	—	—	—	—
Urbanization	—	—	-0.16 (0.30)	—	—	—
Pop. density	—	—	—	-2.58*** (0.21)	—	—
Trend	—	—	—	—	-0.02*** (0.00)	—
Nom. price	—	—	—	—	—	-0.11*** (0.02)
RER	—	—	—	—	—	-0.04*** (0.01)
ρ	-0.21*** (0.03)	-0.22*** (0.03)	-0.27*** (0.03)	-0.29*** (0.03)	-0.23*** (0.03)	-0.22*** (0.03)
Key statistics						
Hausman test	2.21	2.65	4.53	0.46	3.85	2.44
p-value	0.53	0.62	0.34	0.98	0.43	0.66
Log-likelihood	-204	-165	-99	-129	-194	-194
Observations	2,165	2,129	2,031	2,165	2,165	2,165
Countries	49	49	46	49	49	49

Notes: The dependent variable is the logarithm of tin consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.

Table E9: Zinc

	Base	[1]	[2]	[3]	[4]	[5]
Parameter estimates						
y_t	2.89*** (0.24)	3.20*** (0.26)	2.89*** (0.23)	2.87*** (0.43)	2.32*** (0.22)	2.76*** (0.23)
y_t^2	-0.14*** (0.01)	-0.16*** (0.02)	-0.14*** (0.01)	-0.13*** (0.02)	-0.09*** (0.01)	-0.12*** (0.01)
p_t	-0.22*** (0.03)	-0.22*** (0.03)	-0.19*** (0.03)	-0.17*** (0.02)	-0.18*** (0.03)	—
Inv. share	—	-0.06 (0.06)	—	—	—	—
Urbanization	—	—	-0.24* (0.13)	—	—	—
Pop. density	—	—	—	-0.80*** (0.13)	—	—
Trend	—	—	—	—	0.01*** (0.00)	—
Nom. price	—	—	—	—	—	-0.22*** (0.03)
RER	—	—	—	—	—	0.00 (0.00)
ρ	-0.25*** (0.03)	-0.25*** (0.03)	-0.28*** (0.03)	-0.33*** (0.03)	-0.27*** (0.03)	-0.25*** (0.03)
Key statistics						
Hausman test	10.35	7.52	8.94	23.76	9.50	5.75
p-value	0.02	0.11	0.06	0.00	0.05	0.22
Log-likelihood	844	873	875	882	885	850
Observations	2,637	2,585	2,554	2,468	2,637	2,637
Countries	55	55	53	55	55	55

Notes: The dependent variable is the logarithm of zinc consumption. Three (***), two (**), and one (*) asterisks denote significance of parameter estimates at 1, 5, and 10 percent level, respectively. Standard errors in parentheses. "—" indicates that the corresponding variable was not included in the model.