SPECIAL FOCUS

The Role of Substitution in Commodity Demand

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Consumption of non-renewable resources surged over the past two decades, mostly as a result of strong growth in emerging markets and developing economies, especially China. This Focus examines how energy and metals consumption respond to changes in income and prices by accounting for substitutability and complementarity among commodities. It shows that, historically, demand surges have been accompanied by investment and innovation, in turn causing substitution both within commodity groups (for example, from coal to natural gas for energy) and across commodity groups (such as paper for plastic). The Focus concludes that, apart from income, prices of substitute commodities are as important in explaining the variation in commodity consumption as own prices.

Introduction

Consumption of non-renewable resources surged over the past two decades, notably as a result of strong growth in emerging markets and developing economies (EMDEs). The surge was pronounced in metals, where consumption grew 150 percent during this period (Figure SF.1) This increase was driven by China, whose share of world metals consumption reached 50 percent in 2015, up from 10 percent two decades earlier. Similar increases took place in coal consumption, driven by China and India (World Bank 2018).

As in earlier booms, high commodity prices induced investment and innovation on the supply side as well as efficiency gains, substitution, and reduced consumption on the demand side. As a result, commodity prices fell—non-energy prices in a smooth decline since 2011 and crude oil prices in a steep plunge in 2014. This created concerns 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). Meanwhile, discussions intensified regarding environmental concerns about the sustainability of production and consumption of certain commodities. Such concerns include the consequences of climate change, air and water pollution, and plastic waste.

The relationship between commodity consumption, income growth, and commodity prices has typically been studied from a single commodity perspective. In an earlier *Focus* (October 2018 edition of the *Commodity Markets Outlook*), such a relationship was studied by applying the same modeling framework to several individual energy and metal commodities. This analysis expanded on existing literature by explicitly accounting for a "plateauing effect" on commodity consumption, i.e., a level of income at which per capita consumption no longer grows. In this *Focus*, we extend the analysis further by accounting for substitution among commodities through the inclusions of cross-price effects—an area of research that has not been explored widely for industrial commodities. Specifically, the *Focus* addresses the following questions: (1) How has substitution in commodity demand evolved? (2) What is the empirical evidence of substitution in commodity consumption?

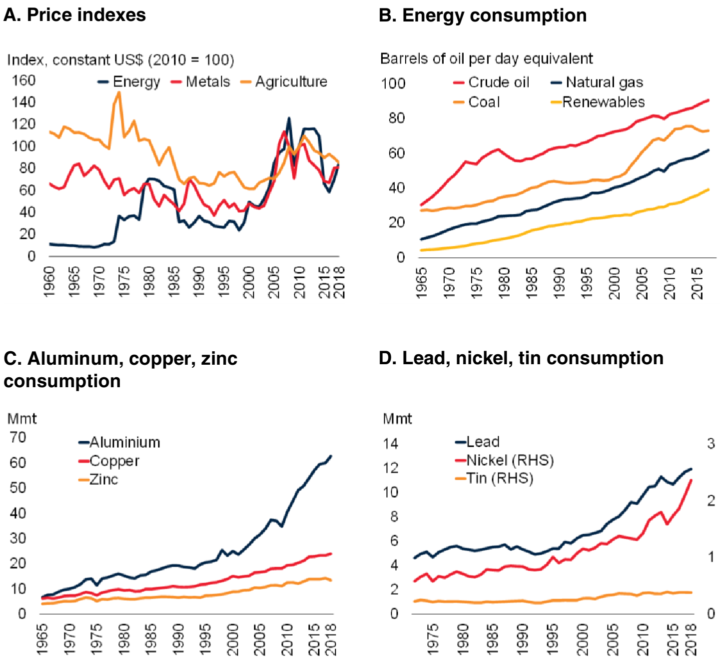
Commodity substitution: Historical perspective

Innovation and substitution between commodities have been key features of commodity markets.[1] Substitution among commodities is a complex process and can take place at short- and long-term horizons as well as within and across commodity groups (Tilton and Guzmán 2016). It can occur from a change in relative prices in the short-term (if alternative materials are readily available), with an extended lag (if the production of new materials entails significant costs), and in the

[1] Discussions of substitutability go back to Hicks (1932), who argued that a change in the relative prices of the factors of production spurs innovation. Hicks' hypothesis, known as the induced innovation hypothesis, has been tested extensively, including in Hayami and Ruttan (1970); Olmstead and Rhode (1993); Hanlon (2015); and Newell, Jaffe, and Stavins (1999).

FIGURE SF.1 Commodity prices and consumption

During the past two decades, commodity prices experienced the longest and broadest cycle after WWII. The price cycle was associated with a consumption surge in several energy and metal commodities, including aluminum, coal, and copper. This surge was in response to strong income growth by emerging and developing economies, notably China.



Source: BP Statistical Review, World Bank, World Bureau of Metal Statistics.
A. Deflated by the World Bank's manufacturing unit value index.
B. Renewables includes hydroelectric and nuclear energy (in addition to biofuels, biomass, geothermal, solar, and wind sources).
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longer term (from development of new technologies and innovation). Substitution can also emerge from exogenous technological shocks.

Within-commodity group substitution is common in agriculture (e.g., soybean oil has replaced palm oil for human consumption, and soybean meal has replaced maize for animal feed); energy (e.g., substitution of coal by natural gas in electricity generation); and metals (e.g., substitution of tin by aluminum for containers or copper by aluminum in electricity transmission). Substitution across commodity groups is common as well.

Apart from innovation, substitution among commodities can be caused by other factors. Domestic policies often change the relative prices of commodities. For example, many oil-producing countries subsidize oil, thus encouraging its consumption at the expense of other energy sources. Trade policies (such as tariffs) and macroeconomic policies (such as exchange rate management) can alter the terms of trade and hence induce substitution. Changing consumer preferences can also lead to substitution. For example, following environmental concerns, consumers have been seeking to minimize the use of petrochemical-based materials (such as plastic) by natural alternatives (such as paper).

The rest of this section elaborates on how innovation and substitution altered consumption paths of commodities in the transport as well industry and consumer products. It also sets the stage for the second section of this *Focus*, which provides evidence in favor substitution by including the prices of substitute commodities based on a commodity demand model. Box SF.1 delves deeper into substitutability by examining three episodes: the beverage and can industry during the 1960s; the oil price crises of the 1970s; and the ongoing changes in the energy mix due to environmental concerns.

Transport

Innovation and substitutability in the transport industry goes back to the industrial revolution. With the invention of the steam engine, animal traction was replaced by trains. As a result, the agricultural commodities used to feed animals were replaced by coal to power the steam engines. The wooden frames along with the cotton- and linen-based sail cloth of sail ships were replaced by steel and iron ore structures and by steam engines (Lundgren 1996) (Figure SF.2).

In the early twentieth century, further substitution between food and energy commodities resulted when electric vehicles began replacing animal traction, which meant that food commodities were substituted by electricity. Later, the first-generation internal combustion engine vehicles that used biofuels substituted for electric vehicles (Kovarik 2013). Later, vehicles powered by gasoline and diesel dominated ground transport and expanded to water transport (diesel and

BOX SF.1 Innovation, disruptive technologies, and substitution among commodities

Substitution is a key feature of commodity markets. There have been three broad episodes of substitution during the last half century that affected commodity consumption in a significant way. The first episode impacted beverage containers. Glass, tin, and steel were gradually replaced by aluminum, plastics, recyclable glass, and (more recently) paper following advances in technology. The second originated with the oil crisis of the 1970s and induced substitution of crude oil by coal (and other energy sources) in electricity generation. The third involves the increasing share of renewable energy for electricity generation (due to environmental considerations) and the substitution of oil by electricity, following advances in electric vehicle and battery technology.

Introduction

Substitution, which has been a key feature of commodity markets, can occur from a change in relative prices: (1) in the short-term if alternative materials are readily available; (2) with an extensive lag if significant costs are involved; and (3) in the longer term following the development of new technologies and innovation. Substitution could also emerge from innovation, not necessarily related to price changes.

Against this backdrop, this box examines the following questions:

i. How has substitutability affected the beverage can and bottle industries?

ii. How have oil price shocks affected substitutability in electricity generation?

iii. How has substitutability affected the vehicle industry?

How has substitutability evolved in the beverage can and bottle industries?

Until the 1960s, glass, tin, and steel were the dominant materials used in the manufacturing of beverage containers (principally soft drinks and beer). 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 example, the share of aluminum cans in beer shipments in the U.S. reached 80 percent by 1986, following their introduction two decades earlier (Figure Box SF1.A).

More recently, the dramatic rise of plastic bottles since their introduction in the late 1970s has limited the share of aluminum cans for soft drinks. Innovation continues today, particularly for soft drinks. Recyclable glass and plastics (and increasingly paper, e.g., Tetrapak) 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. The agreement, first negotiated in 1954 with the objective of maintaining tin prices within a desired range through the management of buffer stocks, collapsed in 1985 following several years of insufficient funds to maintain stocks (Chandrasekhar 1989). Tin lost market share not only from technological advances of its competitors, but also by its own pricing decisions. Commodity agreements were common throughout the twentieth century, both for metals (Tilton and Guzmán 2016) and agricultural commodities (Gilbert 1996). All have ceased activity.

How have oil price shocks affected substitutability in electricity generation?

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, industry, and electricity consumption. The expansion was 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 and policies to reduce oil consumption and seek alternative supplies (Figure Box SF1.B). Efficiency improvements led to reductions in the amount of oil used by the transport sector, while the use of oil for electricity generation was displaced by coal, nuclear power, and

BOX SF.1 Innovation, disruptive technologies, and substitution among commodities *(continued)*

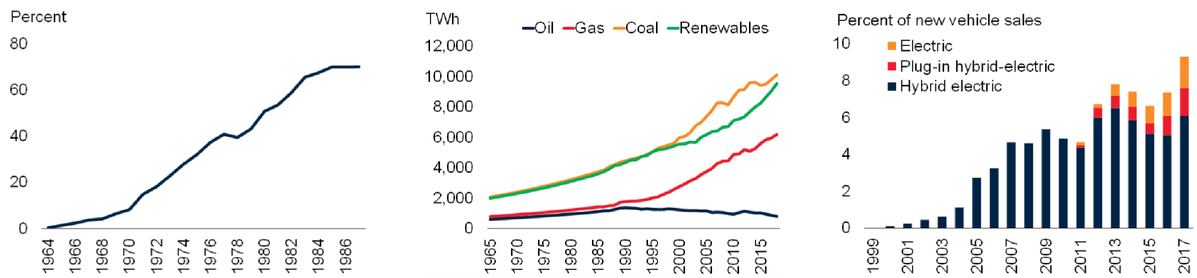
FIGURE BOX SF.1 Broad-based substitution across commodities

Following the introduction of aluminum cans in beer packaging in the mid-1960s, their share reached three-quarters of all beer shipments by 1986 (they replaced refillable glass bottles and tin cans). When prices of oil increased seven-fold after the oil crises of the 1970s, crude oil's share in electricity generation reversed its upward trend, mainly in advanced economies (globally around 1990). Aided by improvements in battery technology, charging infrastructure, and government incentives, hybrid and electric vehicles have enjoyed impressive demand growth.

A. Proportion of packaged shipments of beer in aluminum cans in the U.S.

B. Global electricity generation by fuel

C. Sales of alternative vehicles in the U.S.



Source: BP Statistical Review; Nappi (1990); U.S. Department of Commerce (Bureau of Economic Analysis); World Bank.
A. During 1964-87, the aluminum consumption by beer containers in the U.S. increased from 2.6 to 634 thousand metric tons.
B. Renewables includes hydroelectric and nuclear energy (in addition to biofuels, biomass, geothermal, solar, and wind).
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renewable and natural gas. 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 rose 60 percent (the equivalent of 1.8 mb/d). Thus, the oil price shocks induced the substitution of the equivalent of 4.7 mb/d of oil by other energy sources, plus a net decline of 1.6 mb/d in crude oil consumption (Figure Box SF.1.B).

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 under the *Principles for IEA Action on Coal* directive (IEA 1979). 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.

How has substitutability evolved in the vehicle industry?

Substitutability among commodities is also driven by environmental concerns. First, the fuel mix for electricity generation is changing. This comes in response to a preference for cleaner fuels like natural gas and for renewable sources (e.g., solar) instead of coal and other polluting energy sources such as firewood (Burke and Csereklyei 2016). Natural gas generates 53 kgs of CO2 per mmbtu, compared to 71 kgs from oil and 93 kgs from coal, and also produces fewer particulate emissions (EIA 2016). In transport, numerous countries have 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 and they account for 1.6 percent of global liquid energy consumption.

Second, transitioning toward a lower carbon energy environment is expected to significantly impact the

BOX SF.1 Innovation, disruptive technologies, and substitution among commodities *(continued)*

transportation industry, especially through the gradual replacement of internal combustion engine vehicles by electric vehicles (either fully battery-powered or through some form of hybrid technology).

Initially, electric vehicles faced numerous headwinds, including high prices, long charging times, and limited driving range. However, aided by improvements in battery technology and charging infrastructure, along with government incentives, electric vehicles have enjoyed impressive demand growth. In 2018, the global electric car fleet exceeded 5 million units, up 2 million from the previous year (IEA 2019). In the United States, electric and hybrid vehicles account for nearly 10 percent of total passenger vehicle purchases (Figure Box SF.1.C). China is currently the world's largest electric vehicle 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 electric vehicle penetration.

Not only will electric vehicles induce substitution of oil by other sources of energy (for electricity generation), but they will also induce substitution among metals for its components. An electric vehicle contains five-times more copper (battery, electric motor, and wiring) than an internal-combustion engine vehicle, and large volumes of copper will also be needed for power grid extensions and electric vehicle 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 electric vehicle batteries is moving toward higher nickel content to generate higher energy density.

The transition to cleaner fuels is impacting the ocean transport industry as well. New regulations implemented by the International Maritime Organization, known as IMO 2020, will restrict emissions of sulfur by marine vessels, and come into force on January 1, 2020. Vessel operators have three options to comply with the regulations: install scrubbers to remove the sulfur from ships' exhaust, thereby allowing the continued use of high-sulfur fuels; switch from using high sulfur fuel to a lower sulfur fuel, such as marine gasoil/diesel; or convert vessels to run on alternative fuels, such as liquefied natural gas. Most ships are expected to switch to using lower sulfur fuel. Although the impact of IMO 2020 on the energy mix used in ocean travel will be minimal, the regulation regarding sulfur emissions marks the beginning of an era of ocean transport regulation analogues to the emissions and efficiency standards regulation implemented in ground transport following the 1970s oil crises and, more recently, environmental concerns.

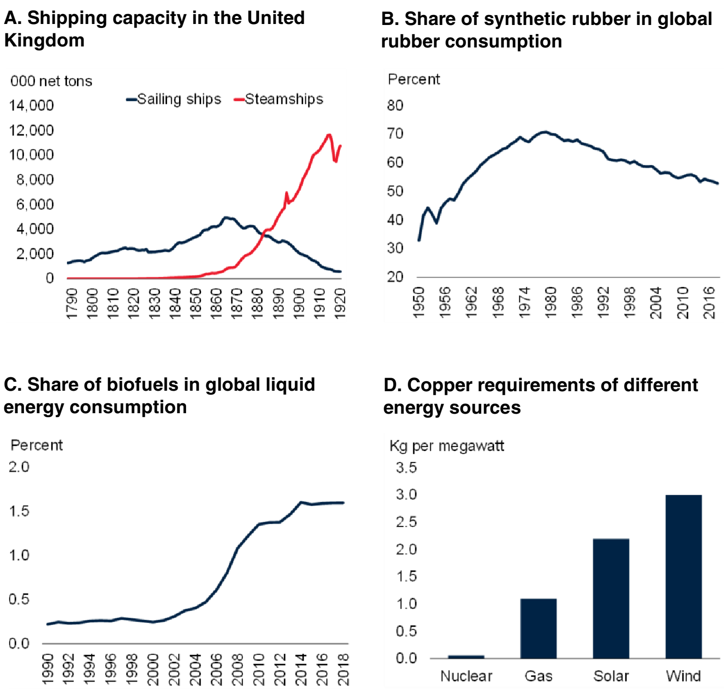
bunker fuel) and air transport (gasoline and jet kerosene). Recent innovations in battery technology and charging infrastructure coupled with environmental concerns are altering the landscape of the transportation industry once again, this time by the rapid growth of hybrid and electric vehicles.

Industrial and consumer products

Innovation and substitutability in various industrial and consumer products have been widespread since the mid-twentieth century. In response to scientific advancements in chemistry, especially petrochemicals, there has been considerable substitution of both agricultural and metal commodities by energy products and composite materials. Synthetic fibers, mostly derived from crude oil and natural gas, currently account for nearly two-thirds of global fiber consumption, while 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 total rubber consumption. Synthetic fertilizers (mostly nitrogen-based), a product of innovations in the early twentieth century, replaced natural nutrients and have become an indispensable part of food production. Plastics (derived from crude oil and natural gas) have penetrated a vast number of consumer products.

FIGURE SF.2 Innovation and substitution across commodity groups

The invention of the steam engine revolutionized ocean travel in terms of speed and carrying capacity but also altered the composition of commodity consumption. Wooden frames along with cotton- and linen-based sail cloth used in sail ships (all agricultural commodities) were replaced by steel frames (made from iron ore) and steam engines (running on coal instead of renewable energy, i.e., wind) used in steamers. Innovations in chemistry introduced numerous oil-based synthetic materials that displaced primary commodities. Synthetic rubber (made from crude oil) displaced natural rubber (agricultural commodity). Biofuels (made from maize, sugarcane, and edible oils, all agricultural commodities) are replacing crude oil. Copper (used in solar panels and wind turbines) is displacing the use of fossil fuels in electricity generation.



Source: BP Statistical Review, Mitchell (1988), World Bank, World Rubber Statistics Handbook.
A. Denotes ocean transport capacity of ships registered in the U.K.
B. Synthetic rubber is a substitute of natural rubber.
C. Consists mostly of maize- and sugar-based ethanol and edible oil-based biodiesel.
D. Denotes the amount of copper used in nuclear facilities, natural gas generation facilities, solar panels, and wind turbines.
Download data and charts.

In metals, copper has been increasingly replaced by plastic tubing in plumbing, while aluminum has displaced heavier materials in the manufacturing, construction, packaging, and transport sectors. In the beverage and food packaging sectors, there is large competition between aluminum, composites, glass, paper, plastic, tin, and other materials. Recent advances in information technology have also led to new types of substitution: paper (made from timber), which was used for information storage in the form of books, is being rapidly replaced by digital storage (which uses energy and metals in its processes). 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 devices and satellites, which use rare-earth metals and composite materials.

Commodity substitution: Empirical estimates

This section empirically examines the role of substitution in commodity consumption. The econometric exercise considers how demand for individual commodities responds to changes in their own price, and that of similar commodities. If substitution occurs between commodities, it is likely that an increase in the price of one commodity would result in an increase in demand for its close substitutes. As such, a negative coefficient for the price of another commodity may weakly indicate the presence of complementarity.[2] The exercise focuses on the two largest energy commodities (crude oil and coal) and two largest metals (aluminum and copper). It confirms that prices of substitute commodities are as important in explaining variations in commodity consumption as own prices. Detailed parameter estimates, which are based on a commodity demand model, are reported in the Appendix.

Energy

As noted earlier (and discussed below in Box SF.1), oil and coal are expected to be substitutes, given that both energy sources are used in electricity generation. Indeed, the results (reported in Table SF.1 and summarized in Figure SF.3) confirm such expectations. For oil, the coefficient on its own price is negative, as expected, suggesting demand falls (rises) as prices increase (decrease). The coefficient on the price of coal is positive, indicating substitution, since a rise in the price of coal results in an increase in demand for

[2] It is also possible for commodities to be complements, where an increase in demand for one commodity leads to an increase in demand for another. For example, some metals are combined into alloys (e.g., copper and zinc are alloyed to make brass).

oil. Likewise, for coal, the coefficient on the price of oil is positive, suggesting a rise in coal demand when oil prices increase, and indicating substitution. Coal's own price coefficient is negative, as expected, suggesting demand increases (decreases) as its price falls (rises). These findings confirm the pattern of replacing oil with other energy sources, notably coal, in electricity generation that began after the oil crises of the 1970s. Indeed, prior to 1979, oil's share in electricity generation was nearly 15 percent while in 2018 it was only 3 percent.

Metals

Detailed results for the two metals are reported in Appendix Table SF.2. For aluminum, while its own price is negative, as expected, the coefficient on the price of copper was not significantly different from zero, suggesting changes in its price have no impact on aluminum consumption. This is not surprising given the much larger volume of aluminum consumption relative to copper (Figure SF.1). In contrast, for copper, the coefficient of the price of aluminum was positive and significant, suggesting that when the price of aluminum rises (falls), demand for copper increases (decreases). This is consistent with the fact that copper has increasingly been replaced by lower priced aluminum in the electrical industry, particularly for high voltage electrical cables.

Conclusion

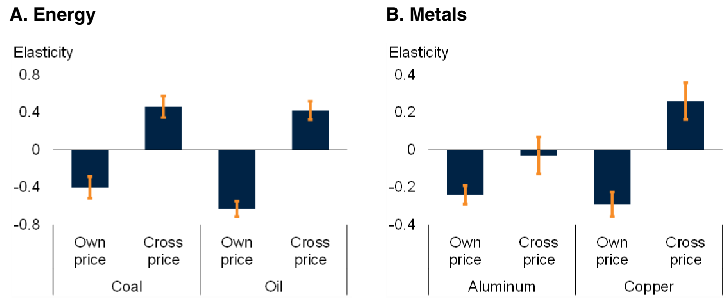
The *Focus* analyzed the role played by substitution in determining demand for different commodities. It documents the historical evolution of substitution and showed that it occurs both within commodity groups (for example, from coal to natural gas for energy), and across commodity groups (such as paper for plastic). The *Focus* also finds empirical evidence in favor of substitution among commodities, notably between oil and coal and between aluminum and copper.

The findings confirm that inter-commodity substitution means that demand surges for a single commodity typically set in motion market forces that result in a reallocation of resources, either through direct substitution, or through investment and innovation, thus ensuring that the world's commodity supply needs are met. 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. Furthermore, income growth is projected to continue, especially in EMDSs, albeit at a slower pace compared to the past two decades. Previous research has shown that EMDEs have high income elasticities of demand compared to advanced economies.

On the other hand, the production and consumption of commodities are often associated with environmental externalities, both at the local and global level. Local externalities are typically easier to address since they require policy actions by a single 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).

FIGURE SF.3 Own and cross-price elasticity estimates

Apart from income, prices of substitute commodities are as important in explaining the variation in commodity consumption as own prices. For example, a 10 percent increase (decline) in the price of coal is associated with 4 percent decline (increase) in coal consumption and 4.2 percent increase (decline) in oil consumption.



Source: Authors' calculations, BP Statistical Review, World Bank data, World Bureau of Metal Statistics.

A.B. Based on estimated long-run coefficients from autoregressive distributed lag estimation for up to 63 countries for 1965-2017 (Annex SF1.1). Blue bars denote elasticity estimates (i.e., a percent change in consumption in response to 1 percent change in income); yellow lines indicate 10 percent confidence intervals.

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Similarly, many countries implement recycling policies to reduce the amount of waste going to landfills. For global externalities, however, such as increased CO_2, ocean plastic waste, or water pollution, global policy actions are required. Because these externalities extend beyond the polluting country, the key policy concern is how to ensure that the production and consumption of commodities is environmentally sustainable rather than on ensuring commodity production meets growing demand.

APPENDIX TABLE SF.1 Parameter estimates for energy

	Coal		Oil	
y_t	-0.87 (0.64)	6.54*** (1.02)	1.81*** (0.37)	1.40*** (0.39)
y_t^2	0.08** (0.03)	-0.39*** (0.05)	-0.07*** (0.02)	-0.04* (0.02)
p_t^{COAL}	0.01 (0.06)	-0.40*** (0.07)	–	0.42*** (0.06)
p_t^{OIL}	–	0.46*** (0.07)	-0.41*** (0.03)	-0.63*** (0.05)
ρ	-0.09*** (0.02)	-0.09*** (0.01)	-0.07*** (0.01)	-0.07*** (0.00)
Log-likelihood	1,930	2,005	5,195	5,248
Observations	2,898	2,898	3,235	3,235
Countries	57	57	63	63

Note: The dependent variable is the logarithm 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.

APPENDIX TABLE SF.2 Parameter estimates for metals

	Aluminum		Copper	
y_t	3.98*** (0.39)	3.84*** (0.41)	3.67*** (0.67)	3.07*** (0.61)
y_t^2	-0.17*** (0.02)	-0.17*** (0.02)	-0.18*** (0.03)	-0.15*** (0.03)
$p_t^{ALUMINUM}$	-0.21*** (0.03)	-0.24*** (0.03)	–	0.26*** (0.06)
p_t^{COPPER}	–	-0.03 (0.06)	-0.27*** (0.04)	-0.29*** (0.04)
ρ	-0.26*** (0.03)	-0.26*** (0.02)	-0.13*** (0.02)	-0.14*** (0.02)
Log-likelihood	964	1,058	472	512
Observations	2,525	2,525	2,300	2,300
Countries	52	52	49	49

Note: The dependent variable is the logarithm of consumption of the respective commodity. Each commodity reports the "best fit" model. 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

A standard demand equation is used (Adeyemi and Hunt 2007; Burke and Csereklyei 2016; Crompton 2015; Evans and Lewis, 2005; Fernandez, 2018; Stuermer 2017):

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

where c_t denotes per capita commodity consumption at year t; y_t^2 is real per capita income; p_t is the real price of the commodity; X_t is a h x 1 vector of control variables, such as fixed effects and cross-price impacts; ε_t is the stochastic error term; and μ, θ_1, θ_2, θ_3 denote parameters and φ' a vector, all to be estimated. The quadratic income term, y_t, allows the calculation of income elasticities that vary across income levels (Baffes et al 2018). Most variables have been expressed in logarithmic terms.

The autoregressive-distributed lag model is estimated by a pool mean group estimation procedure (Pesaran, Shin, and Smith 1999). The 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 while the Bayesian information criterion (BIC) is invoked to determine the lag structure (Pesaran and Shin 1999).

The model is applied to two energy commodities (coal and oil) and two metals (aluminum and copper). Oil, which accounts for about one-third of global energy consumption (measured by energy content), is primarily used for transport and, to a lesser degree, industrial applications including petrochemicals. Most coal (27 percent share of global consumption) is used for electricity generation and less for industrial purposes. Aluminum, by far the most important base metal in volumetric terms (it accounts for 55 percent of global metal consumption), is used in transport, followed by construction, packaging, and electrical grids. Copper (22 percent share of global consumption) is used extensively in the electrical sector, including power cables, generators and motors, as well as in construction and electronics.

Annual data for 1965–2017 for up to 63 countries (depending on the commodity) were used. Data sources include the BP Statistical Review (coal and oil consumption), the St. Louis Federal Reserve Bank (exchange rates), World Bank's Commodity Price Data (world commodity prices, converted into real terms by using country-specific GDP deflators), World Bank's World Development Indicators (per capita income and exchange rates); and World Bureau of Metal Statistics (aluminum and copper consumption). Tables SF.1 and SF.1 report parameter estimates for energy and metals, respectively, both with and without cross-price effects.

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