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?

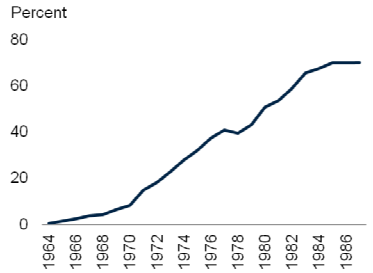
In the decade prior to 1972, global oil consumption was growing at almost 8 percent a year in response to the rapid post-war expansion of transport, industry, and electricity consumption. The expansion was aided by low oil prices (during 1945-72 oil prices averaged about $16/bbl in 2017 constant terms). 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)*

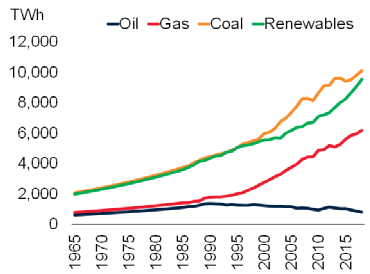
FIGURE BOX SF.1 Broad-based substitution across commodities

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.

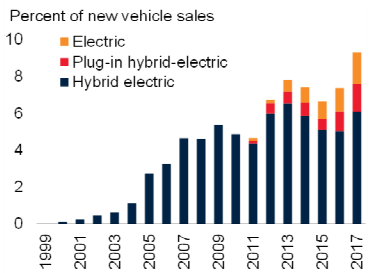
A. Proportion of packaged shipments of beer in aluminum cans in the U.S.



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).
Download data and charts.

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.