# Shifting Commodity Markets in a Globalized World

Editors

Rabah Arezki and Akito Matsumoto

INTERNATIONAL MONETARY FUND

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Cover design: IMF Multimedia Services Division

**Cataloging-in-Publication Data**
**Joint Bank-Fund Library**

Names: Arezki, Rabah, editor. | Matsumoto, Akito, editor. | International Monetary Fund.
Title: Shifting commodity markets in a globalized world / editors, Rabah Arezki and Akito Matsumoto.
Description: Washington, DC : International Monetary Fund, [2017] | Includes bibliographical references and index.
Identifiers: ISBN 9781484310328 (paper) | ISBN 9781484330715 (ePub) | ISBN 9781484330807 (Mobi) | ISBN 9781484330814 (PDF)
Subjects: LCSH: Commodity exchanges | Commodity futures. | Globalization.
Classification: LCC HG6046.S485 2017

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Recommended citation: Arezki, Rabah, and Akito Matsumoto, eds. 2018. *Shifting Commodity Markets in a Globalized World*. Washington, DC: International Monetary Fund.

ISBN 978-1-48431-032-8 (Paper)
978-1-48433-071-5 (ePub)
978-1-48433-080-7 (Mobipocket)
978-1-48433-081-4 (PDF)

Please send orders to:
International Monetary Fund, Publication Services
P.O. Box 92780, Washington, DC 20090, U.S.A.
Tel.: (202) 623-7430 Fax: (202) 623-7201
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Internet: www.elibrary.imf.org
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# Preface

Technology, demography, policies, and institutions are some of the forces that affect commodities such as energy resources, metals, and food. This book is based on research in the Commodities Unit of the IMF's Research Department and explores the interplay of these various forces across different commodity markets. These chapters analyze the forces driving commodity markets over the medium term and their interaction with the global economy.

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**Akito Matsumoto** is acting chief of the Commodities Unit in the IMF's Research Department. He has written on energy, commodities, and international economics, including for peer-reviewed journals, and has organized several conferences on these issues. He holds a Ph.D. from the University of Wisconsin.

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CHAPTER 1

# Introduction

The chapters in this book were prepared by the Commodities Unit of the Research Department of the IMF between 2014 and 2017, a period of great upheaval for global commodity markets. Individual chapters track developments and prospects for energy, metals, and food markets since the early 2000s, the start of what is termed a "commodities supercycle"—the rise of commodity prices over a decade or more as a result of a rapid urbanization and an expansion of infrastructure. The recent commodities supercycle coincides with the growth of large emerging market economies, specifically China and India. This book examines the complex and intertwined set of forces that affect various commodity markets and the complex interplay between these market forces and the broader global economy. Instead of focusing on short-term developments and their immediate causes, this analysis takes a longer view. It examines the relative importance of technology, geography, demography, and policy in each of these commodity markets and how their interplay sends price signals to producers and consumers, who in turn adjust their behavior.

## TECHNOLOGY

Macroeconomists often assume that technological innovation is exogenous (driven largely by external factors or forces), but this volume documents how innovation in energy markets is directly affected by prices. When oil, natural gas, or fossil fuels become scarce, prices increase. This stimulates innovation and the adoption of new technologies and techniques for recovery and use of these resources. Conversely, when these commodities are abundant, prices fall, slowing the pace of innovation and the adoption of new techniques. Deepwater extraction and high-efficiency vehicles are innovations developed during periods of high oil prices, as outlined in Chapter 2. Chapter 3 describes how the development of hydraulic fracturing for the recovery of natural gas from shale rock formations led to significant declines in the natural gas prices and a corresponding increase in the use of natural gas in manufacturing and power generation. Chapter 4 describes how a decline in fossil fuel prices led to an increase in the number of coal-fired power plants in Europe and increased the sale of gas-guzzling vehicles.

## GEOGRAPHY

At the heart of international trade in commodities are cross-country differences in resource endowments. Natural resources are materials or substances that occur in nature and can be used for economic gain, and so these include not only reserves of hydrocarbons, minerals, fisheries, and forests, but also temperate weather, fertile land, and access to water, which are important to agriculture.

A given country's geology and natural resources are largely predetermined, but its ability to exploit its endowments depends on institutional factors. The discovery of major mineral deposits in Latin America and sub-Saharan Africa in recent decades occurred following the liberalization of these economies.

This volume documents that the geography of trade in commodities has evolved as a result of shifts in both supply and demand. On the supply side, Chapter 5 documents how the supply of metals has shifted in recent years from the northern hemisphere (primarily advanced economies) to the southern hemisphere (largely emerging markets) with the depletion of longstanding reserves and the opening of potential new resources for exploration. On the demand side, the rise of large emerging markets has contributed to a rapid increase in global consumption that helped set off the recent commodities supercycle and shift demand for commodities from the western hemisphere and Europe to Asia.

## DEMOGRAPHY

The size and demographic structure of a country's population are closely linked to its pace of economic development. And economic development, in turn, affects the size and structure of the population—in general to reduce family size and increase the share of older people in the total population. This demographic transition also translates into changes in the geographic distribution of a country's population, with people migrating from rural to urban areas. These demographic and economic transitions obviously have important implications for the structure of agriculture and the demand for food products, but they also influence demand for metals and energy because of changes in the demand for housing and transportation services. Chapter 6 explores the implications of demography and urbanization for global food markets and food security.

## POLICY

Policies and regulations, including those designed to address environmental concerns and achieve food or energy security, may either counteract or exacerbate market forces, and they play a key role in commodity markets. One example from the energy market is the explosion of shale oil production in the United States, which was the result of a regulatory shock in the United States. Specifically, the Energy Policy Act of 2005 exempted the chemicals used in hydraulic fracturing from safe drinking water standards. This coincided with a period of high oil prices, driven by the rapid increase in demand from large emerging market economies, which helped spur innovation in hydraulic fracturing techniques as described in Chapter 3.

Trade policy instruments such as export and import tariffs, subsidies, and quotas have significant effects on global food markets and serious distributional consequences for consumers. Food has been a longstanding sticking point in trade negotiations, despite the fact that food represents a relatively small share of global trade. Tariff and nontariff barriers to trade in agricultural commodities are often motivated by concerns over food sovereignty (that is, preserving domestic production capabilities for key foodstuffs) and protecting the well-being of domestic farmers. All countries continue to have a strong anti-trade bias in the structure of assistance to their agricultural sector, and there are multifaceted distortions to global food markets as described in Chapter 6.

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PART I

# Energy Markets

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## CHAPTER 2

# Technology and Unconventional Sources in the Global Oil Market

*Technological factors played an important role in the collapse of oil prices that started in June 2014. Macroeconomists often assume that technological innovation results from independent, external forces (is exogenous), but in oil markets innovation is driven by prices. Indeed, high oil prices prompted breakthroughs in technology in extractive industries and led to the emergence of new sources known as "unconventional oil." Shale oil in particular has important consequences for the oil market outlook in that it not only significantly increases supply but also contributes to more limited and shorter production and price cycles.*

Technology has transformed the oil market in powerful ways. Technological innovation and the subsequent adoption of new recovery techniques—including for drilling and processing—have given rise to new sources known as "unconventional oil." One recent example is shale oil (also known as tight oil), which has become a major contributor to global oil supply. Provided they are effective and widely adopted, improvements in recovery techniques mechanically increase the size of technically recoverable oil reserves. This increase, in turn, changes the outlook for oil supply—with potentially large and immediate implications for oil prices—by changing expectations about the future path of oil production. Increased supply lowers oil prices, but even if this has the effect of reducing investment and hence production, the industry is nonetheless forced to become more efficient, unleashing automatic stabilization forces.

Innovation in recovery techniques typically follows periods of prolonged high prices or changes in regulations that render new techniques more economical. New oil sources often come onstream in times of need—because of, say, the depletion of existing conventional sources—and in places that have economic and institutional systems more favorable to both innovation and the adoption of new recovery techniques. Innovation has led to significant improvements in drilling techniques in particular. The advent of hydraulic fracturing and directional (non-vertical) drilling gave rise to the production of shale oil in the 2000s by allowing for the capture of oil trapped within layers of rock. In the wake of the two oil crises of the 1970s, which dramatically increased oil prices, successive

Prepared by Rabah Arezki (team leader), Claudia Berg, Christian Bogmans, Rachel Yuting Fan, and Akito Matsumoto (team co-leader), with research assistance from Clara Galeazzi and Lama Kiyasseh. The authors thank Rystad Energy and Per Magnus Nysveen in particular for very useful discussions and for kindly providing proprietary data on capital expenditures and cost structures.

improvements in techniques for deepwater drilling spurred production in the North Sea and the Gulf of Mexico. In both these examples innovation opened new oil sources from relatively high-cost producers and gave rise to tensions with the lower-cost producers from the Organization of Petroleum Exporting Countries (OPEC), who in the 1980s and again more recently responded by strategically moderating their production levels.

This chapter addresses four questions about the role of technology and unconventional oil sources in the global oil market:[1]

- What constitute unconventional oil sources?
- Where are the production and reserve centers?
- How have investment and production evolved?
- What lies ahead?

## WHAT CONSTITUTE UNCONVENTIONAL OIL SOURCES?

Today's unconventional oil sources are extra-heavy oil extracted from oil sands, shale (or tight) oil, and ultra-deepwater oil.[2] Unconventional oil is typically more difficult and more expensive to extract and process than conventional oil. The categorization is, of course, time specific because the sources of oil evolve along with improvements in recovery techniques. "Conventional oil" used to refer only to light crude that was easily captured by tapping into a reservoir. But the term now often applies also to heavy oil and deepwater oil, which were once considered unconventional. To give a historical perspective on how "new" oil sources have contributed to the evolution and transformation of the oil market, this chapter adopts a broad, all-encompassing definition of unconventional sources, including those no longer considered unconventional (such as heavy and deepwater oil).

- Oil sands are either loose sands or partially consolidated sandstone containing a naturally occurring mixture of sand, clay, and water saturated with a dense and extremely viscous form of petroleum referred to technically as bitumen and colloquially as tar because of its superficially similar appearance. Heavy and extra-heavy oil are characterized by high viscosity, high density, and high concentrations of nitrogen, oxygen, sulfur, and heavy metals. These characteristics raise the costs of extraction, transportation, and refining. Despite the cost and technical difficulties, major oil corporations regard these resources as providing reliable long-term flows of liquid hydrocarbons with substantial payoffs for any incremental improvements in recovery. However, there are environmental concerns about potential

[1]The focus of this feature is on oil, which refers here to liquids including crude oil, condensate, and natural gas liquids.

[2]See Kleinberg (forthcoming) for a discussion of unconventional sources.

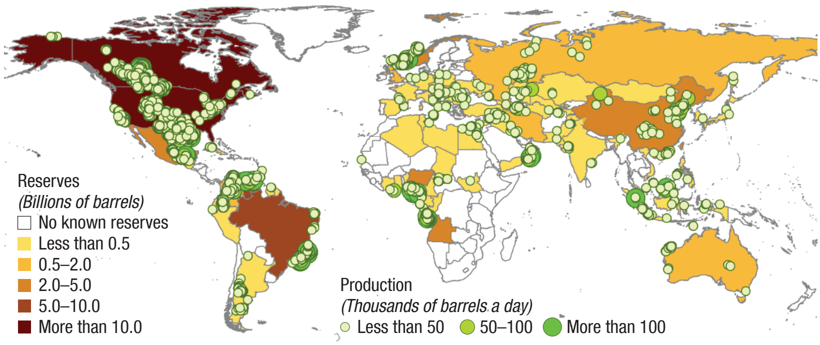
damage from extracting and refining these new oil sources, which have often been met with specific safety regulations and standards meant to help limit the risks.

- Shale oil (also known as tight oil) is petroleum that consists of light crude oil contained in petroleum-bearing rock formations of low permeability, often shale or tight sandstone. The widescale exploitation of shale oil began with the development of shale gas extraction using a combination of hydraulic fracturing, also called fracking, (a well-stimulation technique in which rock is fractured by a hydraulically pressurized liquid) and directional drilling (the practice of drilling nonvertical wells). These gas-recovery techniques were later widely adopted by the oil industry, primarily in the United States. Shale oil sources are developed by relatively smaller corporations. Shale oil also has a different cost structure: there are lower sunk costs than for conventional oil, and the lag between initial investment and production is much shorter.
- Deepwater and ultra-deepwater oil involve offshore production activities that take place at depths of more than 125 meters and 1,500 meters, respectively. Successive improvements in drilling techniques have allowed drilling much farther from coastlines and to much greater depths. The offshore rigs used for ultra-deepwater oil drilling differ very significantly from the rigs used for deepwater drilling: ultra-deepwater rigs are partially submerged in water and can involve dynamic positioning systems, or they can be drill ships—self-propelled offshore drilling rigs that can work beyond a depth of 3,000 meters. Although it has high fixed costs, ultra-deepwater drilling can deliver a steady stream of oil for a very long period, which makes these assets attractive to major international oil corporations.

## WHERE ARE THE PRODUCTION AND RESERVE CENTERS?

Production and reserve centers for unconventional sources are concentrated in a few countries. North America has the highest concentration of economically recoverable proven reserves and production in unconventional sources (Figure 2.1; Table 2.1). These consist of shale oil in the United States and oil sands in Canada. Central and South America also host significant reserves and production centers, comprising heavy and extra-heavy oil and deepwater and ultra-deepwater oil resources in Brazil, Colombia, Ecuador, and Venezuela. The remainder of world reserves and production of unconventional sources are scattered and consist primarily of heavy oil in Europe and deepwater and ultra-deepwater oil in the North Sea and waters off west Africa. It is noteworthy that the Middle East has the highest concentration of conventional oil reserves and production but has a relatively low level of proven reserves and production in unconventional oil.

**Figure 2.1. Unconventional Oil, Proven Reserves and Production, 2016**




Sources: Rystad Energy research and analysis; and IMF staff calculations.
Note: Production and reserves include: oil sands, heavy, extra heavy, tight and shale, deepwater, and ultra-deepwater oil. A proven reserve is one with a greater than 90% probability that the resource is recoverable and economically profitable. Deepwater is defined at 125–1500 meters. Ultra deepwater is defined at 1500 meters and above. When deepwater (or ultra-deepwater) production was also categorized as heavy (or extra heavy) oil, the production was counted once, as deepwater (or ultra-deepwater). Oil refers to crude oil, condensate, and natural gas liquids.

In addition to physical geology, the high concentration of unconventional proven reserves and production reflects the geographical distribution of innovation and the subsequent adoption of new recovery techniques, which in turn reflects the levels of investment in exploration and extraction. Resource economists have long argued that, conceptually, the resource base is uncorrelated to the level of effort applied to explore resources.[3] Knowledge about the actual geology is gained through exploration efforts and constantly evolves with technological improvements. In other words, proven reserves and production are governed as much by economic and institutional factors (above-ground factors) as by actual geology (below-ground factors).

Economic factors affecting the geography of exploration and production include proximity to markets and complementarities with available infrastructure. These factors often lead to agglomeration in both production and proven reserves.[4] Institutional factors affecting exploration and production include

[3]In the exploration model developed by Pindyck (1978), a social planner maximizes the present value of the social net benefits from consumption of oil, and the reserve base can be replenished through exploration and discovery of new fields. Resource exploration and discovery has been investigated either as a deterministic or a stochastic process (see, for example, Pindyck 1978, Arrow and Chang 1982, and Devarajan and Fisher 1982).

[4]Moreno-Cruz and Taylor (2016) propose a spatial model of energy exploitation that determines how the location and productivity of energy resources affect the distribution of economic activity across geographic space. They find that a novel scaling law links the productivity of energy resources to population size, whereas rivers and roads effectively magnify productivity. Arezki and Bogmans

**TABLE 2.1.**

## Unconventional Oil Production, 2016

*(Million barrels a day)*

| Country | Heavy Oil | Oil Sands and Extra Heavy oil | Deepwater | Ultra-Deepwater | Shale and Tight Oil | Total |
|---|---|---|---|---|---|---|
| United States | 0.07 | 0.40 | 0.77 | 0.79 | 7.25 | 9.28 |
| Canada | 0.08 | 2.60 | — | — | 0.60 | 3.28 |
| Brazil | 0.03 | 0.09 | 1.09 | 1.18 | — | 2.39 |
| Angola | 0.00 | — | 1.34 | 0.16 | — | 1.50 |
| Norway | 0.02 | — | 1.36 | — | — | 1.39 |
| China | 0.73 | 0.36 | 0.08 | 0.01 | 0.03 | 1.21 |
| Venezuela | 0.18 | 1.00 | — | — | — | 1.18 |
| Nigeria | 0.08 | 0.00 | 0.83 | — | — | 0.91 |
| Mexico | 0.31 | 0.48 | 0.01 | — | 0.00 | 0.80 |
| Azerbaijan | 0.01 | 0.00 | 0.72 | — | — | 0.74 |
| Colombia | 0.13 | 0.50 | — | — | 0.00 | 0.63 |
| Oman | 0.12 | 0.30 | — | — | 0.01 | 0.43 |
| United Kingdom | 0.05 | — | 0.29 | — | — | 0.34 |
| Russia | 0.19 | 0.10 | — | — | — | 0.30 |
| Ecuador | 0.20 | 0.01 | — | — | — | 0.21 |
| Malaysia | 0.01 | 0.01 | 0.16 | — | — | 0.19 |
| Australia | — | 0.01 | 0.16 | — | 0.00 | 0.17 |
| Equatorial Guinea | — | — | 0.17 | — | — | 0.17 |
| Republic of Congo | — | 0.01 | 0.16 | — | — | 0.17 |
| Indonesia | 0.01 | 0.14 | 0.00 | — | — | 0.15 |
| Kazakhstan | 0.06 | 0.09 | — | — | — | 0.15 |
| Argentina | 0.08 | 0.01 | — | — | 0.04 | 0.13 |

Sources: Rystad Energy research and analysis; and IMF staff calculations.

Note: Deepwater is defined as 125–1,500 meters. Ultra-deepwater is defined as 1,500 meters and above. When deepwater (or ultra-deepwater) production was also categorized as heavy (or extra-heavy) oil, the production was counted once, as deepwater (or ultra-deepwater). Oil refers to crude oil, condensate, and natural gas liquids. Dash denotes zero production in record.

openness to foreign investment and the strength of property rights, including in subsoil assets. Arezki, van der Ploeg, and Toscani (2016) provide empirical evidence of a causal—and economically significant—relationship running from changes in market orientation to discoveries of major hydrocarbon and mineral deposits, over and above increases in resource prices and depletion rates.

The observed differences between known reserves and production across countries reflect differences in production efficiency. These differences can be explained by institutional factors emanating from the ownership structure of the industry. For instance, Wolf (2009) provides evidence that the structure of ownership in the oil sector—that is, the existence of state-owned operators—plays a key role in determining relative efficiency. He finds that, all else equal, non-state-owned oil corporations significantly outperform state-owned ones. Difficulties with production systems can lead to a low propensity to produce from existing reserves. To exploit unconventional sources, oil companies must be able to innovate or to implement new techniques.

(2017) provide evidence for the role of proximity to major markets and state capacity in the production of fossil fuels.

Regulatory changes also play a central role in determining the occurrence of innovation and the subsequent adoption of recovery techniques. Consider shale oil in the United States. The existence of large reserves of oil—and gas—in shale formations in the United States was well known long ago, and shale oil production was attempted several times, first in the mid-nineteenth century. Until the mid-2000s, however, extracting oil from shale rock formations was not cost-competitive with other sources. In part a response to price rises driven by the rapid increase in demand from emerging market economies such as China and India, the advent of shale oil production was also the consequence of a regulatory shock in the United States. The expansion of shale oil extraction was aided by a landmark study conducted by the U.S. Environmental Protection Agency in 2004, which found that hydraulic fracturing posed no threat to underground drinking water supplies. Shortly thereafter, with passage of the Energy Policy Act of 2005, chemicals used in hydraulic fracturing were exempted from Safe Drinking Water Act regulations (Gilje, Loutskina, and Strahan 2016).

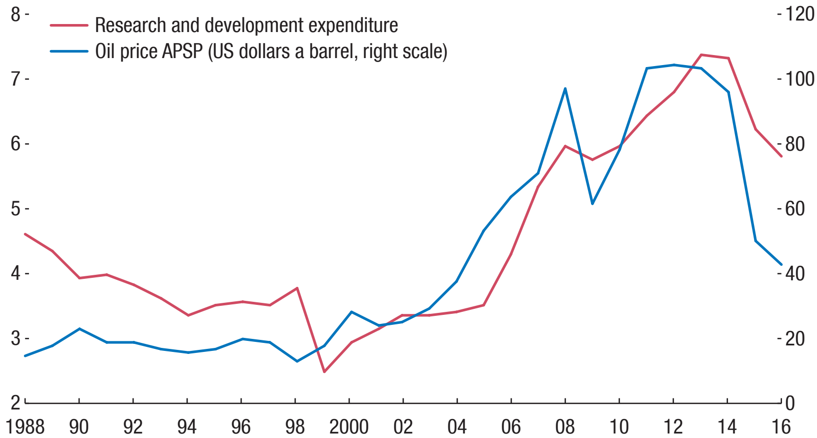
Shale oil deposits have been identified in several other countries, including Argentina, Australia, Canada, China, Mexico, and Russia. However, except for Argentina and Canada, where shale oil production is gearing up, regulatory obstacles and technological challenges, as well as the fall in oil prices, have delayed or discouraged extraction. Most regulatory obstacles relate to environmental concerns, including water supply quality, and to the need to tailor fracking techniques to more complex rock formations.[5] Some countries have gone so far as to ban all exploration and production of shale oil. Overall, the extent to which shale oil production will diffuse globally remains uncertain, contributing to broader uncertainty about the global oil supply outlook.

## HOW HAVE INVESTMENT AND PRODUCTION EVOLVED?

The adage “necessity is the mother of invention” illustrates the cyclical nature of technological change (Hanlon 2015). The direction of technical change is biased toward specific needs, depending on prevailing forces (Acemoglu 2002). In the oil sector, the need to address the rapid depletion of conventional oil reserves in certain locations and the resulting periods of high oil prices have fostered improvements in recovery techniques. Episodes of high prices have been accompanied by significant increases in research and development expenditures, mostly on the part of major corporations, though at times by smaller corporations (Figure 2.2). The current low-price environment provides few incentives for research into oil-recovery techniques. Lindholt (2015) finds that technological improvements resulting from research and development activity have offset the effects of ongoing depletion on the cost of finding and developing additional reserves of oil around the world. However, he finds that over a longer period,

[5]See *Nature Climate Change* (2013) for a discussion of the pros and cons of fracking.

**Figure 2.2. Evolution of Research and Development Expenditure in Selected Integrated Oil and Service Companies**
*(Billions of US dollars, unless noted otherwise)*




Sources: IMF, Primary Commodity Price System; Bloomberg Finance L.P; and IMF staff calculations.
Note: APSP = average petroleum spot price—average of UK Brent, Dubai, and West Texas Intermediate, equally weighted. The companies included are Baker Hughes, BP PLC, Chevron, ExxonMobil Corporation, Halliburton Company, Royal Dutch Shell PLC, Total SA, and Schlumberger Ltd.

depletion generally outweighs technological progress, most likely because technical improvements are cyclical whereas depletion is constant.[6]

The so-called peak oil theory predicted that oil production would top out in the mid-2000s, but this is precisely when the shale revolution began. In many respects, that revolution can be viewed as an endogenous supply response to high prices in the 2000s and hence a challenge to the overly pessimistic view that geological factors limit supply (Arezki and others 2017).[7]

Historically, global investment and operational expenditures in unconventional oil have closely followed oil price developments (Figure 2.3).[8] During episodes of

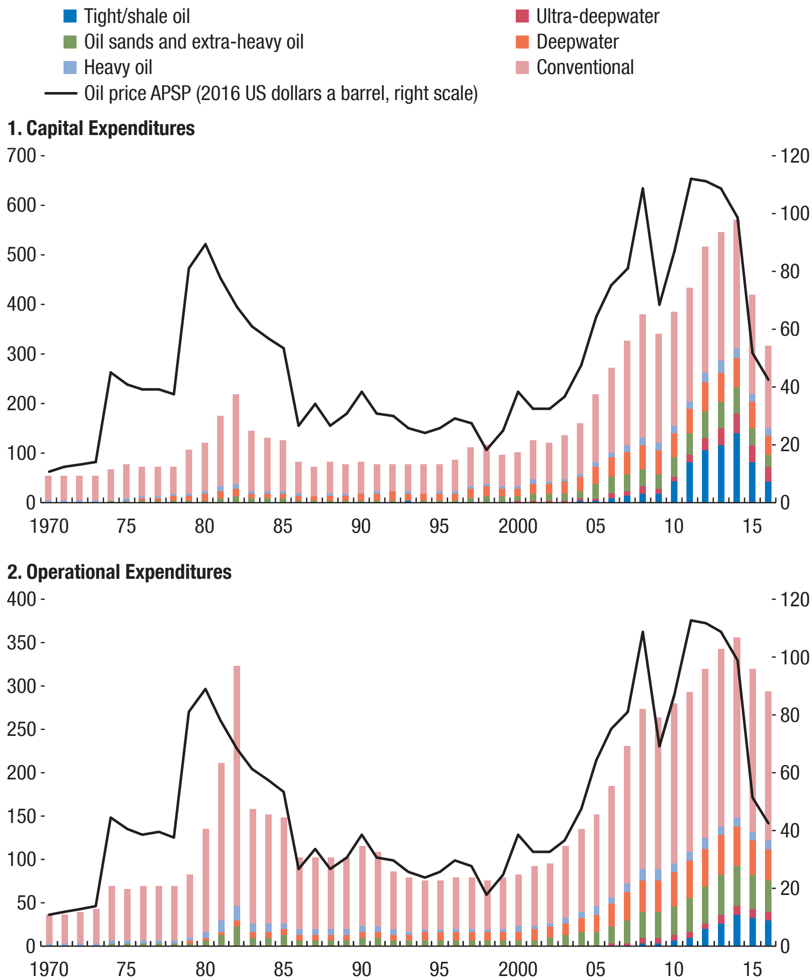
[6]For the Gulf of Mexico, Managi and others (2004, 2005, 2006) use microlevel data from 1947–98 and find empirical support for the hypothesis that technological change has offset depletion for offshore oil and gas production. For the United States, Cuddington and Moss (2001) present evidence that technological improvements respond to instances of scarcity by analyzing the determinants of the average finding cost for additional petroleum reserves over the period 1967–90.

[7]High oil prices also stimulate technological change in the energy-using sector. Aghion and others (2016) provide evidence that firms in the auto industry tend to innovate more in “clean” (and less in “dirty”) technologies when they face higher fuel prices. The current lower-for-longer oil price environment could, however, delay the energy transition by slowing technological change—and subsequent adoption—directed toward moving away from fossil fuel use (Arezki and Obstfeld 2015).

[8]Investment and oil price series are deflated using a price index of US private fixed investment in mining and oilfield machinery obtained from the Bureau of Economic Analysis (www.bea.gov).

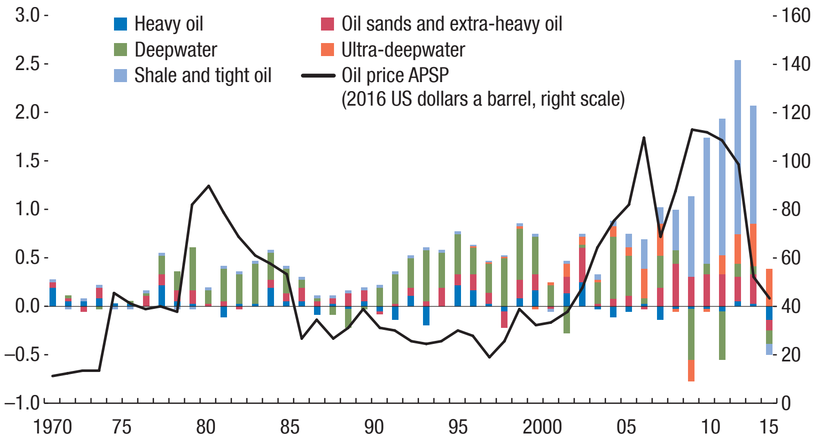
**Figure 2.3. Historical Evolution of Global Capital and Operational Expenditures**

*(Billions of constant 2016 US dollars, unless noted otherwise)*




Sources: IMF, Primary Commodity Price System; IMF, International Financial Statistics (IFS) database; Rystad Energy research and analysis; and IMF staff calculations.
Note: APSP = average petroleum spot price—average of UK Brent, Dubai, and West Texas Intermediate, equally weighted. Capital expenditure includes exploration costs associated with seismic surveys and drilling wildcats or appraisal wells to discover and delineate oil and gas fields, and all development costs related to facilities and drilling of wells. Operational expenditure includes operational expenses directly related to oil and gas activities. The costs are estimated at asset level and calibrated against company-reported values. Deepwater is defined as 125–1,500 meters. Ultra-deepwater is defined as 1,500 meters and above. When deepwater (or ultra-deepwater) production was also categorized as heavy (or extra-heavy) oil, the production was counted once, as deepwater (or ultra-deepwater). Oil refers to crude oil, condensate, and natural gas liquids. CAPEX = capital expenditures; OPEX = operational expenditures.

**Figure 2.4. Growth in Unconventional World Oil Production and Real Oil Prices**
*(Million barrels a day, unless noted otherwise)*

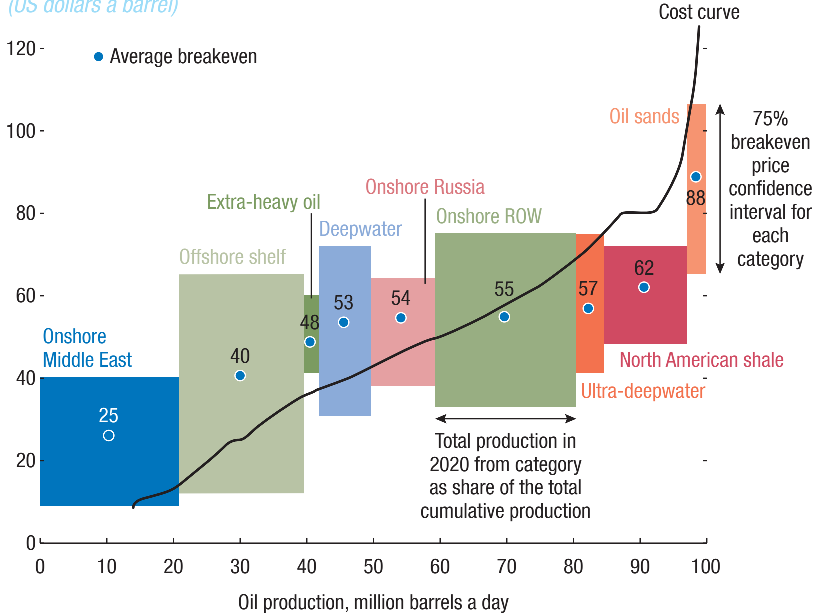



Sources: Bureau of Economic Analysis; IMF, Primary Commodity Price System; Rystad Energy research and analysis; and IMF staff calculations.
Note: APSP = average petroleum spot price—average of UK Brent, Dubai, and West Texas Intermediate, equally weighted. Total world production in 2016 was estimated at 96.5 million barrels a day. Deepwater is defined as 125–1,500 meters. Ultra-deepwater is defined as 1,500 meters and above. When deepwater (or ultra-deepwater) production was also categorized as heavy (or extra-heavy) oil, the production was counted once, as deepwater (or ultra-deepwater). Oil refers to crude oil, condensate, and natural gas liquids.

dramatic price movements, as in the late 1970s, investment in the oil sector responded promptly. In late 2008, during the global financial crisis, oil investment plummeted but then rebounded in 2009 following the sharp albeit temporary drop in oil prices. This episode marks an unprecedented increase in global capital expenditure and reflects a prolonged era of high oil prices. The rapid increase in oil demand, especially from large emerging market economies such as China and India, drove oil prices up and encouraged further investment in tight oil formations, ultra-deepwater oil, and extra-heavy oil, all of which were uneconomical at lower oil prices. Comovement between oil prices and capital expenditure is similar for both unconventional sources and conventional sources, but expenditure in unconventional sources embodies technological changes that contribute to changing the response of global oil production. Shale oil requires a lower level of sunk costs than conventional oil, and the lag between initial investment and production is much shorter. Shale oil thus contributes to shorter and more limited oil price cycles (Arezki and Matsumoto 2016).

The unprecedented increase in capital expenditure in unconventional sources in the 2000s made these sources central to the global oil market. Shale oil in

**Figure 2.5. Global Oil Supply Cost Curve and Breakeven Prices**
*(US dollars a barrel)*



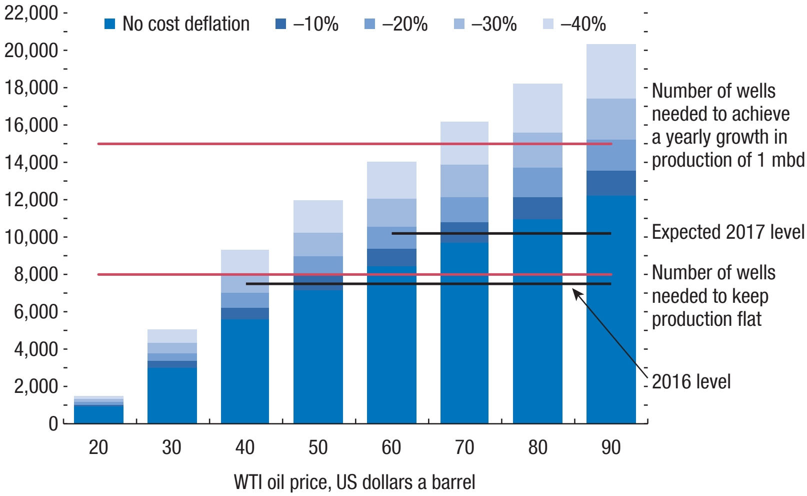

Sources: Rystad Energy research and analysis; and IMF staff calculations.
Note: The breakeven price is the Brent oil price at which the net present value equals zero, considering all future cash flows, using a real discount rate of 7.5%. Oil refers to crude oil, condensate, and natural gas liquids. NAM = North America; ROW = rest of world.

particular has been a major contributor to global supply growth (Figure 2.4).[9] The rapid increase in unconventional sources also helped spur a change in OPEC's strategic behavior, leading to the dramatic collapse in oil prices (Arezki and Blanchard 2014). Although that abrupt decline in prices led in turn to a reduction in investment and expenditure, the large operational efficiency gains already realized acted as automatic stabilizers.

The downward shift in the cost structure induced by lower oil prices is partly temporary. This goes against a commonly held belief that the cost structure—which is often proxied by the breakeven price, or the price at which it is economical to produce a barrel of oil—is constant and driven by immutable factors, such as the nature of the oil extracted and the associated geology (Figure 2.5). In practice, the cost structure depends on a host of factors, including technological improvements and the extent of "learning by doing," which both permanently reduce costs. In some instances, breakeven prices have fallen in sync with oil prices. That type of shift is explained by operational efficiency gains that

[9]In 2016, shale oil added 7.9 million barrels a day (mbd) in a market of 96 mbd—4.4 mbd in crude oil, 2.7 mbd in natural gas liquids, and 0.8 mbd in condensate.

**Figure 2.6. North American Shale Oil Wells at Various West Texas Intermediate Oil Prices and Cost Deflation Scenarios**
*(Annual number of wells)*



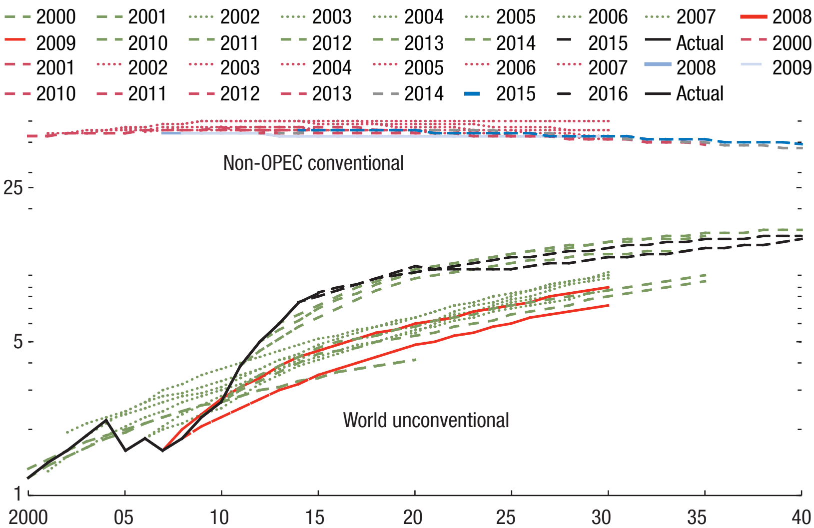

Source: Rystad Energy research and analysis.
Note: mbd = million barrels a day. Refers to spudded wells, defined as wells that are drilled but not extracted. At $60 a barrel, approximately 8,000 shale wells must be drilled, with 10 percent cost deflation, to keep production flat. WTI = West Texas Intermediate.

help the service industries that support oil production (infrastructure, drilling supplies, transportation, storage, and the like) significantly reduce their costs. For shale oil specifically, the extraordinary resilience to the decline in oil prices can be explained by such important efficiency gains and also by the fact that shale production came online at the onset of an investment cycle in which learning by doing was important (Figure 2.6).[10] The shale cost structure is likely to shift back up somewhat because some of the efficiency gains cannot be sustained with an expansion of oil production and with the cost of capital increasing, as it is expected to do as U.S. interest rates rise.

The shift in cost structure has not been uniform across unconventional sources. Oil sands production costs have continued to grow at high rates, in part because of the high costs of decommissioning a processing plant. At the same time, there has been less investment in exploring new fields, and this is expected to lower oil sands production in the future. Deepwater and ultra-deepwater oil production have been subject to active upgrading which has made them

[10]Figure 2.6 indicates that under a scenario of no cost deflation, the oil price level required to keep shale production constant is higher than $80 a barrel. With cost deflation of about 40 percent, about what it has been in the recent past, the required price level is only $40 a barrel. The recent rally in oil prices has been followed by signs of recovery in investment and production.

**Figure 2.7. Unconventional and Conventional Oil Production Outlook Vintages**
*(Million barrels a day, logarithmic scale)*




Source: International Energy Agency.
Note: Reproduced by permission from Wachtmeister, Henke, and Höök 2017. Dates correspond to vintages from forecast. OPEC = Organization of the Petroleum Exporting Countries.

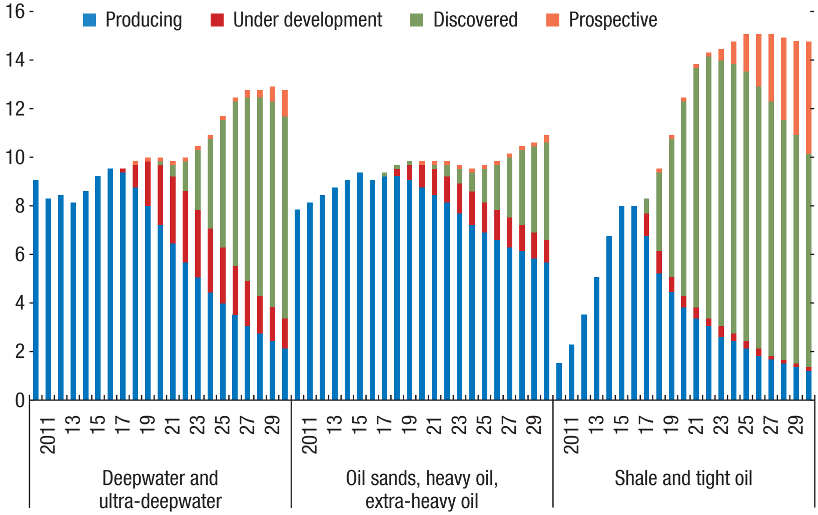
somewhat resilient to price changes. Here again, lower investment in new fields will likely affect future deepwater and ultra-deepwater oil production, albeit with different patterns across regions owing to below- and above-ground factors.

## WHAT LIES AHEAD?

The development of unconventional oil sources is inherently uncertain, which becomes apparent when comparing the ability to forecast unconventional relative to conventional production (Figure 2.7).[11] Technological improvements and their subsequent adoption—including the extent of learning by doing and the geographic diffusion of new techniques—are hard to predict, owing to the interaction between below- and above-ground factors. All in all, the rising importance of unconventional sources in global supply is not only changing the dynamic response of production to prices, it is also creating more uncertainty about the medium-term forecasts.

[11]The International Energy Agency (IEA) does not provide specific forecasts for oil production by OPEC. Wachtmeister, Henke, and Höök (2017) present a detailed assessment of the production forecast prepared by the IEA using a narrower definition of unconventional oil sources. Leduc, Moran, and Vigfusson (2013) present evidence of the rather gradual learning in futures markets.

**Figure 2.8. Unconventional Oil Outlook**
*(Million barrels a day)*




Sources: Rystad Energy research and analysis; and IMF staff calculations.
Note: Deepwater is defined as 125–1,500 meters. Ultra-deepwater is defined as 1,500 meters and above. When deepwater (or ultra-deepwater) production was also categorized as heavy (or extra-heavy) oil, the production was counted once, as deepwater (or ultra-deepwater). Oil refers to crude oil, condensate, and natural gas liquids.

Added to the uncertainty about technological improvements is uncertainty about the likely output by suppliers of conventional oil. In September 2016 OPEC negotiated an agreement to reduce oil production by 1.8 million barrels a day (mbd) originally for six months that was latter extended for another six months. In principle, this would help rebalance the market by the end of 2017, eliminating an excess supply estimated to be a little less than 1 mbd. In practice, rebalancing oil supply with demand accompanied by stable prices will hinge on the prospects for unconventional sources (Figure 2.8). Annual oil demand growth is commonly projected to be about 1.2 mbd, and this will be met over the next few years by unconventional sources, mainly resources under development for deepwater and ultra-deepwater oil, oil sands, and heavy and extra-heavy oil.

Without the increase in shale oil supplies, depletion forces and the legacy of low investment would start to kick in and push prices up significantly in a few years. Instead, in the new normal for the oil market, shale oil production will likely be further stimulated by a moderate price increase (Arezki and Matsumoto 2016). As a result, supply from shale will help moderate what would otherwise be a sharp upward swing in oil prices. Over the medium term, as prices increase further, technical improvements in unconventional oil recovery will be reactivated, which will eventually set off another price cycle.

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## CHAPTER 3

# Structural Changes in Natural Gas Markets

*Natural gas markets are much less integrated than oil markets, a reflection of the cost and logistical difficulty of trading gas across borders. This results in substantial price differences across regions despite increasing liquefied natural gas trade. Global natural gas production and consumption have increased steadily over time and are projected to increase even more rapidly in the medium term. Three major historical developments have had particularly important implications for gas and energy markets: the shale gas revolution in the United States starting in the 2000s, the reduction in nuclear power supply after the Fukushima disaster in Japan in 2011, and the geopolitical tensions between Russia and Ukraine from the mid-2010s. These developments not only had profound effects on regional prices but also revealed specificities about the structure of natural gas markets. Natural gas could constitute a bridge from coal and oil to renewables during the so-called energy transition.*

Natural gas is a cleaner fossil fuel than either petroleum products or coal and does not present the potential environmental liabilities associated with nuclear energy generation. Despite these advantages, the cost and logistical difficulty of trading gas across borders leave natural gas markets much less integrated than oil markets. Shipping or transporting natural gas requires either costly pipeline networks or infrastructure and equipment for liquefying (compressing) the gas, dedicated vessels for transport, and then facilities for regasification at the destination. The lack of integration of gas markets leads to substantial price differences across regions. These have been exacerbated by the U.S. shale gas boom in the 2000s and the Fukushima nuclear disaster in Japan in 2011, despite the growth of trade in liquefied natural gas (Figure 3.1).[1]

Technological improvements in exploration and drilling activities have enabled both new discoveries and exploitation of previously identified reserves of natural gas, and there are many more prominent producers of natural gas today

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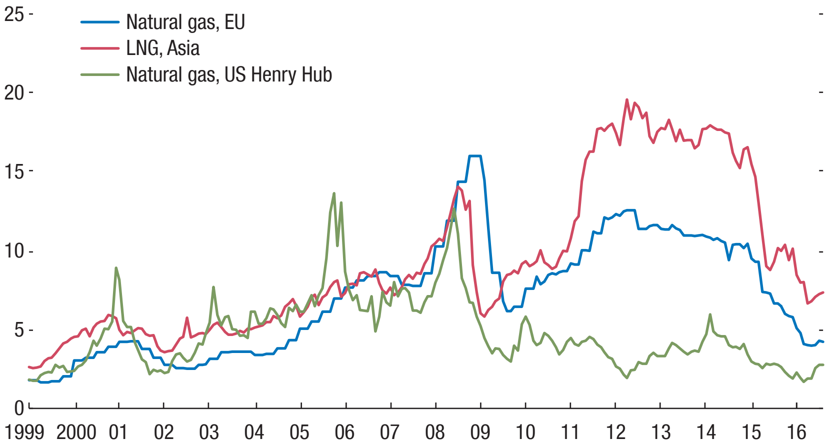
[1]Because of the sector's high capital intensity, natural gas suppliers tend to enter long-term contracts with customers. Prices are indexed to crude oil prices, which introduces rigidities on the price side.

**Figure 3.1. Natural Gas Prices**
*(US dollars a million British thermal units)*




Source: IMF, Primary Commodity Price System.
Note: EU = European Union; LNG = liquified natural gas; US = United States.

than there were in the 1990s.[2] Iran, Russia, Qatar, Turkmenistan, and the United States had the largest reserves of natural gas in 2015. The largest producers of natural gas in 2015 were the United States and Russia, followed by Iran, Qatar, and Canada (Table 3.1).

Natural gas consumption has risen steadily over time and in 2015 accounted for nearly 25 percent of global primary energy consumption, whereas the share of oil has declined rapidly, from 50 percent in 1970 to about 30 percent in 2015. Global natural gas demand is projected to increase strongly in the medium term (IEA 2014), with countries outside the Organisation for Economic Co-operation and Development (OECD) accounting for the bulk of the growth. Natural gas usage faces competition from substitutes for natural gas in all sectors, particularly from renewables and coal in power generation, in part because of subsidies and gas-pricing regimes. In addition, the implementation of widespread carbon taxation would tilt demand from coal toward natural gas and eventually from natural gas toward renewables. On the other hand, natural gas can complement the use of renewables, particularly to compensate for intermittency—at least while battery technology remains insufficient. Natural gas is also expected to make further inroads as a transportation fuel, including the use of liquefied natural gas for commercial trucks, passenger vehicle, and marine vessels.

[2]An index of diversification in global gas supplies shows a steady increase in the extent of diversification (Cohen, Joutz, and Loungani 2011).

**TABLE 3.1.**

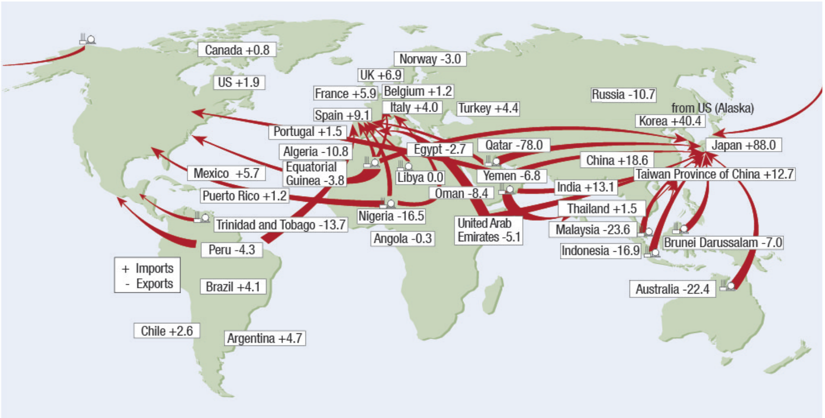
**Production and Consumption of Fossil Fuels and Natural Gas by Country, 2007 and 2015**

| **Fossil Fuels** | | |
|---|---|---|
| **Proven Reserves** | **2007** | **2015** |
| Oil (billion barrels) | 1,419 | 1,696 |
| Natural Gas (trillion cubic meters) | 162 | 186 |
| Coal (million tons) | n.a. | 891,531 |
| **Production** | **2007** | **2015** |
| Oil (thousand barrels a day) | 82,277 | 91,670 |
| Natural Gas (billion cubic meters) | 2,965 | 3,539 |
| Coal (million tons) | 6,688 | 7,861 |
| **Consumption** | **2007** | **2015** |
| Oil (thousand barrels a day) | 87,087 | 95,008 |
| Natural Gas (billion cubic meters) | 2,969 | 3,469 |
| Coal (million tons of oil equivalent) | 3,476 | 3,840 |
| **Natural Gas** | | |
| **Proven Reserves (percent of world reserves)** | **2007** | **2015** |
| Iran | 17.41 | 18.20 |
| Russia | 19.37 | 17.27 |
| Qatar | 15.76 | 13.13 |
| Turkmenistan | 1.44 | 9.35 |
| United States | 4.17 | 5.59 |
| **Production (percent of world production)** | **2007** | **2015** |
| United States | 18.40 | 21.68 |
| Russia | 19.97 | 16.20 |
| Iran | 4.21 | 5.44 |
| Qatar | 2.13 | 5.13 |
| Canada | 6.16 | 4.62 |
| **Consumption (percent of world consumption)** | **2007** | **2015** |
| United States | 22.03 | 22.43 |
| Russia | 14.21 | 11.29 |
| Iran | 4.23 | 5.51 |
| China | 2.46 | 5.69 |
| Japan | 3.04 | 3.27 |
| European Union | 16.33 | 11.59 |

Source: British Petroleum, *Statistical Review of World Energy, 2016*.
Note: n.a. = not available.

The pattern of global trade in natural gas has evolved rapidly. Because natural gas has mainly been transported to consumers via pipeline, only one-third of the natural gas that is consumed is traded internationally. Europe and North America are by far the largest markets integrated by pipelines, but their net imports have declined since 2005 on account of weaker economic activity and higher gas production in the United States. One-third of internationally traded natural gas is shipped as liquefied natural gas, and that share has been expanding rapidly, mainly to Asia (Figure 3.2). There were nearly 20 countries producing liquefied natural gas in 2013. Qatar has rapidly developed liquefied natural gas export capacity in the past decade and is to date the largest exporter, accounting for about one-third of global natural gas trade. Australia has been investing massively to export liquefied natural gas to Asian markets and may exceed Qatar as the world's largest exporter in coming years.

**Figure 3.2. Liquefied Natural Gas Imports and Exports, 2013**
*(Millions of tons)*




Source: Argus Media (www.argusmedia.com/Natural-Gas-LNG).
Note: UK = United Kingdom; US = United States.

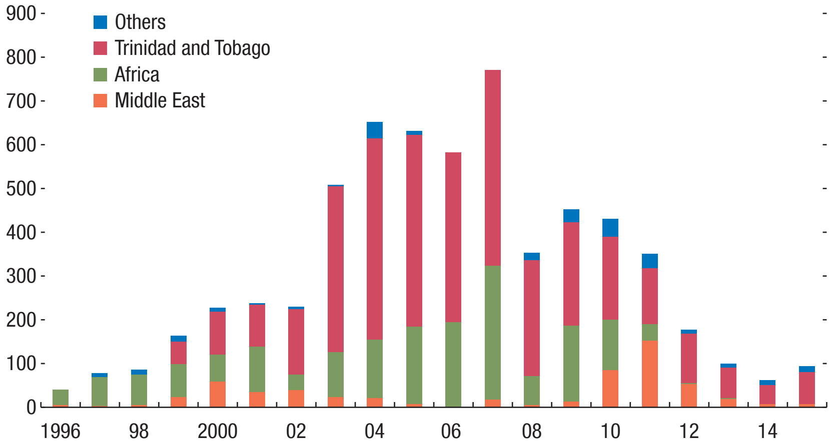
## GLOBAL IMPLICATIONS OF THE U.S. SHALE BOOM

The surge in the production of shale gas made the United States the largest natural gas producer in the world as of 2011,[3] and the United States started exporting liquefied natural gas in the spring of 2016 and became a net exporter of natural gas in the fall of 2016. With surging supply, natural gas prices in the United States fell sharply since the global financial crisis in 2008 and have not recovered their precrisis levels. Moreover, the structural shift represented by the United States becoming the world largest producer of natural gas has left U.S. prices effectively decoupled from those in the rest of the world. In particular, prices in Asia and the European Union doubled after the financial crisis, partly because the price of imported natural gas was indexed to oil prices until oil prices collapsed, and while natural gas prices there fell in line with oil prices after 2014, U.S. gas prices remained much lower.

Energy users in the United States and Mexico have been the main beneficiaries of the energy price declines that resulted from the U.S. shale revolution. However, U.S. shale production has helped to stabilize international energy prices,

[3]Natural gas production from shale deposits in the United States began in the 1980s, but the combination of hydraulic fracturing and horizontal drilling allowed gas production to increase sharply in the 2000s (with higher natural gas prices supplying additional motivation). Shale gas production accounts for about half of total U.S. natural gas production. The drilling technology was applied to extract oil from shale deposits in part as a response to high oil prices, and the number of rigs drilling for shale oil has risen sharply.

**Figure 3.3. United States: Liquified Natural Gas Imports**
*(Billion cubic feet)*




Source: US Energy Information Administration.

including by freeing global natural gas supplies for European and Asian markets and thus offsetting some of the shortages caused by geopolitical disruptions.[4] Also, in Europe imports of U.S. shale oil displaced imports of U.S. coal and lowered overall energy costs.

The shale gas boom in the United States has had a significant impact on the geography of global energy trade.[5] U.S. fossil fuel imports decreased to $97 billion (0.5 percent of GDP) in 2016 from $425 billion (2.9 percent of GDP) in 2008. Both U.S. demand for coal and U.S. coal prices also declined. This in turn encouraged increased exports of coal to Europe, which, together with weak activity there following the recession, reduced Europe's demand for natural gas.[6] The shale gas boom also drastically reduced U.S. liquefied natural gas imports from Africa, the Middle East, and Trinidad and Tobago (Figure 3.3) and also substantially reduced natural gas imports from Canada, triggering a sharp decline in prices. Exporters have shifted energy exports to other locations such as China,

[4]Both the shale oil and shale gas booms led to lower world average energy prices, the shale gas boom in particular increased the dispersion of regional prices.

[5]Shale gas development has significant potential in many parts of the world, notably in Argentina, Australia, China, Poland, and Russia, where shale gas developments are underway, but also in many other locales. Development of this potential could further shift the patterns of global energy and nonenergy trade. However, shale gas production is expected to rise at a slower pace elsewhere than in the United States, because many of the conditions that facilitated the U.S. shale gas boom are not in place or are in place at an insufficient scale.

[6]With regard to trade, this shift has affected primarily Algeria, Norway, and Russia, the largest gas exporters to Europe.

Europe, and India in response to the U.S. reduction in energy imports, but Trinidad and Tobago has seen its exports of liquefied natural gas plummet since the start of the U.S. shale gas boom, and the country is actively seeking to reorient its liquefied natural gas exports toward Asian markets.[7] In the United States, the shale gas boom has made redundant much of the liquefied natural gas import infrastructure. The infrastructure cannot easily be converted to export capacity because liquefaction capacity is different from import regasification capacity. In addition, U.S. firms are required to obtain authorization to export natural gas (except to Canada and Mexico), although there are signs that these regulatory obstacles are loosening.[8] In the medium term, the removal of U.S. gas export restrictions will trigger the build-up and reconversion of liquefied natural gas facilities for export purposes and in turn could help reduce energy price differences worldwide and further affect other natural gas exporters.

The U.S. advantage in natural gas has also led to an increase in U.S. competitiveness in nonenergy products. Results of a bivariate vector autoregression, including the difference in industrial production and the difference in the price of natural gas between the United States and Europe, suggest that natural gas prices can have a substantial independent impact on economic activity (Figure 3.4). This specification controls for global shocks such as the global financial crisis, an issue that has been overlooked in other studies.[9] A 10 percent reduction in the relative price of natural gas in the United States is found to lead to an improvement in U.S. industrial production relative to that of the euro area of roughly 0.7 percent after 1.5 years. Box 3.1 provides estimates of the gain in international competitiveness of U.S. manufacturing exports due to cheaper natural gas.

Cheaper natural gas prices benefited energy-intensive sectors in general and the natural-gas-intensive petrochemical sector in particular. Indeed, the petrochemical industry has made very sizable investments in new plants in the United States, and this is likely to continue as shale gas supplies will likely continue to expand for the foreseeable future.

These phenomena also suggest that when considering the effect on the U.S. economy of the oil price decline that began in 2012, the positive effects should be somewhat discounted given that natural gas prices declined before oil prices, unlike in the past when oil and gas prices moved in tandem.

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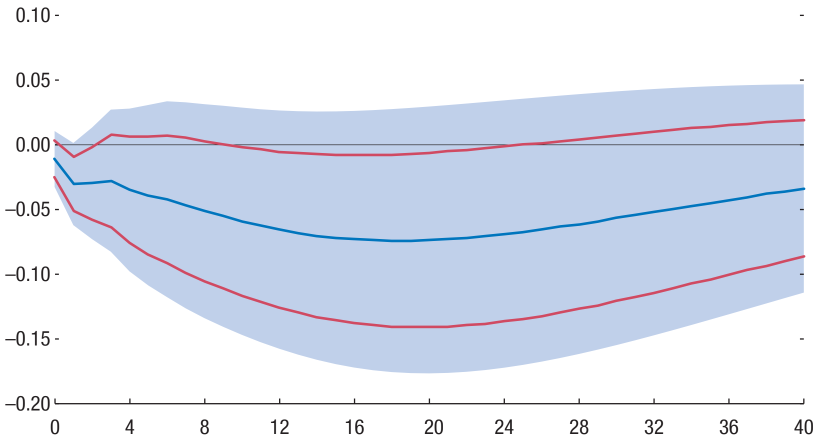
[7]The fall in liquefied natural gas exports from Trinidad and Tobago also coincided with supply constraints due to maintenance activities on liquefied natural gas facilities.

[8]It is estimated that if the United States were to export at its potential, the U.S. trade deficit would be reduced by more than $164 billion, approximately 1 percent of GDP, in 2020 (IHS 2013).

[9]Using industry-level data, Melick (2014) estimates that the fall in the price of natural gas since 2006 is associated with a 2–3 percent increase in activity for the entire manufacturing sector, with much larger effects of 30 percent or more for the most energy-intensive industries. Celasun and others (2014) find that a doubling of the natural gas price differential in favor of the home country would increase manufacturing industrial production by 1.5 percent.

**Figure 3.4. Impulse Response of Relative Industrial Production to a One Unit Relative Natural Gas Price Shock**
*(Months forward on x-axis)*




Source: IMF staff calculations.
Note: The estimated vector autoregression model includes two variables: the relative industrial production in the United States and the euro area and the relative natural gas price in the United States and Germany, using monthly data for 2005–13. The impulse-response functions correspond to the response of relative industrial production to a one unit shock in relative natural gas prices. Red lines indicate 80 percent confidence intervals, and the shaded areas correspond to 95 percent confidence intervals.

## AFTERMATH OF THE FUKUSHIMA DISASTER IN JAPAN

The Fukushima Daiichi nuclear disaster in March 2011 highlighted the environmental liabilities associated with nuclear power generation and induced a sharp increase in natural gas usage. Before the disaster, about one-quarter of Japan's energy was generated by nuclear reactors. Following the disaster, the Japanese government decided to halt production at all nuclear power plants. To compensate for the resulting loss in electricity generation, electric power companies enhanced their use of fossil-fuel power stations and appended natural gas turbines to existing plants. As a result, Japan's liquefied natural gas imports increased dramatically—by about 40 percent (Figure 3.5).

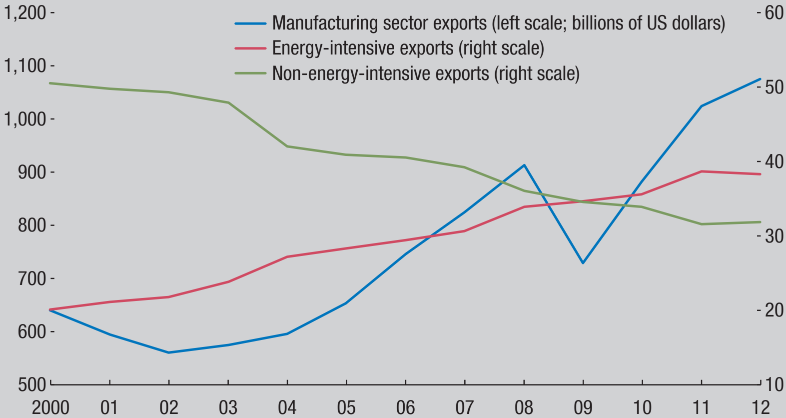
Japan became the world's largest importer of liquefied natural gas. In 2013, its imports of liquefied natural gas amounted to 119 billion cubic meters, more than a third of the world total. Increased natural gas demand from Japan has benefited producers in Asia, the Middle East, and Oceania at a time when global natural gas demand has slowed (Figure 3.6). Japan's imports have helped offset some of the negative effects of the reduction in U.S. liquefied natural gas imports. Exports to Japan of liquefied natural gas from Australia, Brunei Darussalam, Indonesia, Malaysia, and Qatar rose rapidly. The sharp increase in natural gas demand led to

## Box 3.1. The Trade Implications of the U.S. Shale Boom

The shale boom has led to a debate in the United States about whether relaxing restrictions on exports of natural gas will diminish the gains in external competitiveness resulting from lower domestic natural gas prices. The shale gas boom led to a decoupling between U.S. natural gas prices and those in Europe and Asia since 2005, and these price differentials are expected to persist. At the same time, the share of energy-intensive manufacturing exports in total U.S. manufacturing exports has been rising steadily, whereas the share of non-energy-intensive exports has been declining (Figure 3.1.1).

**Figure 3.1.1. Manufacturing Sector Exports**

*(Percent of total US manufacturing exports, unless indicated otherwise)*




Source: IMF staff calculations.

This box examines the global trade implications of international differences in natural gas prices using the U.S. shale gas boom as a natural experiment. The main finding, based on sector-level data, is that the current price gap between the United States and the rest of the world has led on average to an increase in U.S. manufactured product exports by 6 percent since the start of the shale gas boom. Even though natural gas and energy costs in general represent relatively small shares of total manufacturing input costs, the lower natural gas price in the United States, which is expected to persist in the future, has had a noticeable effect on U.S. energy-intensive manufacturing exports.[10]

[10]These results are also robust to an array of checks including additional controls such as country differences in labor costs and GDP. Arezki, Fetzer, and Pisch (2017) present extensive technical details and robustness checks. There are a multitude of factors driving U.S. manufacturing exports that go beyond scope of this box. The interpretation of the present results is, of course, all else equal.

## Box 3.1. The Trade Implications of the U.S. Shale Boom (*continued*)

### Energy Intensity and Manufacturing Exports

For the period 2000–12, which covers the shale gas boom in the United States, the logarithm of manufactured product exports is regressed on the interaction between differentials in energy intensity and in price between the United States and the rest of the world. The specification is a classical equation suggested by trade models. The coefficient associated with the interaction term is expected to be positive; that is, the more energy intensive a product is, the more likely it is to be exported. The equation estimated is

$$\ln(\text{product export}_{i,j,k,t}) = \alpha_{i,j,k} + \gamma_t + \eta \times \text{Energy Intensity}_{k,} \times \text{Price Differential}_t + \varepsilon_{ijkt}, \quad [3.1.1]$$

in which $\alpha_{i,j,k}$ are origin, destination, and sector-specific joint fixed effects capturing sector-specific distance, and $\gamma_t$ are time fixed effects capturing common shocks. The product export is equal to the value exported of a specific manufacturing sector at the five-digit level for which information is available, from Schott 2008, on the customs district of origin *i* and the country of destination *j* and sector *k*. The direct energy intensity is the share of energy cost obtained using input-output tables from the Bureau of Economic Analysis, as described by Fetzer (2014). The price differential is taken to be the ratio between the United Kingdom and the United States prices obtained from the OECD.[11] The baseline sample consists of more than 940,000 observations corresponding to an unbalanced panel of manufacturing product exports from origin to destination pairs.

### What Is Learned from the Results?

The coefficient associated with the interaction between energy intensity and price differential is large, positive, and statistically significant (Table 3.1.1). The baseline point estimate is 0.42 with a standard error of 0.09. The direct energy cost share for manufacturing products slightly more than 5 percent, and the total energy cost share is about 8 percent. In comparison, the direct labor cost share for manufacturing goods is 20 percent. The measure of the price differential between the rest of the world and the United States is of a factor of three, on average.[12] This suggests that for the average manufacturing product, U.S. exports have risen by at least 6 percent (0.42 × 3 × 0.05).

The results are checked to determine their robustness to using the natural gas cost share as opposed to the energy share and also to the use of year dummies instead of natural gas price differentials; further, oil and petroleum manufacturing products, which have a direct energy cost share above 60 percent, are dropped. The direct natural gas cost share is on average 2 percent for manufacturing products. This measure does not account for the fact that gas could be indirectly consumed through electricity. The baseline results are robust to using those alternative specifications, and broadly similar figures are obtained.

Further evidence suggests that the channels through which cheaper domestic natural gas prices in the United States might have an impact on manufacturing exports are operating at both the intensive margin (expansion by existing firms) and the extensive margin (new firm entry). As more countries exploit new sources of natural gas, it is likely that not only will the geography of trade in energy products continue to change, but that the geography of manufacturing exports will change as well.

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[11]Using benchmarks other than the United Kingdom yields similar results, because the variation in the relative price is coming mostly from U.S. prices.

[12]The price differential is measured as the ratio between rest of the world's natural gas prices and those of the United States.

**Box 3.1. The Trade Implications of the U.S. Shale Boom (*continued*)**

**TABLE 3.1.1.**

| | Energy Cost Share | | Natural Gas Cost Share | |
|---|---|---|---|---|
| | (1) Total | (2) Direct | (3) Total | (4) Direct |
| Total Utility Share × price Difference | 0.415*** (0.099) | | | |
| Direct Utility Share × price Difference | | 0.432*** (0.111) | | |
| Total Nat Gas Share × price Difference | | | 0.423*** (0.099) | |
| Direct Nat Gas Share × Price Difference | | | | 0.402*** (0.115) |
| Observations | 944,135 | 944,135 | 944,135 | 944,135 |
| Adjusted $R^2$ | 0.277 | 0.277 | 0.277 | 0.277 |

Note: Dependent variable is logarithm of the value of product exports at the five-digit level. The specification is a classical equation suggested by trade models and also controls for year, product, and location (destination and origin) fixed effects. The regressions include product level. Standard errors are in parentheses. Nat. = natural.
* $p < .10$; ** $p < .05$; *** $p < .01$.

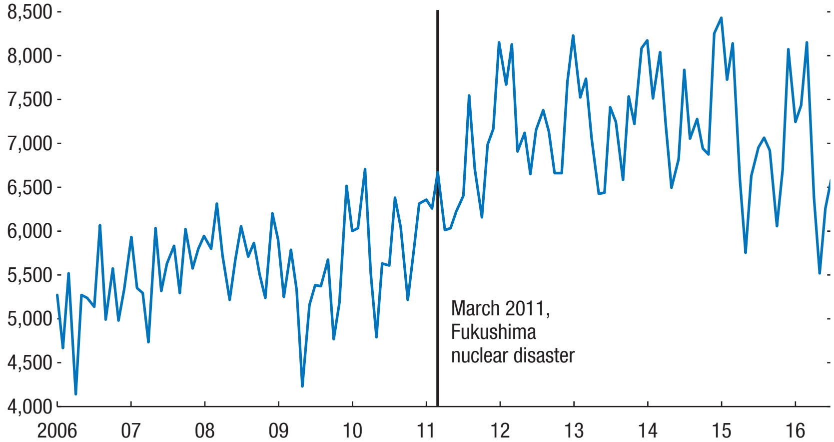
higher prices in Asia, and in Japan in particular, with prices in Asia reaching twice European prices and four times U.S. prices at one point. However, after Japan began to reactivate its nuclear power plants and increase the use of ultra-high efficiency coal plants, the price difference between Asia and Europe narrowed substantially, although Europe continues to rely primarily on pipeline gas. Natural gas prices in Europe and Asia declined substantially due to the oil price collapse, as they are typically indexed to oil prices.

## RISKS FROM GEOPOLITICAL TENSIONS BETWEEN RUSSIA AND UKRAINE

The ongoing crisis in Ukraine highlights European energy markets' dependence on natural gas. In January 2009, Gazprom, the Russian energy utility, shut off all supply to Europe through Ukraine. In 2009, the spot gas price increased by 50 percent, but the one-month-forward contract price moved up slowly—by 20 percent—during the three-week shutoff, and crude oil prices did not react noticeably. Europe's dependence on natural gas transiting through Ukraine subsequently decreased from 80 percent to roughly 50 percent. On June 16, 2014, Gazprom stopped providing natural gas to Ukraine but left the transit and supply to Europe unaffected.

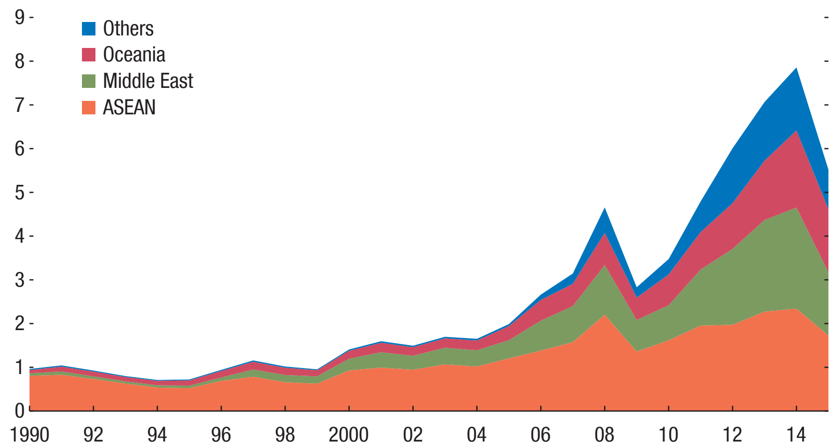
Ukraine and countries in southeast Europe appear particularly vulnerable to potential disruptions of Russian gas supplies. Should the gas cutoffs persist and be extended to other countries, the greatest impact will be on Ukraine and countries in southeast Europe that receive Russian gas transiting through Ukraine—in particular Bulgaria and countries of former Yugoslavia, which rely on Russian gas

**Figure 3.5. Japan: Liquefied Natural Gas Imports**
*(Thousands of metric tons)*




Source: Thomson Reuters Datastream.

**Figure 3.6. Japan: Liquefied Natural Gas Imports by Region**
*(Trillions of Japanese yen)*




Source: Thomson Reuters Datastream.
Note: ASEAN = Association of Southeast Asian Nations.

for virtually all of their import requirements and have only limited access to gas from alternative sources. Other countries, however, will be affected through rising spot prices, which may spread from natural gas to other fuels. Such risks can be mitigated through the accumulation of reserves, purchasing pipeline gas from Algeria and Norway, importing liquefied natural gas,[13] or buying Russian gas transported via other pipelines. Other fuels, notably coal and oil products, could also be substituted for gas.

Continental Europe imports a substantial portion of the gas it needs from Russia. In 2013, roughly 152 billion cubic meters of Russian gas were exported to Europe via pipeline, which amounts to 36 percent of European gas consumption. On average, Russia has supplied about 30 percent of Europe's natural gas needs. Roughly half of the gas supply from Russia is transported via pipeline through Ukraine (down from 80 percent before the Nord Stream pipeline was built). The share of natural gas in primary energy consumption ranges widely among European nations, from less than 2 percent in Sweden to 42 percent in the Netherlands.

The geopolitical tensions in the region have barely affected natural gas and crude oil prices so far. This is less surprising in the case of crude oil than for natural gas because there are significantly fewer concerns about the consequences of a potential Russian oil supply disruption than for a natural gas supply disruption. In May 2014, Russia signed a $400 billion deal to transport 38 billion cubic meters a year of gas from Eastern Siberia to China beginning in 2018. Pricing on the deal has not been disclosed, but the price is thought to be somewhat below what Europeans are paying for pipeline gas from Russia. This gives Russia greater export flexibility should European gas demand continue to fall.

## CONCLUSIONS

Overall, the pattern of global trade in liquefied natural gas—and in energy more generally—is expected to evolve rapidly. In particular, the United States is now a net exporter of natural gas; Japan is likely to remain the world's largest importer of liquefied natural gas; and Europe is likely to continue to face uncertainty in its supply of natural gas as a result of the geopolitical tensions between Russia and Ukraine. Energy policy plays a key role in shaping the energy mix, including for coal and renewables, which in turn affects global trade in energy. Specifically, Europe and Japan are at a crossroads, facing a difficult balance between energy security, environmental concerns, and economic efficiency goals. In the medium term, natural gas prices in Asia are expected to be lower, assuming the return of nuclear power in Japan and lower oil prices. European gas prices could edge lower as countries in the region move further toward spot-priced gas imports and index long-term contracts to the spot price, but again the tensions between Russia and Ukraine create uncertainty. Russia has been actively

[13]Limited imports of liquefied natural gas from the United States began in 2017.

exporting natural gas to Europe in an attempt to prevent U.S. imports from penetrating deeply into the European market. Domestic natural gas prices in the United States are expected to rise with growing liquefied natural gas exports but should remain lower than those in Europe and Asia, given the costs of liquefaction. Natural gas consumers in Mexico also benefit from this situation as they receive low-priced pipeline natural gas from the United States.

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## CHAPTER 4

# The Energy Transition in an Era of Low Fossil Fuel Prices

*The human influence on the climate system is clear and is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system.*
—Intergovernmental Panel on Climate Change, *Fifth Assessment Report (2014)*

The international response to climate change began in 1992 with the Rio Earth Summit and adoption of the Rio Convention that sets out the UN Framework on Climate Change (UNFCCC). The Rio Convention came into force in 1994 and has near-universal membership of 190 countries, and a Conference of Parties (COP) is held annually to review its implementation. One result of the 2015 Paris Climate Conference (COP21) was the Paris Agreement, which commits signatories to work toward limiting global temperature rise. Each country commits to reduce its greenhouse gas emissions by an amount referred to as its Intended Nationally Determined Contribution (INDC). The post-COP21 agenda focuses on implementation of these INDCs, at the heart of which is the so-called energy transition—the move away from using fossil fuels (petroleum products, natural gas, and coal) and toward using clean energies.

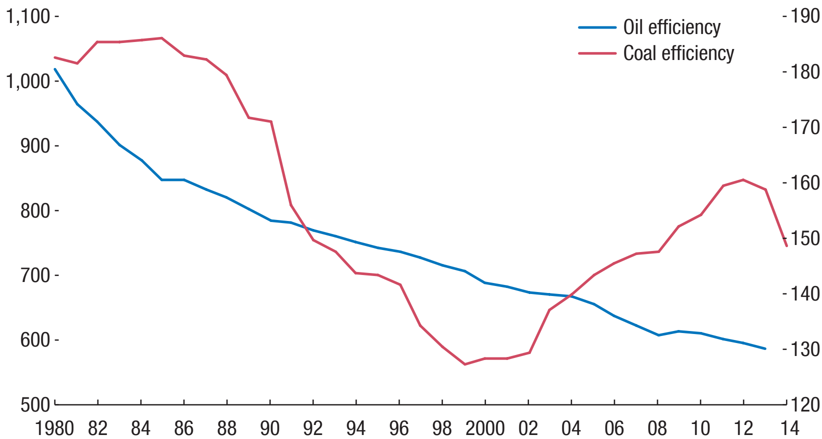
While the energy transition is arguably at an early stage, with important differences in goals and achievements across countries, what is not in question is that we are at a critical juncture. Indeed, to avoid the irreversible consequences of climate change induced by greenhouse gas emissions, the energy transition must take firm root while fossil fuel prices are low and likely to stay that way for some time. Solidifying the move from fossil fuels toward clean energy involves both significant opportunities and significant risks, which energy policies will need to address.

This chapter answers four key questions about the energy transition:

- What forces now affect fossil fuels?
- What is the state of clean energy?
- What are the opportunities and risks associated with the energy transition?
- What is the way forward?

Prepared by Rabah Arezki (team leader), Christian Bogmans, Rachel Yuting Fan, and Akito Matsumoto, with research assistance from Vanessa Diaz Montelongo.

**Figure 4.1. World Energy Efficiency**
*(Oil efficiency: barrels per million 2005 US dollars in GDP; coal efficiency: tons per million 2005 US dollar in GDP, right scale)*




Sources: US Energy Information Administration; World Bank, *World Development Indicators*; and IMF staff calculations. Updated September 16, 2016.

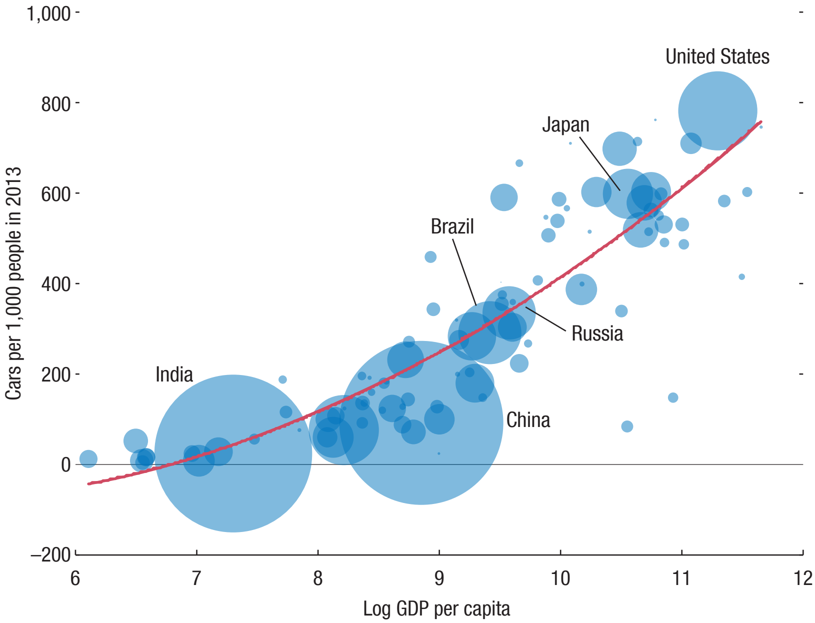
## WHAT MARKET FORCES NOW AFFECT FOSSIL FUELS?

Oil prices have dropped by more than half since June 2014 and are expected to remain low for a long time owing to a variety of factors (see Arezki and Obstfeld 2015). Important supply-side factors include the advent and relative resilience of shale oil production and increased oil production by members of the Organization of Petroleum Exporting Countries (OPEC). On the demand side, slower economic growth in emerging markets has tended to reduce oil demand growth reinforcing the effect from the secular increase in global oil efficiency (Figure 4.1), which is expected to continue. That said, the expansion of the middle class in giant emerging market economies is expected to increase dramatically the demand for transportation services and the level of car ownership and, in turn, to support oil demand growth (Figure 4.2). The balance among these forces will determine the growth of demand for oil.

Prices for natural gas and coal have also experienced declines that look likely to be long lived. The North American shale gas boom has resulted in record low prices in the region. Recent discoveries of extensive gas fields in some developing economies add to the pool of available reserves.[1] The resumption of nuclear-powered electricity generation in Japan permanently contributes to lower natural gas prices

[1]The recent discovery of the giant Zohr gas field off the Egyptian coast and, more recently, the discovery of natural gas off the coast of Senegal will eventually have repercussions for prices in Europe, the Mediterranean region, and west Africa. In addition, many other locales, especially in

**Figure 4.2. Car Ownership, 2013**
*(Size of bubble represents population in 2013)*



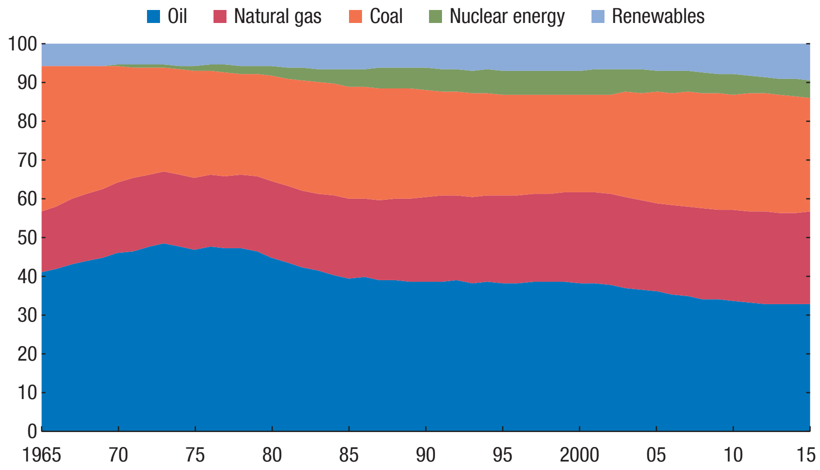

Sources: IMF, World Economic Outlook database; International Road Federation, *World Road Statistics*; and IMF staff calculations.
Note: Cars per 1,000 people for India is from 2012 (most recently available).

in Asia. Coal prices also are low, owing to oversupply and the scaling down of demand because of environmental concerns and slower economic activity, especially from China, which burns half the world's coal.

The share of oil in global primary energy consumption has declined rapidly, from 50 percent in 1970 to about 30 percent today (Figure 4.3). The share of coal, now about 30 percent of global energy consumption, has actually risen since the early 2000s, mostly due to rising demand from China and recently also from India. In contrast with oil, more coal is burned for each unit of global GDP than in the early 2000s (Figure 4.1). Natural gas consumption has increased steadily since the 1970s and now accounts for nearly 25 percent of global primary energy consumption. Global demand for natural gas is projected to increase strongly over the medium term (IEA 2015), with emerging market and developing economies accounting for most of this growth. The projected growth in oil and coal demand falls short of that for total energy demand, partly because, unlike emerging

developing economies, are opening up for resource exploration and offer significant potential (see Arezki, Toscani, and van der Ploeg 2016).

**Figure 4.3. World Energy Consumption Share by Fuel Type**
*(Percent)*




Source: *BP Statistical Review of World Energy* 2016.
Note: Consumption of renewables is based on gross primary hydroelectric generation and gross generation from other renewable sources, including wind, geothermal, solar, biomass, and waste.

markets, advanced economies are expected to drastically reduce their demand. According to the International Energy Agency, the shares of oil and coal in total energy consumption are expected to drop from 36 percent and 19 percent, respectively, in 2013, to 26 percent and 12 percent, respectively, in 2040.

Oil is used mostly to fuel transportation, whereas coal and natural gas are used mainly as inputs into the power sector (electricity and heat generation), which accounts for more than one-third of total primary energy consumption (Table 4.1). Coal is the biggest source of energy for electricity generation, followed by renewables (including hydropower) and then natural gas.[2] Roughly equal, and substantial, amounts of energy are also consumed in industry, transport, and building construction, including as inputs to the electricity and heat that these sectors consume. The transport sector accounts for roughly two-thirds of global oil use.

In terms of carbon dioxide emissions, the cleanest energy source among fossil fuels is natural gas, and oil is second. Coal is the dirtiest, especially when used by

[2]The share of natural gas in total primary energy demand is expected to rise, but it faces competition from substitutes for gas in many sectors, especially from renewables and coal in power generation—in part because of subsidies and gas-pricing regimes. In particular, natural gas use is expected to increase in the transport sector, where its use is now very limited. This development, along with the eventual use of liquefied natural gas as a shipping fuel, will contribute to the displacement of oil as the primary fossil fuel energy source.

**TABLE 4.1.**

World Energy Consumption, 2013

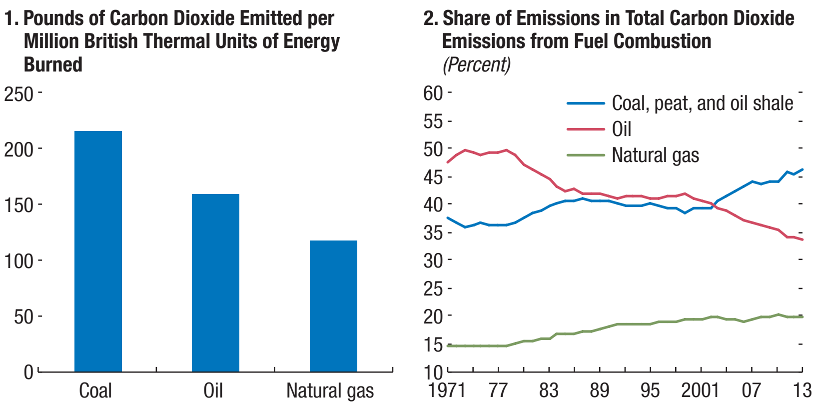
*(Million tons of oil equivalent)*

| Energy Source | Power Generation (electricity and heat) | Final Consumption | | | Total Primary Energy Demand |
|---|---|---|---|---|---|
| | | Industry | Transportation | Buildings | |
| Coal | 2,404 | 768 | 3 | 128 | 3,929 |
| Oil | 284 | 302 | 2,357 | 317 | 4,219 |
| Gas | 1,172 | 557 | 96 | 627 | 2,901 |
| Nuclear | 646 | – | – | – | 646 |
| Hydro | 326 | – | – | – | 326 |
| Bioenergy/Biofuels | 155 | 194 | 65 | 861 | 1,376 |
| Other Renewables | 127 | 1 | – | 32 | 161 |
| Electricity and Heat | – | 842 | 26 | 1040 | . . . |
| **Total** | **5,115** | **2,664** | **2,547** | **3,004** | **13,559** |

Sources: International Energy Agency, *World Energy Outlook* and *World Energy Balances*; and IMF staff calculations.
Note: Because of statistical discrepancies, individual data in each row do not sum exactly to total primary energy demand.
– = negligible.

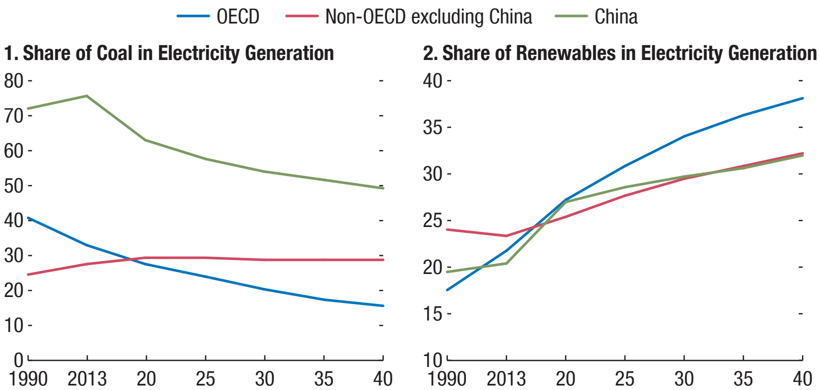
older, low-efficiency plants, which also tend to emit more air pollutants such as nitrogen oxides and sulfur oxides (Figure 4.4, panel 1). Despite the increased use of renewables and the decreased use of oil as fuel, total greenhouse gas emissions have increased because of the increase in demand for coal (Figure 4.4, panel 2). In fact, global carbon intensity per unit of energy has increased since the beginning of the 1990s owing to the rising consumption of coal, especially in Asia (see Steckel, Edenhofer, and Jakob 2015). Even while China, the world's largest coal consumer, shifts toward renewable energy resources, coal intensity is expected to increase in other fast-growing emerging market economies, especially India, especially if coal prices stay low (Figure 4.5, panel 1).

**Figure 4.4. Carbon Emission for Various Fuels**




Sources: International Energy Agency; and IMF staff calculations.

**Figure 4.5. Electricity Generation**
*(Percent)*




Sources: International Energy Agency; and IMF staff calculations.
Note: These shares relate to electricity generation only and exclude the heating sector. OECD = Organisation for Economic Co-operation and Development.

If the energy intensity of economic activity does not fall or if developing economies do not adopt state-of-the-art technology for coal-powered plants to lower the carbon intensity of electricity generation, economic development in most regions of the world will continue to drive global emissions upward. Emissions will reach dramatic levels and, in turn, accelerate global warming. Poorly designed regulations for the use of coal in developing economies could also discourage technological innovation in the electricity sector. As a result, the world might not benefit, in terms of lower global emissions, from the downward trend in coal use in advanced economies.

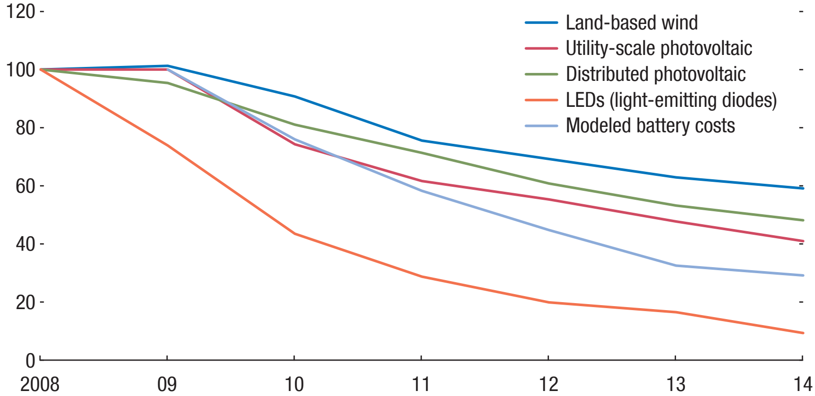
Given its relative cleanliness and abundance, natural gas can play a key role in the transition from coal to renewables. Growth in U.S. shale gas production is expected to make natural gas the energy of choice in the United States. There is also potential for growth in the use of shale gas and conventional natural gas in China and many other places around the globe (see Chakravorty, Fischer, and Hubert 2015).

## WHAT IS THE STATE OF CLEAN ENERGY?

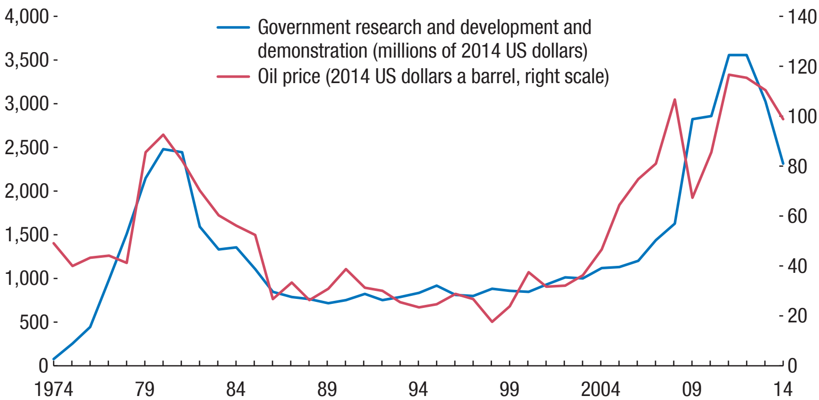
One of the most notable trends in energy consumption is the increased use of renewable energy resources (Figure 4.5, panel 2), which has been supported by a formidable reduction in the costs of various renewables, including solar and wind (Figure 4.6, panel 1). These cost reductions are the result of research and development (R&D) efforts to promote clean energy and energy efficiency (“grey” technology) (Figure 4.6, panel 2). This R&D investment dates to the 1970s, an

## Figure 4.6. Cost of Renewables and Research and Development Efforts

**1. Renewable Energy: Indexed Cost Reductions since 2008**
*(2008 = 100)*



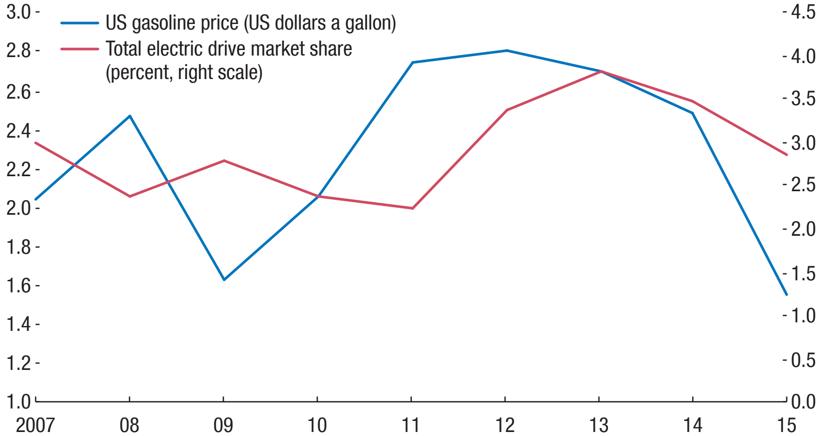

**2. OECD Spending on Research and Development and Demonstration and Oil Price**




Sources: International Energy Agency, Energy Technology Research Development and Demonstration 2015; and US Department of Energy.

era of record-high fossil fuel prices, and was mostly government financed. This is no surprise: the private sector typically does not internalize the positive externalities associated with an increase in R&D. Public R&D spending early on, however, paved the way for corporate R&D spending during the 2000s, another period of high fossil fuel prices. The result has been a flow of technological innovations across sectors, including the development of electric and natural-gas-powered vehicles. The outlook for alternative fuel vehicles is somewhat mixed. There has been an increase in use of compressed natural gas for transportation, particularly commercial fleets and buses. But sales of electric cars, notably plug-in hybrid

**Figure 4.7. US Sales of Electric Vehicles and Gasoline Price**




Sources: IMF, Primary Commodity Price System; and Electric Drive Transportation Association.
Note: Total electric drive market share includes hybrid vehicles.

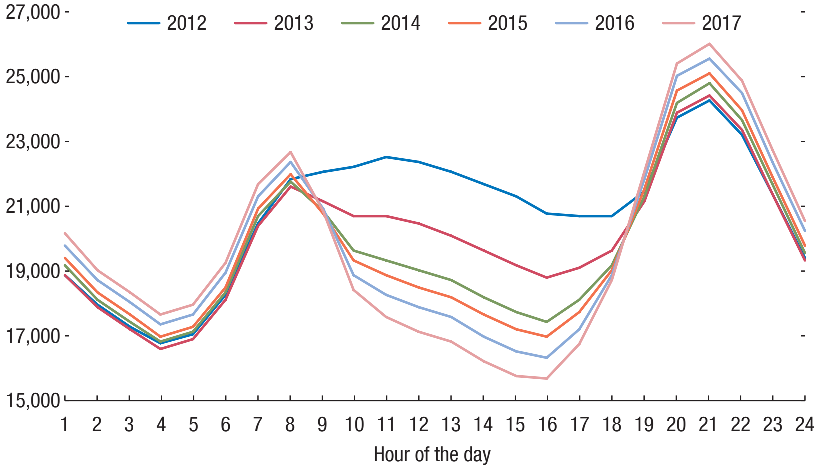
vehicles, still have a low penetration rate, accounting for less than 1 percent of car sales in the United States. Unsurprisingly, electric car sales decreased with the recent drop in gasoline prices (Figure 4.7).

Among primary energy sources, renewables (including hydropower) are the least carbon intensive. The International Energy Agency forecasts that the share of renewables in global total primary energy consumption will increase from 14 percent in 2013 to 19 percent in 2040 as a result of expected energy policy changes. Electricity generation is set to change dramatically: the share of renewables is projected to increase from 22 percent to 34 percent over this period.

One obstacle to increased use of renewable energy in power generation is intermittency and hence reliability. Unstable supplies of wind, sun, and rainfall can trigger a mismatch between supply and demand. Addressing this will require ramping up of supply during daily peaks to achieve load balancing.[3] In other words, the intermittencies associated with the increased usage of renewables trigger spikes in demand for "controllable" power, for example power generated from natural gas (Figure 4.8). To overcome this problem, the power sector needs to develop economical battery backup technology and foster electricity exchange. Battery technology has shown steady progress, suggesting that electricity storage technology eventually will facilitate a more widespread reliance on renewables.

[3]The net load curve represents the variable portion of the load that integrated system operators must meet in real time. The net load is calculated by taking the forecast load and subtracting the forecast of electricity generation from variable generation resources, wind, and solar (see California ISO 2016).

**Figure 4.8. Duck Curve: Illustrative Change in Projections of Net Load Curve**
*(Megawatts)*




Source: California Energy Commission staff, Energy Assessments Division.
Note: Projections are based on load shapes and production profiles from actual data of the California Independent System Operator on March 22, 2013.

Bioenergy has long played a role in electricity generation. Biosolids are relatively cheap sources of energy because they are residuals from other processes or are simply waste materials. Power plants fired by biomass can also compensate for generation lapses associated with other renewables because they can operate at any time of the day. Both advanced and developing economies are expected to develop more bioenergy-based facilities. For use in transportation, biofuels are usually blended with conventional gasoline or diesel, sometimes in response to governmental mandates. As a result, the share of biofuels in transportation fuels has doubled over the past decade. Biofuels can reduce carbon emissions, but they also put pressure on food markets and have been blamed for food price increases (see Chakravorty and others 2015).

Nuclear power makes up only a small share of global energy consumption. Carbon emissions associated with nuclear energy generation are limited, but in the aftermath of the March 2011 Fukushima disaster, several countries imposed moratoriums on nuclear energy use to address environmental liabilities and safety concerns. The human health risks associated with potential exposure to radiation are fairly well known, but nuclear energy's overall impact on the environment is hard to judge because waste management of used nuclear fuel is still at an early stage. There are also concerns about the potential for radioactive materials involved in nuclear power generation to be diverted to military use. There are, however, important benefits to nuclear energy. For example, unlike renewable energy, nuclear power has no problems of intermittency. Also, immediate fatalities associated with power plant accidents—as opposed to long-term health consequences related to radiation and pollution exposure—are historically much lower for nuclear plants than for any other type of power plant, including coal-fired plants (Table 4.2). Finally, nuclear power is seen as a source of relatively clean energy. Some countries, including China and the United States, view use of nuclear energy as a way to curb greenhouse gas emissions. Despite the serious issues to be solved in terms of safety and waste management, many scientists argue that it will be hard for many countries to achieve their INDC targets without greater use of nuclear energy.

## WHAT ARE THE OPPORTUNITIES AND RISKS ASSOCIATED WITH THE ENERGY TRANSITION?

The persistence of low fossil fuel prices complicates the energy transition by slowing or threatening progress in developing renewables (see Arezki and Obstfeld 2015).[4] Renewables account for only a small share of global primary energy consumption, but they will need to displace fossil fuels to a much greater extent to forestall further significant climate risks. Evidence indicates that higher fossil fuel prices strongly encourage both innovation and adoption of cleaner technology (see Aghion and others 2012; Busse, Knittel, and Zettelmeyer 2013). Not only do the current low prices for oil, gas, and coal eliminate many of the economic incentives for research into fossil fuel substitutes, they have already raised demand for fossil fuels in some countries. In Germany, for example, the use of coal (the dirtiest fossil fuel) has risen at the expense of natural gas (the cleanest).[5] Lower gasoline prices also reduce the incentive to purchase fuel-efficient or electric cars (Figure 4.7). Similarly, the number of clean- or grey-energy patents correlates positively with the price of fossil fuels (Figure 4.9). Finally, low prices for energy in general may hamper overall economic growth and overall energy consumption if consumers substitute the purchase of more energy for other commodities.

Because coal is currently relatively cheap, it is tempting for countries to use coal for power generation. This is true even for those countries that have committed to reducing their reliance on coal and especially if they cannot afford cleaner alternatives, which are typically more expensive. As mentioned, even advanced economies in Europe increased their use of coal when the shale revolution in the United States displaced coal there and international coal prices dropped.[6]

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[4]Low oil prices may in part reflect, in addition to the factors discussed earlier in the chapter, an independent process of structural transformation that is taking place in China and is diminishing (or slowing down the growth of) the oil intensity of GDP (see Stefanski 2014).

[5]As the relative price of coal to natural gas in Europe declined in recent years, the share of coal in electricity generation increased in Germany, from 43.1 percent in 2010 to 46.3 percent in 2013. Over the same period, the share of natural gas fell from 14.3 percent to 10.9 percent.

[6]The share of coal as an input in power plants among European members of the Organisation for Economic Co-operation and Development increased from 23.7 percent in 2010 to 26.0 percent in 2012 (with the increase in coal use largely arising from displacement of natural gas use), although

**TABLE 4.2.**

Summary of Severe Accidents by Energy Chain and Country Group, 1970–2008

| Energy Chain | OECD | | EU 27 | | non-OECD | |
|---|---|---|---|---|---|---|
| | Accidents | Fatalities | Accidents | Fatalities | Accidents | Fatalities |
| Coal | 87 | 2,259 | 45 | 989 | 2,394[1] | 38,672 |
| | | | | | 162 | 5788 |
| | | | | | 818 | 11,302 |
| | | | | | 1,214 | 15,750 |
| Oil | 187 | 3,495 | 65 | 1243 | 358 | 19,516 |
| Natural gas | 109 | 1,258 | 37 | 367 | 78 | 1556 |
| LPG | 58 | 1,856 | 22 | 571 | 70 | 2789 |
| Hydro | 1[2] | 14 | 1[3] | 116 | 9[4] | 3961 |
| | | | | | | 26,108[5] |
| Nuclear[6] | — | — | — | — | 1 | 31 |
| Biofuel | — | — | — | — | — | — |
| Biogas | — | — | — | — | 2 | 18 |
| Geothermal | — | — | — | — | 1 | 21 |

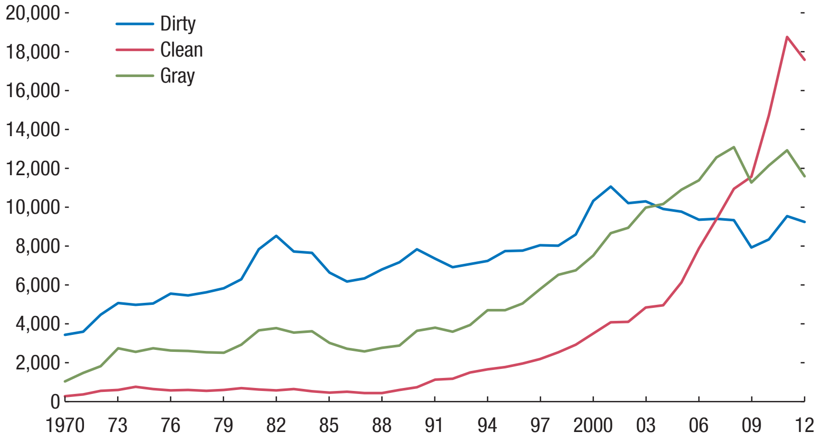
Source: Burgherr and Hirschsberg 2014.
Note: Severe accidents are those with five or more fatalities. EU 27 = members of the European Union during 2007–13; LPG = liquified petroleum gas; OECD = Organisation for Economic Co-operation and Development.
[1]First line non-OECD total, second line non-OECD without China, third line China 1994–99, fourth line China 2000–08.
[2]Teton Dam failure (USA, 1976).
[3]Belci Dam failure (Romania, 1991).
[4]First line non-OECD without China, second line China.
[5]Banqiao/Shimantan Dam failures (China, 1975) together caused 26,000 fatalities.
[6]Only immediate fatalities of the Chernobyl accident are shown here. See text for a more detailed discussion of the nuclear chain.
Paul Scherrer Institut (PSI), Laboratory for Energy Systems Analysis, CH-5232 Villigen PSI, Switzerland
Energy Policy 74(2014) S45–S56

In addition to these short-term demand effects, low coal prices may have longer-term consequences by boosting capacity investment in coal power plants and simultaneously reducing efforts to develop more efficient technology. Specifically, the prospect that environmental concerns would decrease demand for coal power provided an incentive to power plant manufacturers to improve plant efficiency and reduced emissions; with lower coal prices and increased demand, they might moderate these development efforts. This could leave emerging market economies that have fewer energy options with less efficient and more pollution-intensive coal power plants.

Another key technology under development that could be slowed by low coal prices is carbon capture and storage, which can significantly reduce carbon emissions not only for power plants but also for other carbon-emitting industries such as steel production. At this point, carbon capture and storage and clean coal technologies are not considered to be primary global-warming mitigation tools, but pursuing these technologies may still be important for coal and oil producers Without carbon capture and storage, in the long term, if and when the energy transition is achieved, fossil fuels could become "stranded assets"—assets that

the share of renewable energy increased as well. Japan increased its share of natural gas and coal significantly after it stopped nuclear power production following the Fukushima accident.

**Figure 4.9. Number of Energy Patents in the World**



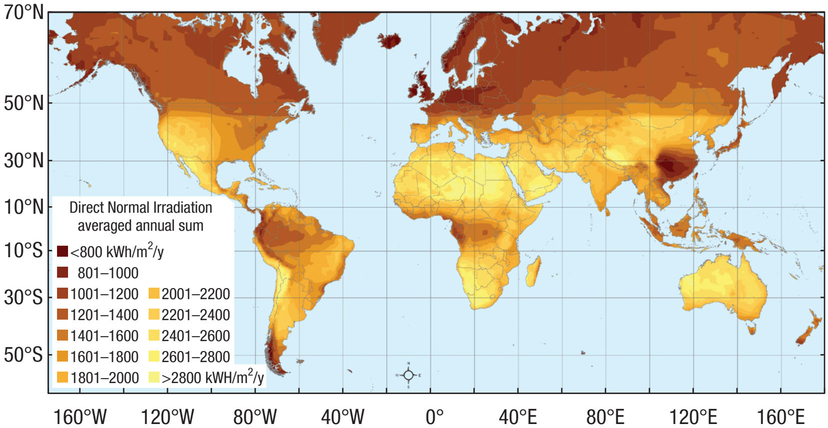

Source: Aghion and others 2012.
Note: "Dirty" indicates automobile technologies affecting internal combustion engines, "clean" indicates automobile technologies in electric vehicles, hybrid vehicles, fuel cells for hydrogen vehicles, and so forth; and "gray" indicates innovations in fuel efficiency.

either lose their value unexpectedly or prematurely or become liabilities. In the case of fossil fuel industries, the stranded assets might include "stranded reserves"—fossil fuel reserves that are no longer recoverable—and "stranded or underutilized capital"—sunk capital investments that become obsolete (for example, oil platforms that are never used). Because it remains to be seen how rapidly the energy transition might take place, however, there is significant uncertainty regarding the time horizon over which fossil fuel assets become stranded.

One important lesson from earlier energy transitions is that these transitions take time to complete—witness the transition from wood and biomass to coal in the eighteenth and nineteenth centuries and the transition from coal to oil in the nineteenth and twentieth centuries. History may not be repeated in this case, however, because the technological forces unleashed by the public and private response to climate change appear to be more potent than the factors that drove earlier energy transitions and may speed up this transition, notwithstanding the potential delays from the current environment of persistently low fossil fuel prices. Considering the industry's carbon emissions intensity, coal-related assets are more exposed to the risk of becoming stranded than oil and natural gas assets.

Stranded assets could cause heavy losses for coal and oil companies and for countries that rely heavily on fossil fuel exports, many of which have attempted to diversify to mitigate these risks. Many major oil companies have long diversified among fossil fuels by investing more heavily in the production of natural gas and also in so-called breakthrough renewable technologies. Oil-exporting countries have also attempted to diversify their economies away from oil, but this has

Figure 4.10. Direct Normal Irradiation




Source: US National Aeronautics and Space Administration; and The Institute of Engineering Thermodynamics at the German Aerospace Center.

proven challenging. Nevertheless, opportunities exist. For example, the United Arab Emirates has endorsed an ambitious target of drawing 24 percent of its primary energy consumption from renewable sources by 2021.

Solar power concentration is highest in the Middle East and Africa and parts of Asia and the United States, according to the U.S. National Aeronautics and Space Administration (Figure 4.10). Interestingly, Morocco, host of the 2016 United Nations Conference on Climate Change (COP22), unveiled the first phase of a massive solar power plant in the Sahara Desert that is expected to have a combined capacity of two gigawatts by 2020, which would make it the single largest solar power production facility in the world.

## WHAT IS THE WAY FORWARD?

Large economies tend to be the biggest emitters of greenhouse gases, and the 10 largest emitters are responsible for more than 60 percent of the global total (Table 4.3). Any effort to address global warming should therefore encompass all the largest economies (see Arezki and Matsumoto 2016). Although high-income countries are big greenhouse gas emitters in per capita terms, energy efficiency has been improving rapidly in these countries, and many are therefore already reducing greenhouse gas emissions, with some committed to doing more. As a result, consumption of fossil fuels in advanced economies can therefore be expected to continue to decrease. As a result, even though advanced economies account for the bulk of current emissions, emerging market and developing economies will

**TABLE 4.3.**

Global Share of Greenhouse Gas Emissions by Country

*($CO_2$ emissions from fuel combustion, 2013)*

| Country | Share (of global) | $CO_2$/Population (tons of $CO_2$ per capita) | $CO_2$/GDP PPP (kilograms of $CO_2$ per current international dollar) | GDP Per Capita (current PPP) |
|---|---|---|---|---|
| China | 28.0 | 6.65 | 0.55 | 12,196 |
| United States | 15.9 | 16.18 | 0.31 | 52,980 |
| India | 5.8 | 1.49 | 0.28 | 5,418 |
| Russia | 4.8 | 10.75 | 0.43 | 25,033 |
| Japan | 3.8 | 9.70 | 0.27 | 36,223 |
| Germany | 2.4 | 9.42 | 0.21 | 43,887 |
| Korea | 1.8 | 11.39 | 0.34 | 33,089 |
| Canada | 1.7 | 15.25 | 0.35 | 43,033 |
| Iran | 1.6 | 6.79 | 0.42 | 16,067 |
| Saudi Arabia | 1.5 | 16.39 | 0.31 | 52,993 |
| Total share (top 10 countries) | 67.3 | | | |

Sources: International Energy Agency; World Bank, *World Development Indicators*; and IMF staff calculations.
Note: $CO_2$ = carbon dioxide; PPP = purchasing power parity.

drive the growth of future emissions. These economies remain heavily reliant on coal, and their consumption of coal and other fossil fuels will continue to rise.

There are important variations in countries' efforts to shift their energy mixes at least partly toward renewables and away from fossil fuels, especially coal and oil. In 1991 Sweden became the first country to adopt a carbon tax, and it now gets more than 38 percent of its energy from renewables. The European Union as a whole gets 13 percent its energy from renewables. In an effort to reduce its very high pollution levels, China has an ambitious plan to meet a significant portion of its future energy needs with renewables.

As noted, the 2015 Paris Climate Conference (COP21) was by all accounts a success, with nearly every country committing to reduce its greenhouse gas emissions through the INDCs (Table 4.4). The first internationally coordinated attempt to reduce carbon emissions occurred well before the 2015 Paris Agreement, in 1997 with the Kyoto Protocol agreed at COP3, but a few major countries, including China, India, and the United States, did not accept its legally binding targets. The 2009 Copenhagen conference (COP15) failed to yield an agreement, and no real progress occurred until the 2015 Paris conference. Again, the challenge following COP21 is implementation, and setting the right incentives for achieving the INDCs will be essential. This is complicated by the Trump Administration's decision in 2017 to begin the process of withdrawing the United States from the Paris Agreement.

The International Energy Agency and most scientists agree that the INDCs, in their current form, are insufficient to avoid the worst effects of climate change (IEA 2015). In addition to implementing mitigation efforts, countries will also need to undertake adaptation initiatives to adjust to the realities of a warmer planet. These may include population shifts from exposed areas or new infrastructure and housing better suited to withstand new climate risks.

**TABLE 4.4.**

| Greenhouse Gas Emissions: Target Reductions, Paris Agreement, December 2015 | |
|---|---|
| **United States**[1] | Between 26 percent and 28 percent below 2005 levels by 2025 |
| **European Union**[1] | 40 percent below 1990 levels by 2030 |
| **Japan**[1] | 26 percent below 2013 levels by 2030 |
| **Canada**[1] | 30 percent below 2005 levels by 2030 |
| **China**[1] | 60 percent to 65 percent below 2005 levels by 2030 ($CO_2$ emissions intensity) |
| **India**[2] | 33 percent to 35 percent below 2005 levels by 2030 ($CO_2$ emissions intensity) |
| **Russia**[1] | 25 percent to 30 percent below 1990 levels by 2030 |
| **Brazil**[1] | 37 percent below national baseline scenario by 2025 |
| **South Africa**[2] | Between 398 and 614 million tons of $CO_2$ emissions by 2025 and 2030 |

Source: Admiraal and others 2015.
Note: As of November 29, 2015, 184 parties (including the European Union) had submitted their Intended Nationally Determined Contributions (INDCs) in preparation for the adoption of the Paris Agreement in December 2015.
[1]Unconditional INDC.
[2]Conditional INDC.

But mitigation and adaption—alone or in tandem—will be neither fully acceptable nor sufficient, given that climate change will be irreversible. For instance, some ecosystems will be unable to adapt to rising temperatures and the result will be substantially reduced biodiversity. Short of pervasive and economically viable carbon capture and storage technologies, the planet will be exposed to potentially catastrophic climate risks (see Meehl and others 2007) unless renewables become cheap enough to guarantee that substantial fossil fuel deposits remain underground for a very long time, if not forever. In economic terms, the price of fossil fuels should reflect the negative externalities that their consumption inflicts. That means the price of carbon should equal the social cost of carbon, which is the present discounted value of marginal global warming damage from burning one ton of carbon today.[7] In other words, the best way to meet the challenge of implementing the INDCs would be a global carbon tax, which is the most efficient way to reduce emissions.

Politically, low fossil fuel prices may provide an opportunity to eliminate energy subsidies and introduce carbon prices at a politically acceptable, even if not optimal, level. Global carbon pricing will have important redistributive implications, both across and within countries, and so the best approach is gradual implementation, complemented by mitigating and adaptive measures that shield the most vulnerable.[8] A low initial carbon price could rise gradually over time toward efficient levels, perhaps through future international agreements. Agreement on an international carbon price floor would be a good starting point in such a process and would definitely be preferable to a failure to address

[7]See D'Autume, Schubert, and Withagen 2016; Golosov and others 2014; and Rezai and van der Ploeg 2014 for useful references on the design of carbon taxes.

[8]Farid and others (2016) discuss macro and financial policies to address climate change.

comprehensively the problem of greenhouse gas emissions, which would expose this and future generations to incalculable risks (Stern 2015).[9]

Developing economies, in particular, may need aid to facilitate the clean technology imports necessary to enable them to participate in the energy transition.[10] Such aid would help offset the transitional costs associated with removing carbon subsidies and levying positive carbon taxes. The Green Climate Fund was established within the framework of the United Nations to help developing economies put in place adaptation and mitigation practices. It is intended to be the centerpiece of efforts to raise climate finance to $100 billion a year by 2020. The IMF is also supporting its member countries in dealing with the macroeconomic challenges of climate change.[11]

## CONCLUSIONS

Shifting away from fossil fuels to clean, renewable energy resources or to nuclear energy can help reduce greenhouse gas emissions. And moving from coal to natural gas for electricity generation can also contribute significantly to reducing carbon emissions. For each country, developing and expanding its renewable energy sector will require an overhaul of the existing energy infrastructure and involve training and retooling the labor force. These transformations will eventually be a source of jobs and cleaner, more sustainable growth, but the process also involves transitions and disruptions that must be addressed. Indeed, with global energy prices at historically low levels and with prospects for such low prices to persist, with interest rates are at historic lows, and with countries around the world looking to infrastructure spending both to support demand and to spur future potential growth, the time may be right to undertake the investment needed to jumpstart the energy transition.

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[9]Li, Narajabad, and Temzelides (2014) show that, even when some degree of uncertainty is accounted for, taking into account the damage from climate change can cause a significant drop in optimal energy extraction.

[10]Collier and Venables (2012) discuss Africa's needs to achieve its potential in hydro and solar power.

[11]See "The Managing Director's Statement on the Role of the Fund in Addressing Climate Change" (IMF 2015).

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PART II

# Metal and Food Markets

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CHAPTER 5

# Metal Prices Signal Global Economic Shifts

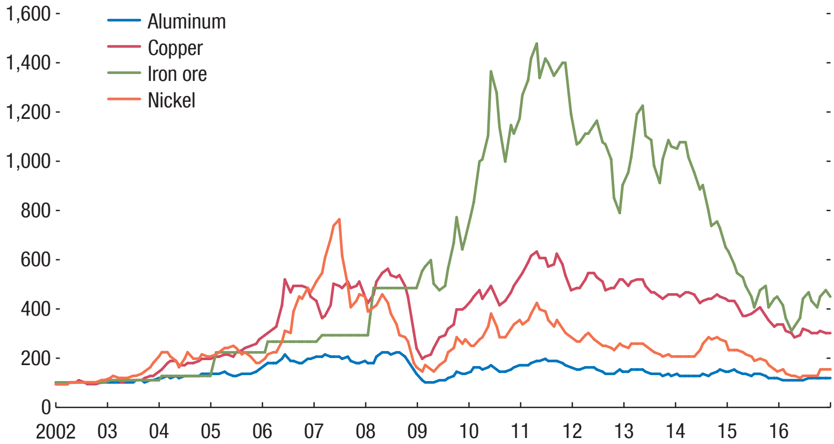
Metal prices have been declining since 2011 after a long upward trend that began in the early 2000s (Figure 5.1). Some analysts consider this to be a signal that we are nearing the end of the so-called commodities supercycle. Although that is difficult to ascertain with confidence, the prolonged fall in metal prices is consistent with a more typical commodity boom-and-bust cycle. Indeed, after a period of high metal prices during the 2000s, investment and capacity in the sector increased substantially. At the same time, high prices led to downward adjustments in demand. Those adjustments contributed to a gradual decline in metal prices after 2011, which in turn lowered profit expectations and reduced investment in the sector, especially in high-cost mines. The decline in investment will eventually reduce capacity, and lower production should eventually lead to a rebound in metal prices and, in turn, an upturn in investment. In fact, prices did rebound to some degree in 2016.

Understanding the evolution of metal markets is important for at least two reasons. First, metals are at the heart of the world economy because they are key intermediate inputs to industrial production and construction. Metal markets are thus shaped by shifts in the volume and composition of global demand and supply, and transformations in metal markets also signal important changes in the world economy. Second, for some countries, metal exports are a large portion of total exports, and fluctuations in metal prices can have important macroeconomic consequences. This chapter addresses the following questions:

- What are metals?
- Where are the primary centers of metal production and consumption?
- How have metal markets evolved?
- What lies ahead?

Prepared by Rabah Arezki (team leader), Rachel Yuting Fan, Akito Matsumoto, and Hongyan Zhao, with contributions from Frederik Giancarlo Toscani and research assistance from Vanessa Diaz Montelongo.

**Figure 5.1. Metal Price Indices**
*(2002 = 100)*




Sources: IMF, Primary Commodity Price System; and IMF staff calculations.

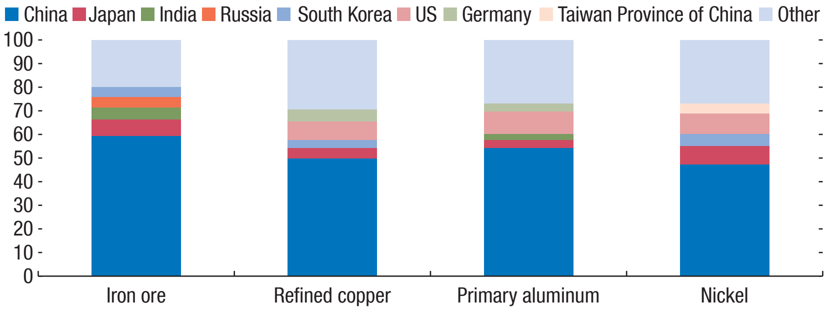
## WHAT ARE METALS?

Metals are mineral bodies that come in a variety of forms. "Base metals" are those that oxidize or corrode relatively easily. Among the base metals, a distinction is made between ferrous and nonferrous metals. Ferrous metals, typically iron, tend to be heavy and relatively abundant. Nonferrous metals, which are generally more expensive than ferrous metals, do not contain iron in significant amounts and have desirable properties such as low weight (for example, aluminum), higher conductivity (for example, copper), or nonmagnetic properties or resistance to corrosion (for example, zinc and nickel). In contrast to base metals, "noble metals" are resistant to corrosion or oxidation. These include the precious metals—so called because of their perceived scarcity—such as gold, platinum, silver, rhodium, iridium, and palladium. Chemically, precious metals are less reactive than most elements and have high luster and high electrical conductivity.

Unless otherwise indicated, this chapter focuses on four main base metals: iron ore,[1] copper, aluminum, and nickel. All four experienced price declines since 2011, although to varying degrees (Figure 5.1). These metals are used for many purposes but especially for construction and machinery because of their ductility and malleability.

[1]Iron ore is rock from which iron metal can be economically extracted.

Figure 5.2. Metal Consumption in 2015
*(Share of world consumption, percent)*

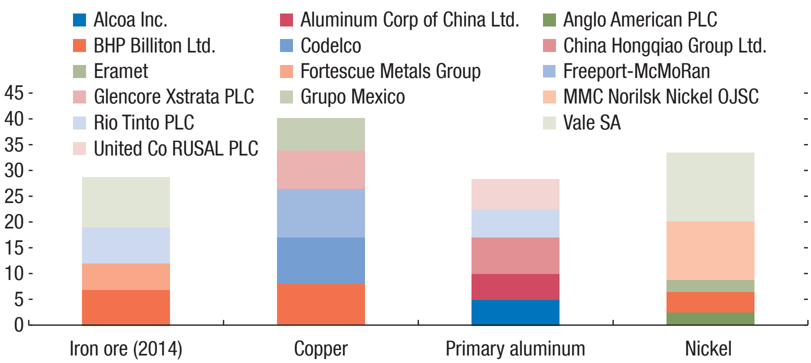



Sources: Bloomberg Finance L.P.; World Bureau of Metal Statistics; and IMF staff calculations.

## WHERE ARE THE PRIMARY CENTERS OF METAL PRODUCTION AND CONSUMPTION?

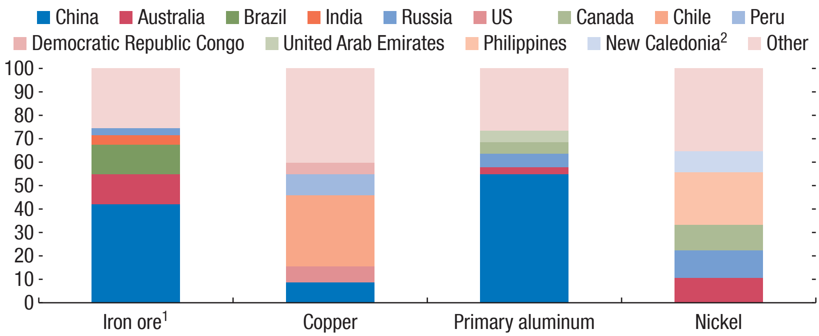
Metal production and metal consumption are concentrated in a few countries, but the locations often overlap (Figures 5.2 and 5.3). China is a primary center for both consumption and production, which reflects its importance in global industrial production. A few individual entities, including some multinationals and state-owned corporations, control large market shares in the production and refining of some key metals. This high degree of concentration at times causes concern about the potential for market manipulation and collusion, for example, through output restrictions, export bans, and/or stock accumulations (see Rausser and Stuermer 2014 for an analysis of collusion in the copper market).

Figure 5.3. Top Five Companies Producing More Than 2 Percent of World Production
*(Share of world production, percent)*




Sources: Bloomberg Finance L.P.; and IMF staff calculations.

Figure 5.4. Metal Production in 2015
*(Share of world production)*




Sources: Bloomberg Finance L.P.; World Bureau of Metal Statistics; and IMF staff calculations.
[1]Mine production for China is based on crude ore, rather than usable ore, which is reported for the other countries. [2]Overseas department of France.

From an economic point of view, iron ore is by far the most important base metal, with about $225 billion in global sales.[2] Nearly all iron ore goes toward production of steel, which is used for construction, transportation equipment, and machinery. Iron ore prices were previously determined largely through negotiations between Japanese steelmakers and Japanese iron ore producers. The market has recently become more transparent, and the price on delivery at Chinese ports is now used as the benchmark price. Because mining iron ore is capital intensive, production is concentrated among a few producers (Figure 5.4), and production levels depend crucially on the level of investment, which has declined in recent years. The top iron-ore-producing country, China, accounts for about half of global production, followed by Australia and Brazil.[3] The demand for iron ore comes primarily from steel-producing countries such as China, which consumes more than half of world production. In turn, half of world steel production is used for construction. In advanced economies, the use of scrap metal is becoming more important, reducing the demand for iron ore.

Copper is the second most important base metal by value, at roughly $130 billion annually.[4] Copper is used for construction and electrical wire. Chile is the largest producer, followed by China and Peru. Relatively few companies are involved in copper production; Chile's Codelco is the largest. Copper prices have

[2]World production of iron ore is currently 3 billion metric tons with its metal content weighing about 1.4 billion tons, according to the U.S. Geological Survey. The price of iron ore with 62 percent iron content was evaluated at $100 a metric ton, close to the average price in 2014

[3]China's share, however, is much smaller when the ore's metal content is taken into consideration. Iron ore is also important for individual countries, such as Ukraine, which relies on coal and iron ore to produce steel.

[4]World mine production was 18.7 million metric tons in 2014. It is evaluated at $7,000 a metric ton, close to the average price in 2014.

been more transparent than those for iron ore because copper futures markets and London Metal Exchange settlements are used as benchmarks. China consumes about half of all refined copper.

The third most important base metal by value is aluminum, at $90 billion annually.[5] Aluminum is used in the aerospace industry as well as other industries requiring light metal. Aluminum is slightly different from other base metals because it requires refining, typically from bauxite which is quite abundant. That refining process is very energy intensive, and as a result, large producers of aluminum are located where electricity is cheap. The largest producer is China, followed by Russia, Canada, and the United Arab Emirates. Aluminum prices are more stable than those of other metals because electricity prices are heavily regulated in most countries. Recycling has become an important part of aluminum production because recycling is much less energy intensive than producing primary aluminum. China consumes about half the world's production of primary aluminum. In contrast, developed economies rely more on recycling and in turn have less influence over primary aluminum prices.

The fourth most important base metal is nickel, at about $40 billion annually.[6] Nickel is used in alloys such as stainless steel. The Brazilian mining company Vale and Russia-based Norilsk Nickel are the top two producers, and together they account for 23 percent of global production. Conventional roasting and reduction processes are used to extract nickel metal from ore, typically at purity levels greater than 75 percent. China consumes about half the world's smelted and refined nickel; the next largest consumer is Japan.

Nickel markets have been affected by the policies of producing countries because producers sometimes seek to take advantage of the oligopolistic nature of these markets. Indonesia, which produced 27 percent of global output in 2012, imposed an export ban on nickel ore in January 2014 to increase incentives for domestic processing. The Philippines and New Caledonia (a dependent territory of France in Oceania) have sought to use the opportunity created by that ban to increase their own market share, but they may be unable to meet the portion of Chinese demand that previously relied on Indonesian production. On the other hand, the global inventory of refined nickel has been increasing, suggesting a supply glut.

## HOW HAVE METAL MARKETS EVOLVED?

In recent decades there have been dramatic shifts in the volume and the structure of both demand for and supply of major metals.[7] Global production has

[5]World primary aluminum production was about 50 million metric tons, and the associated price was $1,900 a metric ton.

[6]Nickel mine production was 2.4 million tons in 2014, and the price of refined nickel was roughly $17,000 a metric ton.

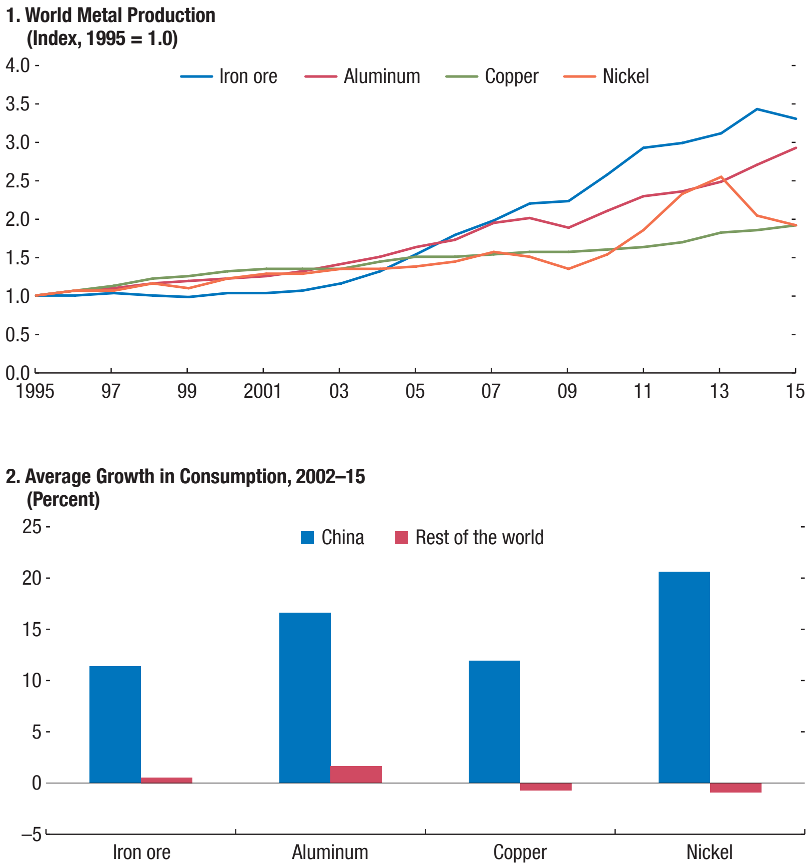
[7]Metals include aluminum, copper, iron ore, lead, nickel, tin, uranium, and zinc.

increased for most metals owing to the rapid investment in capacity that occurred during the 2000s (Figure 5.5, panel 1). The concentration of demand has shifted from advanced economies toward emerging market and developing economies and from the western hemisphere and Europe toward Asia—especially China because of its rapid growth (see Figure 5.3; Figure 5.5, panel 2; Figure 5.6, panel 1). On the supply side, the so-called frontier of extraction of nonferrous metals, including precious metals such as gold, has shifted advanced economies to emerging market and developing economies because of the rapid improvement in the investment climate first in Latin America and then in sub-Saharan Africa (see the Annex for further detail on this dramatic shift in global metal supplies). High-income member countries of the Organisation for Economic Co-operation and Development (OECD) accounted for close to half the discoveries of major mines between 1950 and 1990. Since 1990, sub-Saharan Africa and Latin America and the Caribbean have doubled their shares of such discoveries, although the actual level has fallen to only about half that in the period running from 1950 to 1990. The pattern of global trade in metals has radically changed as a result of this shift in the location of major discoveries. It should be noted that for steel and aluminum, production tends to occur in countries that not only have combined deposits of iron ore or bauxite—which are abundant worldwide—but that also have port facilities, easy access to energy, and proximity to markets.

On the demand side, growth has been the driving force behind global metal consumption since the early 2000s (see Figure 5.6), and the growth of Chinese demand largely explains the shift in global demand toward Asia. In fact, China is now the main consumption center for most metals. Metal consumption in India, Russia, and Korea has also increased but still lags far behind China's, whereas consumption in Japan has stagnated somewhat. The rapid rise in demand from emerging markets has been a key factor in determining the price levels of metal and other commodities (for systematic evidence on the importance of China and emerging markets in driving metal and oil prices, see Gauvin and Rebillard 2015; Aastveit, Bjørnland, and Thorsrud 2015).

On the supply side, investment in the metal sector has been on the decline, although this trend should reverse in the wake of the price rebound that began in 2016. Indeed, available data on investment by major iron-ore-producing companies suggest that the rapid increase in investment during the period of high metal prices in the early 2000s was followed by a gradual decline since 2011 that closely followed the trajectory of metal prices (Figure 5.6, panel 3). For ferrous metals, investment is a good indicator of future supply capacity, as mentioned. For nonferrous metals, a much more relevant indicator of supply is the actual quantity available from mineral deposits. A unique data set on new discoveries of mineral deposits is used here to assess the emergence of new frontiers for metal extraction, and that assessment indicates that prices played little role in driving discoveries of mineral deposits (see the Annex). Instead, rapid improvements in institutions in Latin America and Africa, including those related to property rights and political stability, led to a gradual increase in the number of major discoveries of metals in those regions since the 1990s. These findings have important implications both

Figure 5.5. Evolution of the Metal Market



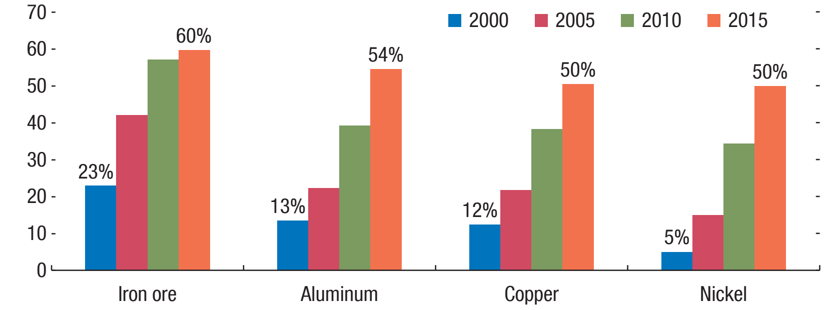

Sources: Bloomberg Finance L.P.; World Bureau of Metal Statistics; and IMF staff calculations.
Note: The figures reported for iron ore production in China are in crude terms relative to what other countries report. Iron ore production data should thus be interpreted with caution: production figures for iron ore are not consistent with those for consumption because the latter are based on effectively usable iron ore.

for the welfare of individual countries and for our global understanding of the balance of forces shaping metal markets and the pattern of global trade in metals.

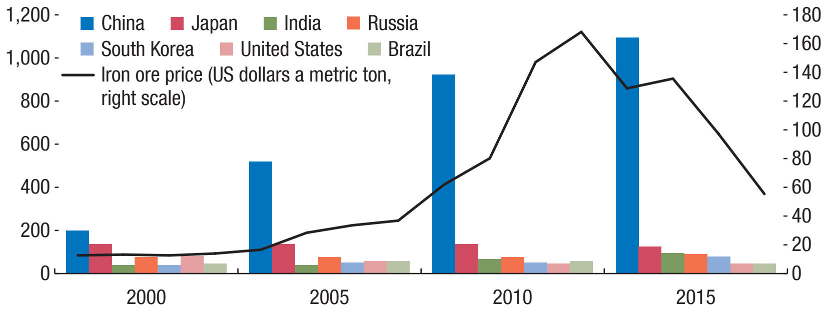
The overall pattern of global metal trade in recent decades has been characterized, as noted, by a shift in the major destination countries from the western hemisphere and Europe to Asia and a shift in the source countries from advanced economies to emerging market and developing economies. In 2002, metals were exported mainly from Canada and Russia to the United States or from Australia to Japan, Korea, and China. By 2014 almost half of metal exports were going from Australia, Brazil, and Chile to China. China has become the

## Figure 5.6. Development of the Metal Market

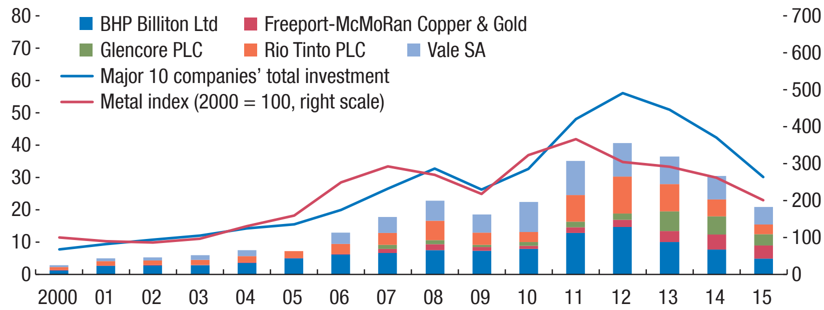
**1. China's Share of Global Consumption**
**(Percent)**




**2. Development of Iron Ore Demand and Iron Ore Price**
**(Millions of metric tons, unless noted otherwise)**




**3. Investment of Major Metal Companies and Metal Price Index**
**(Billions of US dollars, unless noted otherwise)**




Sources: Bloomberg Finance L.P. ; IMF Primary Commodities Price System; World Bureau of Metal Statistics; and IMF staff calculations.
Note: Investments are deflated by the mining price index and oilfield machinery, rebased to 2000 = 100. Total investment is the sum of capital expenditures for Anglo American PLC, BHP Billiton Ltd., Corp. Nacional del Cobre de Chi, Freeport-McMoRan Copper & Gold, Glencore PLC, Grupo Mexico SAB de CV, Mitsubishi Corp, Mitsui & Co. Ltd., Rio Tinto PLC, and Vale SA.

**TABLE 5.1**

**Metal Trade Evolution (millions of U.S. dollars)**

**1. Bilateral Metal Trade, 2002**

| Country | China | Germany | Japan | Korea | United States |
|---|---|---|---|---|---|
| Australia | 1,043 | 63 | 2,309 | 1,067 | 181 |
| Brazil | 605 | 360 | 700 | 179 | 754 |
| Canada | 90 | 270 | 353 | 212 | 4,232 |
| Chile | 784 | 197 | 768 | 541 | 687 |
| Russia | 196 | 161 | 716 | 93 | 1,061 |

**2. Bilateral Metal Trade, 2014**

| Country | China | Germany | Japan | Korea | United States |
|---|---|---|---|---|---|
| Australia | 52,153 | 53 | 10,985 | 6,283 | 268 |
| Brazil | 12,851 | 1,194 | 3,004 | 1,368 | 1,207 |
| Canada | 2,496 | 311 | 1,522 | 1,074 | 8,815 |
| Chile | 15,249 | 415 | 4,875 | 3,252 | 2,349 |
| Peru | 5,621 | 593 | 1,030 | 856 | 351 |

Sources: U.N. Comtrade; and IMF staff calculations.
Note: Data shows exports of metals from the countries listed at the left of the rows to the countries listed at the tops of the columns. The gradient of color from green to red refers to the absolute size of trade volume in each panel.

largest importer of metals, with its share increasing from less than 10 percent in 2002 to 46 percent in 2014 (Table 5.1).

Many developing economies depend heavily on metal exports (Table 5.2). For Chile, Mauritania, and Niger, for example, metals now account for more than half of their total exports of goods. Countries whose metal exports as a share of GDP have risen dramatically are vulnerable to fluctuations in metal prices. Since 2002, the discovery of new metal deposits has dramatically changed the list of leading exporters (as a percentage of GDP), adding to the list of resource-dependent countries that face new challenges in terms of macroeconomic management.

China has recently attempted to rebalance its economy away from investment-led growth toward growth supported by more domestic consumption. Metal use is intensive in machinery, construction, transportation equipment, and manufacturing industries, and so the declining growth in these sectors has slowed the growth of Chinese demand for metal since 2010 (Figure 5.7). The global metal price index has decreased correspondingly. On one hand, with increased domestic consumption, the share of the services sector in the Chinese economy will

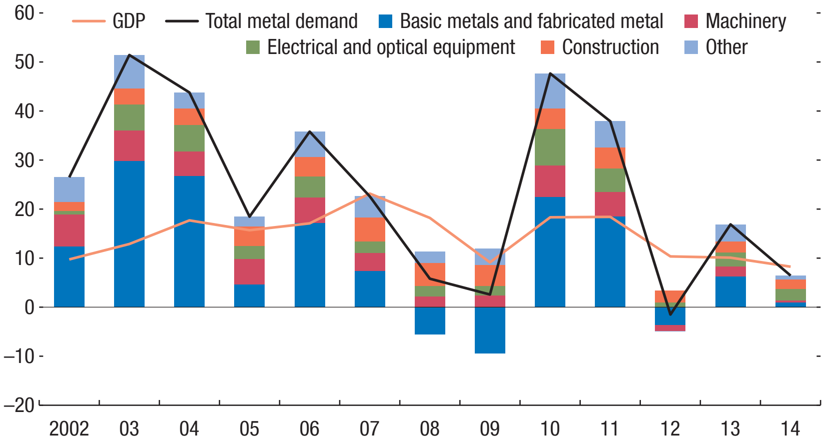
**TABLE 5.2**

**Net Metal Exports**
*(Percent of GDP)*

| | | |
|---|---|---|
| **2002** | Zambia | 11.27 |
| | Chile | 8.82 |
| | Guinea | 8.02 |
| | Mozambique | 7.27 |
| | Papua New Guinea | 7.07 |
| | Niger | 4.31 |
| | Iceland | 4.21 |
| | Peru | 3.62 |
| | Namibia | 2.88 |
| | Bolivia | 2.16 |
| **2014** | Mongolia | 26.52 |
| | Mauritania | 21.06 |
| | Chile | 15.00 |
| | Zambia | 14.76 |
| | Iceland | 8.67 |
| | Peru | 6.23 |
| | Niger | 5.94 |
| | Australia | 5.23 |
| | Bolivia | 4.75 |
| | Guyana | 4.64 |

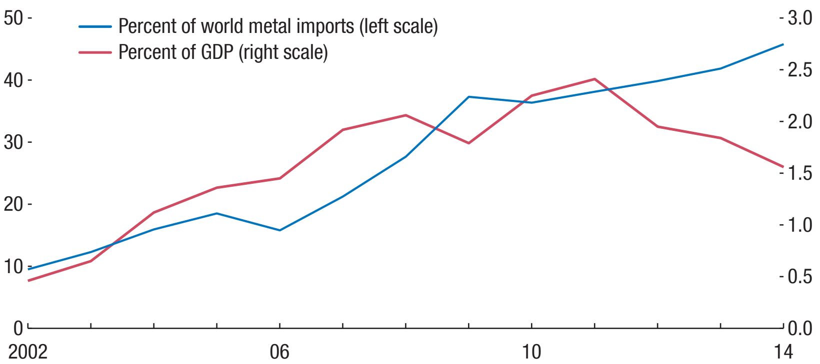
Sources: IMF, World Economic Outlook Database; UN Comtrade; and IMF staff calculations.

**Figure 5.7. China: Composition of Metal Use, Growth Rates by Sector**
*(Percent)*



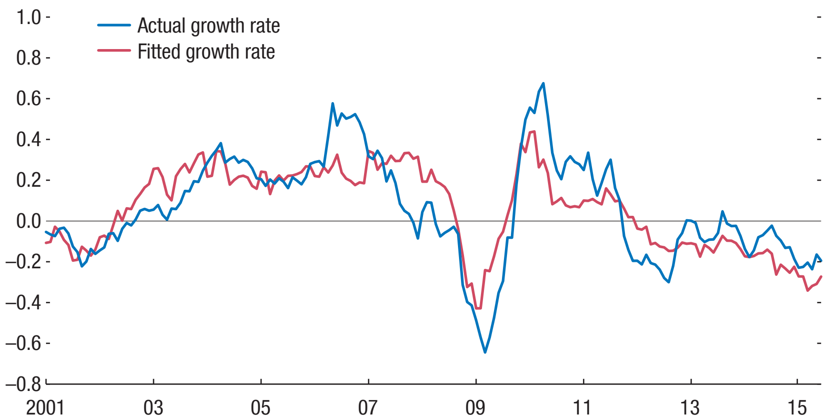

Sources: National Bureau of Statistics of China; World Input-Output Database; and IMF staff calculations.
Note: The growth rates of total demand for metals are calculated as the weighted sum of output growth rates for each sector, with weights being the shares of metal input in the individual sector in the total economy. The share of metal input for each sector is based on the World Input-Output Database. The value of the share of metal input in the most recent year (2011) was chosen, given that the share of metal input has been quite stable over the years. Because output data for China are not available at the sector level, profit data by sector were used as a proxy for most of the industries. For nonindustry sectors, GDP data by industrial classification were used.

**Figure 5.8. China: Metal Imports**
*(Percent)*




Sources: IMF World Economic Outlook Database; UN Comtrade; and IMF staff calculations.

Figure 5.9. Growth Rates of Metal Price Index
*(Index, 2005 = 100)*




Sources: IMF, Primary Commodity Price System and Global Data Source; and IMF staff calculations.
Note: The figure shows the actual and fitted annual growth rate of the metal price index. The fitted growth rate is based on a regression of the annual growth rate of the metal price index on the annual growth rate of China's industrial production.

increase, and this should also slow the consumption of metals. On the other hand, infrastructure and housing needs in China remain high, and strong construction growth can increase metal demand, as seen during 2016. Even so, despite the dramatic increase in Chinese metal imports, these represent less than 2 percent of China's GDP (Figure 5.8).

## WHAT'S AHEAD?

The slower pace of investment in Chinese manufacturing and the ample global supply of metals have both exerted downward pressure on metal prices in recent years. However, the decline in metal prices started much earlier, and it therefore makes sense to explore what may lie ahead. It is helpful in this regard to go beyond the price outlooks generated by the behavior of futures markets and instead to review the forces that underpin the demand and supply of metals.

On the demand side, Chinese economic growth is projected to slow further, albeit gradually, but with considerable uncertainty around the timing and the nature of the shift. In broad terms, however, the effect of slower growth in China will be to lower metal prices (Figure 5.9).[8] In addition, a slower pace of growth in China's industrial production could produce further metal price declines.

[8]This conclusion is the result of a basic econometric exercise using historical data and regressing the annual change of the logarithm of China's industrial production as an independent variable and the annual change of the logarithm of the IMF's metal price index as the dependent variable. The

Outside China, a number of advanced economies have prioritized infrastructure spending, including the United States, and such spending is sometimes associated with stronger metal demand. However, overall metal consumption by advanced economies is lower than in emerging markets, and advanced economies also rely more heavily on recycled metals, both of which would limit the increased metal demand likely to result from increased infrastructure spending.

On the supply side, declining investment in the metal sector is unlikely to lead to a substantial price rebound in the near future, although temporary outages or the closure or exiting of large mines would help prices recover. Low energy prices have in fact helped keep down or reduce mining and refining costs, including for copper, steel, and aluminum. High-cost or high-pollutant mines would certainly close first, considering that current metal prices may be close to the breakeven point for these high-cost mines. However, SNL Metals & Mining research suggests that metal prices will have to fall much further to trigger significant reduction in capacity due to plant closures. that prices would need to fall further before substantial capacity becomes vulnerable to closure (SNL Metals & Mining 2015). Moreover, the expansion of metal extraction in Latin America and Africa as a result of an improved investment climate is unlikely to be reversed to any great extent; to the contrary, the investment climate in those regions can be expected to steadily improve. As a result, ample global supply will likely continue to push down metal prices.

The interplay between weaker demand and a steadily increasing supply, given the existing cost structure in global metal markets, points to a continued glut, leading to a low-for-long price scenario. In turn, the risk associated with such a scenario is that investment will continue to falter and lead to a sharp increase in prices down the road.

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exercise shows that 60 percent of the variance in metal prices is explained by fluctuations in China's industrial production.

## ANNEX 5.1. THE NEW FRONTIERS OF METAL EXTRACTION

The fundamental factors that underpin demand for primary commodities, including metals, garner a great deal of attention, but supply-side factors do not. As described in the main part of this chapter, the center of gravity for global metal demand has shifted from the western hemisphere toward Asia as a result of the high growth in emerging markets—especially China—over the past two decades. And while demand for metals emanating from emerging markets has been a key driver of recent global market developments, progress in the quality of institutions has helped to increase the supply of metals and to shift its composition. In fact, developments on the supply side have been perhaps just as dramatic as on the demand side, particularly the discoveries of major metal deposits that signal new potential for a further expansion of global supply. This analysis shows how the frontiers of metal exploration and extraction have shifted from advanced to emerging and developing economies.[1]

### Metal Deposit Discoveries

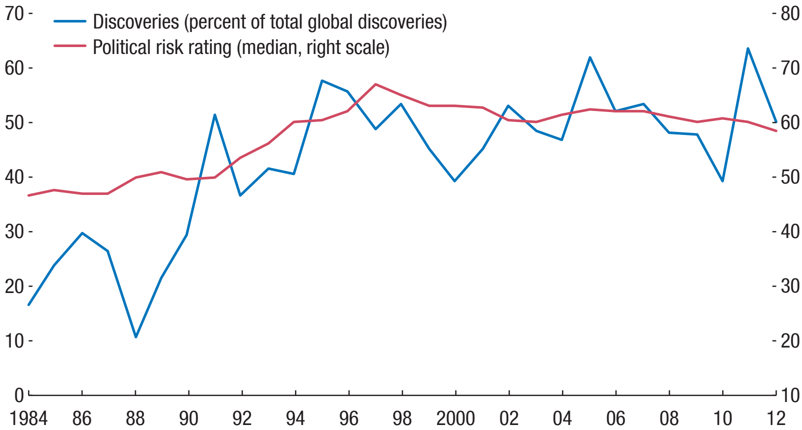
Available data suggest that developing economies have substantial deposits of metals that have yet to be discovered. There is an estimated $130,000 of known subsoil assets beneath the average square kilometer of the member countries of the OECD, which contrasts with only about $25,000 for African countries (Collier 2011 and McKinsey Global Institute 2013). It is unlikely that those differences represent actual variations in the geological formations in advanced and developing economies. Instead, they can be attributed to institutional differences, specifically the quality of property rights and the stability of political institutions, that can dampen exploration efforts in developing economies. There were rapid and significant improvements in the institutional environments of many developing economies during the 1990s, however, and a cursory look at the data on political risk seems to indicate that the timing of these improvements coincides with an increase in the share of metal discoveries in Latin America and Africa (Figure 5.1.1).

Figure 5.1.2 shows how the frontier of metal exploitation has gradually moved from advanced to developing economies. Even as the total number of discoveries remained broadly constant, the distribution changed significantly. High-income OECD member countries accounted for 37 to 50 percent of all discoveries during 1950–89, but only 26 percent during 2000–09, whereas the shares of sub-Saharan

The authors of this annex are Rabah Arezki and Frederik Toscani.

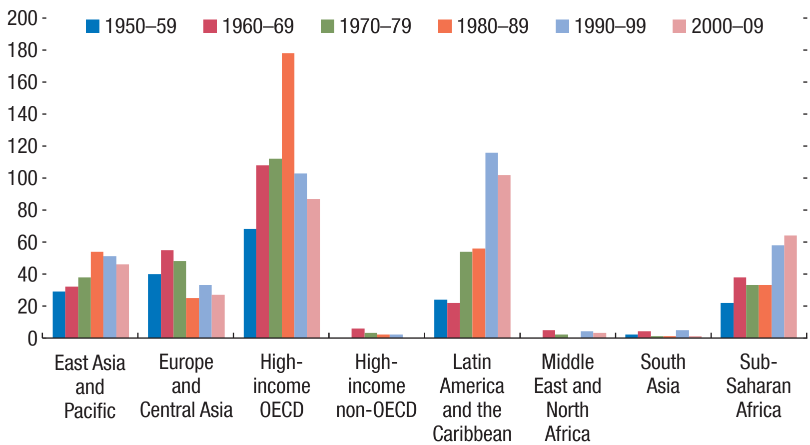
[1]The data used in this annex are from MinEx Consulting. The list of metals used in the analysis is comprehensive and includes precious metals and rare earth elements. The data set excludes iron ore and bauxite, which tend to be relatively more abundant than other metals and require for their exploitation proximity to port facilities in the case of the former and substantial energy availability for the latter.

**Figure 5.1.1. Discoveries in Latin America and the Caribbean and Sub-Saharan Africa**




Sources: *International Country Risk Guide*; MinEx Consulting; and IMF staff calculations.

**Figure 5.1.2. Number of Mine Discoveries by Region and Decade**




Source: MInEx Consulting.
Note: OECD = Organisation for Economic Co-operation and Development.

Africa and Latin America and the Caribbean doubled. Latin America was home to the most discoveries of metal deposits since 1990.

## What Factors Drive Discoveries?

Investments in exploration and extraction activities involve sunk costs and are thus subject to the so-called hold-up problem—when two parties may both benefit by cooperating but refrain from doing so because they fear ceding to the other increased bargaining power or other advantages.[2] For an investment to be profitable, there must be a stable political environment, a low risk of expropriation, and a favorable investment climate (Acemoglu, Johnson, and Robinson 2001; Bohn and Deacon 2000). Cust and Harding (2014) provide evidence that the quality of the institutional environment substantially affects oil and gas exploration.[3] Mining operations could be considered more "expropriatable" than oil facilities because mining outputs do not move through pipelines but instead must be transported exclusively on land.

To assess the importance of institutional factors in the discovery of metal deposits, this analysis uses a three-way panel data set, a zero-inflated Poisson model with the number of mine discoveries by country, year, and type of metal as the dependent variable.[4] $N_{itm}$ denotes the number of mines discovered in country $i$ at time $t$ and for a specific metal $m$. $N_{itm}$ is assumed to follow a Poisson distribution.

The main explanatory variable of interest is a country's political risk rating, obtained from the Political Risk Index in the *International Country Risk Guide* (ICRG), which reflects property rights and political stability. Because metals differ in their abundance and location, metal fixed effects are included in the regressions. Also included are country fixed effects to capture time-invariant country characteristics that are hard to observe, such as actual geology and year fixed effects to control for technology and other global shocks. In addition, price changes are controlled for over the past five years. The baseline specification is as follows:

$$\log E\left(N_{itm}/X_{itm}\right) = a + bX_{itm}, \tag{5.1}$$

[2]The results presented in this section are also robust to an array of checks including additional controls and estimators. Arezki, Toscani, and van der Ploeg (2016) present extensive technical details and an in-depth discussion of endogeneity.

[3]Their identification strategy relies on exploiting variations in institutions and oil deposits sitting on both sides of a border.

[4]Large numbers of zeros and the heteroscedasticity of errors may imply that ordinary least squares results will be biased and inconsistent. Silva and Tenreyro (2006) suggest the Poisson pseudo–maximum likelihood estimator to address this issue. This analysis follows this suggestion and uses zero-inflated Poisson models. The count data are modeled as a Poisson count model, and a logit model is used to predict zeros.

in which $X$ includes $d$, $f$, and $g$, which are time, country, and metal fixed effects, respectively; and the key covariates, which are lagged changes in prices for specific metals, $\Delta price_{t-1,m}$ ; and the measure of political risk, *ICRG*. The key coefficients of interest are $\gamma$ and $\beta$.

It should be noted that the quality of institutions may be endogenous to metal discoveries in that these discoveries may, for instance, trigger conflicts over resources and erode institutions (Ross 2001, 2013). Any such endogeneity will tend to bias the coefficient associated with institutions toward zero, and as such, that coefficient should be interpreted as presenting a lower bound. To somewhat alleviate issues of reverse causality, the political risk rating is included with a one-year lag. In addition, lagged discoveries are controlled for, to account for the clustering of discoveries. The interactions between *ICRG* and metal price and between price and fixed effects are also explored. Other robustness checks consist of adding controls such as GDP per capita and the initial capital stock and using price levels instead of changes. The main results remain unchanged.

The *ICRG's* PRR Political Risk Rating is found to be statistically and economically significant (Table 5.1.1). The results indicate that a 1 standard deviation improvement in the PRR Political Risk Rating in a particular country—which corresponds to a move from the conditions in, for example, Mali to those in South Africa, or South Africa to Chile, or Chile to Canada—would lead to 1.2 times as many metal discoveries in that country. A thought experiment can further convey the relevant magnitude: if the median quality of property rights in Latin America and sub-Saharan Africa were to suddenly improve to equal those of the most advanced economies in each of these regions (Chile and Botswana, respectively), there would be a 15 percent increase in the number of metal discoveries worldwide, all else equal. The increase in the number of discoveries increases to 25 percent if instead the quality of Latin American and sub-Saharan African property rights were to suddenly rise to the same level as in the United States, again all else equal.

This analysis indicates that the quality of a country's institutions is an important driver of exploration for and ultimately discovery of metal deposits. Institutions affect discoveries through a variety of channels, not only on the perceptions of risk by potential foreign investors. For instance, better institutions could affect the adoption of better technologies or improve the quality of the labor force. The analysis here does not attempt to separate such additional channels.

The results also suggest that movements in metal prices during the past five years are not statistically significant in explaining the number of discoveries. Instead, the likelihood of additional discoveries appears to increase with the number of previous discoveries, as would be expected given the reduced risk of exploring close to a known deposit.

**TABLE 5.1.1.**

Impact of Political Institutions on Mineral Discoveries

| Variables | (I) Number of Discoveries | (II) Number of Discoveries | (III) Number of Discoveries | (IV) Number of Discoveries |
|---|---|---|---|---|
| **Political Risk Rating, Lagged** | **0.0216***** | **0.0171**** | **0.0192**** | **0.0195**** |
| | **(0.00729)** | **(0.00782)** | **(0.00783)** | **(0.00787)** |
| Polity2 Score, Lagged | | 0.0128 | 0.0179 | 0.0173 |
| | | (0.0155) | (0.0156) | (0.0155) |
| Stock of Discoveries, Lagged | | | 0.0161*** | 0.0162*** |
| | | | (0.00343) | (0.00344) |
| Political Risk Rating × Change in Metal Price | | | | −0.00635 |
| | | | | (0.0165) |
| Log Change in Metal Price | −0.449 | −0.464 | −0.466 | −0.0207 |
| | (0.316) | (0.320) | (0.320) | (1.159) |
| Log Change in Metal Price, Lagged | −0.334 | −0.341 | −0.345 | −0.345 |
| | (0.315) | (0.314) | (0.322) | (0.322) |
| Constant | −18.22** | −18.00* | −18.36 | −18.13 |
| | (7.164) | (9.997) | | (12.01) |
| Country Fixed Effects | YES | YES | YES | YES |
| Year Fixed Effects | YES | YES | YES | YES |
| Metal Fixed Effects | YES | YES | YES | YES |
| Observations | 37,252 | 35,480 | 31,812 | 31,812 |

Source: IMF staff calculations.
Note: Robust standard errors are in parentheses.
* $p < .10$; ** $p < .05$; *** $p < .01$.

## What Are the Implications?

The shift in the frontier of metal exploitation from advanced economies to emerging market economies will likely have important consequences for the individual countries with newly found metal deposits, especially in Latin America and Africa. Indeed, these discoveries expand the list of resource-rich countries. New mines mean more investment and jobs and increased government revenues. There are new trade routes from Latin America and Africa to emerging Asia. There are also, however, new challenges facing newly resource-rich countries in the conduct of macroeconomic policy over both the short and the long term. A future steady increase in the quality of institutions if coupled with a slowdown in demand could lead to excess supply and exercise further downward pressure on prices.

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# CHAPTER 6

# Food Supplies and Food Security

There has been debate over whether food supplies can expand sufficiently to meet the demands of an ever-increasing population since at least 1798, when the English political economist Thomas Robert Malthus published his *Essay on the Principle of Population.* According to Malthusian theory, populations grow exponentially but food supplies grow only arithmetically; at some point, therefore, the human population should outgrow its ability to feed itself. Since Malthus, a large body of literature has explored the interplay between technology, population, agriculture, economic growth, and income.[1] For most of human history—and certainly in Malthus's time—income per capita was basically stagnant. This is no longer true. The modern era is instead characterized by rapid economic growth and diverging growth and income trajectories across countries.

Nowadays the issue of food security no longer centers around food supplies—that is, the ability of humankind to produce enough food—but rather on people's access to adequate calories and nutrition.[2] As such, food security is mainly perceived as an issue facing poor countries, but the issue is broader: developments in food markets are far-reaching and indicative of structural developments at the global level.[3] Rapid growth in emerging markets, the evolving size and demographic structure of the populations of countries at every level of economic development, and technological innovation have and will continue to shape global food markets, including the structure of agriculture and the demand for food products. Furthermore, food markets are segmented and subject to multifaceted distortions created by investment and trade. This chapter takes an in-depth look at recent developments in and the likely future evolution of global food markets and discusses the implications for food security. The chapter addresses the following questions:

- What is special about food markets?

Prepared by Rabah Arezki (team leader), Claudia Berg, Christian Bogmans, Rachel Yuting Fan, and Akito Matsumoto, with research assistance from Vanessa Diaz Montelongo.

[1]See among others Galor and Weil (2000); Galor (2005 and 2011); and Gollinand, Parente, and Rogerson (2002).

[2]According to the World Food Summit (1996) declaration: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."

[3]See Arezki and others (2016) and references therein for a discussion on food price fluctuations and their consequences.

- What are the drivers of food production and consumption?
- How has global food trade evolved?
- What are the risks to food security?

## WHAT IS SPECIAL ABOUT FOOD MARKETS?

"Food" is an edible or potable substance that helps sustain life. Food crops include cereals including wheat, maize, oats, and rice; fruits and vegetables; meat; seafood; beverages, including coffee, tea, and cocoa; oilseeds such as soybeans and groundnuts; and sugar.[4] These categories differ in a variety of ways in terms of nutritional value, perishability, and storability.

As an economy develops, a smaller share of the population works in agriculture, but farming remains the primary source of income for more than 750 million people—that is 30 percent of the world's workforce. In sub-Saharan Africa agriculture employs 60 percent of the workforce (World Bank 2015a). Many millions around the world survive through cash cropping or subsistence farming. The economic process of structural transformation, which induces labor to flow from the agricultural sector (low productivity) to the industrial sector (high productivity), explains most of the rapid increase in aggregate productivity since the industrial revolution (Duarte and Restuccia 2010).

Unsurprisingly, most food products are consumed domestically—about 85 percent of food is produced in the country where it is consumed according to the World Bank (2015a). The differences in the trade patterns for various food products depend, among other things, on whether they are cash crops. Changes in transportation technology and costs have shaped the degree to which global commodities markets are integrated, including markets for food products that initially had very limited geographical reach. The transport changes occurred in two stages (Radetzki 2011). The first occurred during the latter half of the 19th century and included the introduction of refrigerated ships which enabled long-distance transport of meat and fruit. The second stage began in the 1950s but came to fruition in the 1970s and involved the introduction of huge specialized bulk carriers, along with the concomitant loading and unloading facilities in major harbors. This enabled economic transport of low-value products across vastly extended distances. The result was a further dramatic decline in the cost of shipping—particularly for extended, transoceanic transport routes—which in turn led to a convergence of food prices across regional markets.

The extent to which international price variations are transmitted across borders is often determined by taxes, subsidies, price controls, weak market integration, and local distribution costs. In general, the transmission of international price fluctuations to domestic prices is minimal, but not insignificant. In advanced economies, the average long-term pass-through of a 1 percent food

[4]Some of the aggregate figures presented here also include nonedible agricultural commodities.

price shock to domestic food prices is about 0.10 percent, and it is about 0.15 percent in emerging market economies.[5] For this reason, and because most food production is consumed domestically, local agricultural and weather conditions have the most significant effects on domestic food prices.

Food has long been a sticking point in global trade negotiations, including in talks over tariff and nontariff barriers, despite the fact that agricultural trade represents only 8 percent of merchandise trade by value according to the World Trade Organization (WTO 2015). Tariff and nontariff barriers have often been motivated by concerns over food sovereignty and by efforts to protect the livelihoods of domestic farmers. The Doha Development Round of trade negotiations, or Doha Development Agenda (DDA), under the WTO stalled in July 2008 as a result of disagreements over agriculture. More recently, exporters in both advanced and developing economies have opposed a proposal under WTO consideration for a Special Safeguard Mechanism that would allow developing economies to take contingency restrictions against agricultural imports if those imports injure domestic farmers

The rationale for the Special Safeguard Mechanism is to counterbalance official support for agriculture in exporting countries. Over the past two decades, direct agricultural support has declined in the advanced economies of the Organisation for Economic Co-operation and Development, but it has ramped up in emerging market economies, which have largely switched from taxing their farmers to providing them direct support (Figure 6.1). Historically, in advanced economies the distortions tend to favor farmers, whereas in developing economies they tend to favor urban consumers at the expense of small farmers (Anderson 2016). All countries continue to have a strong anti-trade bias in the structure of assistance to their agricultural sectors (Anderson 2016).[6] Trade policy instruments, such as export and import tariffs, subsidies, and quotas, have serious distributional consequences for consumers. Markets that are especially distorted include those for soybeans, sugar, rice, wheat, beef, pork, and poultry (Anderson, Rausser, and Swinnen 2013).[7]

## WHAT ARE THE DRIVERS OF FOOD PRODUCTION AND CONSUMPTION?

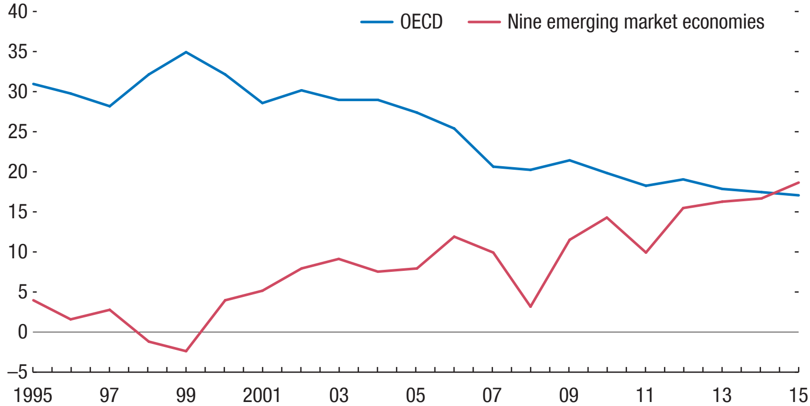
The main production and consumption centers for food are concentrated in a few countries, but they often overlap; the location of production centers varies

[5]See also Furceri and others (2016).

[6]Available data from the World Bank's World Integrated Trade Solution on the evolution of import tariffs on food products indicate that they fell from 22 percent to 11.5 percent between 1991 to 2014. Tariffs did not increase in any region. However, tariffs remained especially high in East Asia at 30 percent. In North America tariffs were the lowest at around 8 to 9 percent. These results are based on effectively applied average import tariff data for food products (in percent) calculated by aggregating, over all trading partners, the lowest applicable tariff for each partner.

[7]Cotton markets are also severely distorted.

**Figure 6.1. Producer Support Estimate**
*(Percentage of gross farm receipts)*



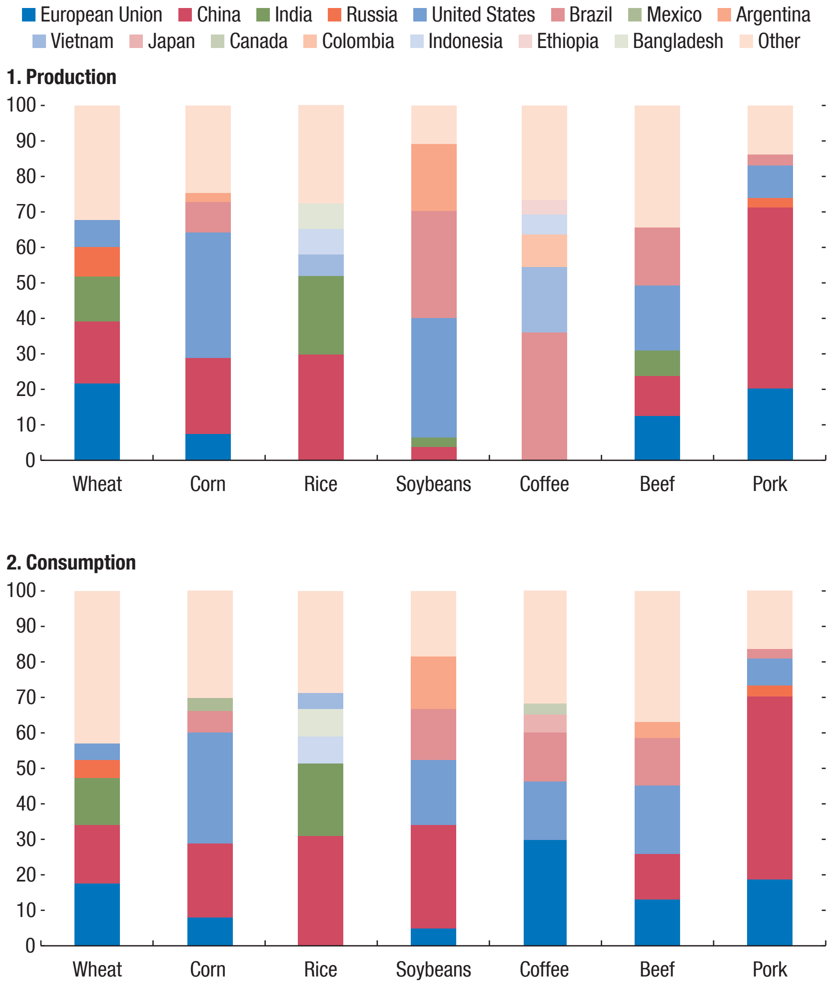

Source: Organisation for Economic Co-operation and Development (OECD) 2016, Producer and Consumer Support Estimates, Agriculture Statistics (database).
Note: OECD country classification is based on current membership. Emerging market economies are Brazil, China, Colombia, Indonesia, Kazakhstan, Russia, South Africa, Ukraine, and Vietnam. Vietnam is included from 2000 onward.

considerably with the type of food under consideration (Figure 6.2). For example, China is both a large consumer and a large producer of rice, pork, and soybeans, the latter a key animal feed. The United States is both a large producer and a large consumer of both corn and beef, and the European Union is the same for wheat. Of course, many raw food products are key intermediate inputs to the agro-industrial production of processed food products, including those for export.

Global food demand could double by 2050 compared to 2005; dietary shifts will account for around 70 percent of that increase, and global population growth will account for the remaining 30 percent (Tilman and Clark 2015). In general, population growth drives food consumption levels, and income growth reorients the composition of demand (Figure 6.3). There is a strong relationship between income per capita and consumption of meat protein, refined sugars, animal fats, oils, alcohol, and total calories (Tilman and Clark 2015). A case in point is China. China's remarkable economic growth over the past thirty years brought sustained increases in consumer income, and the Chinese have moved away from staples such as grains and rice, and toward a more diversified and higher-quality diet.[8] There are of course different preferences in individual countries which cause income growth to have varying effects on the composition of food demand. For

[8]In China, per capita food consumption of cereals decreased by 7 percent, and consumption of sugar and vegetable oils increased by 14 and 16 percent, respectively. Consumption of protein increased as well: meat by 37 percent and seafood by 42 percent. The increases in fruit and milk consumption were especially dramatic, both increasing by 115 percent.

**Figure 6.2. World Food Production and Consumption by Country, 2015**
*(Percent of world production or consumption)*

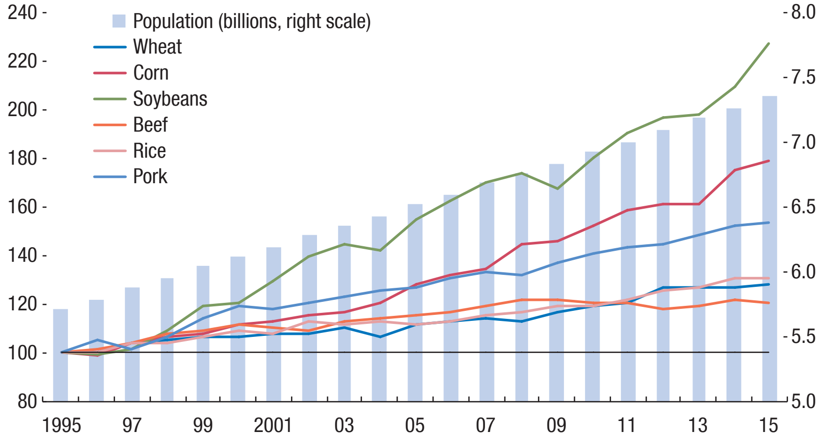



Sources: US Department of Agriculture; and IMF staff calculations.

example, India is a major exception to the general trend toward higher meat consumption, a reflection of religious traditions that favor vegetarianism.

Another driver of demand for food, in addition to population and income growth, is the use of agricultural products, especially grains, for nonfood uses such as animal feed and fuel. For example, some types of biofuels are produced from grain (for example, ethanol from corn). The use of biofuels has grown exponentially over the past decade, and this has pressure on food markets and has been blamed for food price increases (Chakravorty, Hubert, and Marchand 2015).

**Figure 6.3. Population and World Food Consumption**
*(Index, 1995 = 100, unless noted otherwise)*




Sources: US Department of Agriculture; World Bank, *World Development Indicators*; and IMF staff calculations.

The availability of arable land and certain types of technology and equipment also drive food production levels. Most of the unused land that is suitable for agriculture is located in developing regions—primarily sub-Saharan Africa and South America, as shown in Table 6.1. The global population is forecast to reach 9.7 billion by 2050, up from 7.3 billion in 2015 (United Nations 2015). Almost half of this population growth—1.3 billion people—will occur in Africa, with Asia adding an additional 0.9 billion people. This population growth will require increasing food calorie production by 70 percent by 2050 (International Food Policy Research Institute 2016). If all unused land were put into service by then, all else equal, total food production would help feed 9 billion people—far fewer than the expected global population of 9.7 billion. It is important to note that these rough calculations leave aside other factors that could either increase overall production such as technological innovations or reductions in food waste, or decrease it, such as warmer temperatures, water shortages, or land degradation.

The food supply increases that will be necessary to feed a growing global population should come mostly from productivity increases. Land use expansion for agriculture should be limited to the extent possible to ameliorate environmental and social concerns such as biodiversity loss, ecosystem degradation, increased carbon emissions, and conflict over traditional land-use rights. The challenge therefore, is to increase productivity on currently cultivated land and slow the rate of land degradation and deforestation. The potential to increase agricultural productivity is especially high in sub-Saharan Africa, where yields are 50 percent below potential levels (Fischer and Shah 2011).

**TABLE 6.1.**

## Used-to-Available Land by Region, 2013
*(Thousands of hectares)*

| | North Africa | Sub-Saharan Africa | South America | North America | Europe | Oceania | Asia | World |
|---|---|---|---|---|---|---|---|---|
| Used Land | 46,151 | 221,805 | 192,393 | 205,091 | 292,457 | 48,912 | 568,454 | 1,575,263 |
| Unused Suitable Land | 46,595 | 162,198 | 130,946 | 7,242 | 27,189 | 15,628 | 13,392 | 403,190 |
| Total Available Land | 92,746 | 384,003 | 323,339 | 212,333 | 319,646 | 64,540 | 581,846 | 1,978,453 |
| Ratio Used/Available | 0.50 | 0.58 | 0.60 | 0.97 | 0.91 | 0.76 | 0.98 | 0.80 |

Sources: Food and Agriculture Organization of the United Nations (FAO), FAOSTAT and GAEZ; and IMF staff calculations.

Notes: Used land is the total of arable land and land under permanent crops, from FAOSTAT. Unused suitable land is calculated from GAEZ. Arable land is land under temporary agricultural crops, temporary meadows for mowing or pasture, under market and kitchen gardens, and temporarily fallow (less than five years). Land under permanent crops is land cultivated with long-term crops that do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under "forest"). Permanent meadows and pastures are excluded from land under permanent crops. Unused suitable land is land that is suitable for agriculture, not forested, not protected, and not currently in use. Land is considered suitable if it is ranked by GAEZ as highly or very highly suitable for 1 crop out of 5 (maize, soybeans, wheat, sugarcane, palm oil).

## HOW HAS GLOBAL FOOD TRADE EVOLVED?

In recent decades the patterns of global food demand have shifted more than the patterns of global food supply. As for other commodities, demand for food has shifted from the western hemisphere and Europe toward Asia because of differences in population growth that affect the level of demand and changes in income that affect the composition of demand. The supply shift from advanced economies toward emerging market and developing economies has been less pronounced for food than for other commodities such as minerals and metals. Although some emerging markets have increased their shares, the lion's share of global food trade is still sourced from advanced economies (Table 6.2). That is true despite potentially high returns on capital invested in the agricultural sector in many developing economies which would justify an inflow of capital into agriculture in those economies (see, for example, Gollin, Lagakos, and Waugh 2014a and 2014b).

There are wide gaps across countries in agricultural yields, which is a measure of land productivity defined as crop production per unit of land under cultivation (Table 6.3). These gaps reflect multifaceted impediments to investment and technology transfers in the agricultural sectors of developing economies. There is limited evidence of any convergence in the levels of agricultural productivity in those economies with the levels in advanced economies. The example of maize demonstrates the huge disparity between agricultural yields in the United States and in sub-Saharan Africa (Figure 6.4). There was a spike in large-scale, cross-border land acquisitions after food prices rose rapidly following the food crisis of 2007–08. This suggests that capital has started to flow from advanced economies into the agricultural sector in developing economies, but also reveals some important fault lines between investors and recipient countries (Box 6.1). Specifically, because many of these land deals occur in countries that are "food insecure," the detrimental effects of a future food crisis could be amplified. Also, it is not assured that new investors will help local producers integrate into existing supply chains, invest in local infrastructure or other public goods, or adequately compensate displaced land users.

**TABLE 6.2.**

Food Exports
*(Share of global exports)*

| Region | 1990 | 2000 | 2013 |
|---|---|---|---|
| OECD | 0.7766 | 0.7406 | 0.6240 |
| Non-OECD | 0.2234 | 0.2594 | 0.3760 |
| Brazil | 0.0236 | 0.0292 | 0.0661 |
| China | 0.0370 | 0.0411 | 0.0393 |
| India | 0.0051 | 0.0103 | 0.0263 |
| Argentina | 0.0258 | 0.0281 | 0.0262 |
| Indonesia | 0.0046 | 0.0108 | 0.0224 |

Sources: Food and Agriculture Organization of the United Nations (FAO); and IMF staff calculations.
Note: Food refers to food excluding fish aggregate from FAO. OECD and Non-OECD country classification is based on current membership. OECD = Organisation for Economic Co-operation and Development.

**TABLE 6.3.**

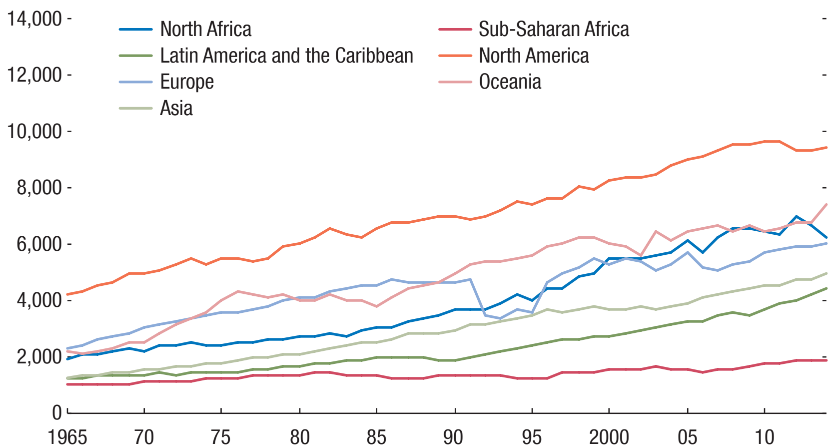
**Weighted Average Yield of Crops**
*(Ratio relative to highest producer)*

| | North Africa | Sub-Saharan Africa | Latin America and the Caribbean | North America | Europe | Oceania | Asia |
|---|---|---|---|---|---|---|---|
| Maize | 0.60 | 0.19 | 0.43 | 1.00 | 0.56 | 0.77 | 0.48 |
| Rice | 0.88 | 0.22 | 0.48 | 0.81 | 0.59 | 1.00 | 0.44 |
| Soybeans | 0.82 | 0.40 | 0.88 | 1.00 | 0.63 | 0.68 | 0.42 |
| Wheat | 0.63 | 0.60 | 0.65 | 0.71 | 1.00 | 0.48 | 0.73 |

Source: Food and Agriculture Organization of the United Nations (http://faostat3.fao.org/download/Q/QC/E).
Note: The table shows the weighted average yield of crops by region, normalized relative to the highest producer. The average yield is weighted by the area of harvested land: weighted average yield = $(\Sigma_i(\text{area}_i \times \text{Yield}_i)/(\Sigma_i(\text{area}_i))$. Yield is in hectograms/hectare; area harvested is in hectares.

The lack of net capital flows to developing economiesis not specific to the agricultural sector (Alfaro, Kalemli-Ozcan, and Volosovych2008). In many ways, the myriad factors deterring investment in agriculture are emblematic of the multifaceted challenges these countries face in improving their institutions overall. There is ample evidence that agricultural development is greatly affected by the rate of technology adoption (or lack thereof) and by human capital and credit constraints (see for instance, Besley and Case 1993; Foster and Rosenzweig 1995; and Dercon and Christiaensen 2011). Other factors that limit agricultural investment include a lack of adequate infrastructure (Donaldson and Hornbeck 2016), expropriation risks (Jacoby and others 2002), and land tenure issues (Besley and Burgess 2000).

**Figure 6.4. Maize Yield**
*(Kilograms a hectare)*




Sources: Food and Agriculture Organization of the United Nations; and IMF staff calculations.
Note: Yield refers to a five-year moving average. Oceania includes Australia, Fiji, Guam, Micronesia, New Caledonia, New Zealand, Papua New Guinea, and Vanuatu.

## Box 6.1. A Global Rush for Land

Against the backdrop of increasing global demand for food, there has been growing interest on the part of governments, agribusinesses, and investment funds in acquiring long-term property rights or leases over large areas of farmland, mostly in developing economies (Arezki, Deininger, and Selod 2013). Most of these land acquisitions have been in food-insecure countries that are in dire need of investment in the agriculture sector. These deals could lead to positive or negative outcomes. This box presents evidence related to these transnational land acquisitions and discusses the policy implications.

### What Drives Large-Scale Land Deals?

The term "land deal" refers to a large-scale, cross-border acquisition of land, typically at the expense of smallholder production or greenspace. Such a deal is defined as an intended, concluded, or failed attempt to acquire land through purchase, lease, or concession that meets the following criteria: (1) it entails a transfer of rights of use, control, or ownership of land through sale, lease, or concession; (2) it was initiated since the year 2000; (3) it covers an area of 200 hectares or more; and (4) it implies the potential conversion of land from smallholder production, local community use, or important ecosystem service provision to commercial use.[9] The global food crisis of 2007–08 led to a massive increase in food prices, thereby raising the value of farmland and the value of securing land for food production to insure against the next food crisis. Although the benefits of cultivating vacant land today remain small, increased uncertainty in the wake of the crisis may have led private investors to raise their estimates of the potential future profitability of optioning such land through sales or leases (Collier and Venables 2012).

Figure 6.1.1 shows the sharp increase in the annual number of land deals in the years leading up to the food crisis of 2007–08. In 2009, at the height of the rush for land, a land deal was negotiated almost every single day that averaged 223 square miles in size, which is an area more than five times the size of Paris. As shown in the figure, the appetite for farmland by investors and governments quickly receded in the years following the crisis.

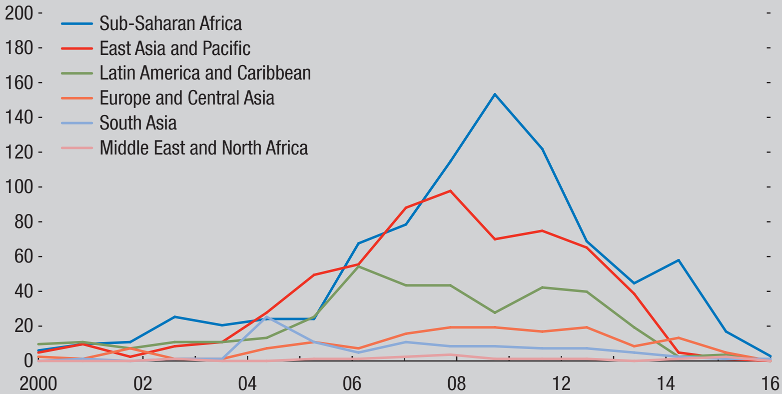
As of June 2016, the Land Matrix database has information on 2,152 transnational deals, the vast majority, or 76.5 percent, of which are linked to agricultural projects, with a cumulative size of almost 59 million hectares in 88 countries. This expanse corresponds to an area roughly the size of France or Ukraine. This is substantial but still fairly modest compared to the total stock of uncultivated and nonforest suitable land, which amounts to roughly 400 million hectares—1 billion hectares when forest land is included. Sub-Saharan Africa (884 deals) and East Asia (611 deals) have been the most important target regions for investment, followed by Latin America (368 deals).

The boom-bust pattern shown in Figure 6.1.1 is consistent with the idea that farmland (option) values are rapidly changing, fueled by substantial shifts in food prices and by uncertainty. Evidence suggests that much of the acquired land has been left idle, raising concerns about the motive behind these large-scale land investments, or hinting at potential obstacles to bringing such agricultural projects to fruition. According to the Land Matrix database, only 49 percent of the land acquired in these deals has been cultivated to some extent, and this fraction is significantly smaller in sub-Saharan Africa (37 percent).

[9]The analysis presented in this box focuses on cross-border deals only.

**Box 6.1. A Global Rush for Land (*continued*)**

**Figure 6.1.1. Evolution of Deals over Time by Target Region**
*(Number of deals)*




Sources: Land Matrix; and IMF staff calculations.

## What Do the Data Tell Us?

To explore the determinants of interest in transnational farmland deals, this analysis uses a bilateral Poisson regression to model the occurrence and count of projects in origin-destination pairs. Let $N_{ij}$ be the expected number of projects undertaken in host country *j* by investors from country *i*. The regression pools all land deals between 2000–16.

Following the standard gravity model from the trade literature, land investment is attributed to origin and destination country characteristics, $VarOrig_i$ and $VarDest_j$ respectively, and bilateral variables, $VarBilat_{ij}$. The baseline specification is then as follows:

$$N_{ij} = c + \alpha_i \cdot VarOrig_i + \beta_j \cdot VarDest_j + \gamma_{ij} \cdot VarBilat_{ij} + \varepsilon_i \qquad (6.1.1)$$

in which $\alpha_i$, $\beta_j$ and $\gamma_{ij}$ are the parameters of interest, and $\varepsilon_i$ is an error term. With a large number of zeros in the data, the ordinary least square estimator may be biased and inconsistent. To overcome this issue, a Poisson pseudo-maximum likelihood estimator is used (Silva and Tenreyro 2006).

The analysis uses a novel measure of uncultivated, nonforest land that takes into account proximity to market. Data are obtained from the Food and Agriculture Organization's *Global Agro-Ecological Zones* (FAO 2016). To analyze the relationship between this type of foreign direct investment and governance, data on law and order from the *International Country Risk Guide* (The PRS Group 2009), a measure of investor protection from the World Bank's *Doing Business* dataset, and an index of tenure security (de Crombrugghe and others 2009) are included. Physical distance and dummy variables for common language and a former colonial relationship are included as a proxy for trade costs. Finally, an index of food security from the Economist Intelligence Unit is included.

## Box 6.1. A Global Rush for Land (*continued*)

The results of our regressions based on equation 6.1.1 are presented in Table 6.1.1. They confirm the importance of trade costs and an abundant supply of uncultivated arable land. Interestingly, and in contrast to the existing literature on capital flows, poor land governance is associated with more land deals (see column (1). As weak land governance and food insecurity are highly correlated (with a correlation coefficient of $\rho = 0.77$), this finding suggests that food-insecure regions are associated with more land investment. Governments of food-insecure countries, while eager to host large-scale land investments, often face the challenge of ensuring that such outside investments actually help alleviate domestic hunger. This is especially difficult in light of weak land governance.

### What Are the Implications for Food Security?

Land deals may have either positive or negative effects. On one hand, these deals signal that capital in the agricultural sector is flowing from rich to poor countries and hence help transfer new technology and agronomic knowledge to local farmers. On the other hand, the clustering of these deals in food-insecure countries can potentially amplify the detrimental effects of a future food crisis. Host country governments can remedy these risks by investing in monitoring capacity to ensure that land is leased to investors who (1) promote integration of local producers into value chains; (2) co-invest in local public goods; and (3) compensate displaced land users.

**TABLE 6.1.1.**

Impact of Land Governance and Food Security on Land Deals

| | (1) | (2) |
|---|---|---|
| **Bilateral Variables** | | |
| Distance (log) | −0.838*** | −1.061*** |
| | (0.0669) | (0.0793) |
| Former Colonial Relationship | 1.529*** | 0.874*** |
| | (0.269) | (0.253) |
| **Origin Country Variables** | | |
| Net Food Exports (over GDP) | 8.199*** | |
| | (1.180) | |
| Food Security Index | | 0.0403*** |
| | | (0.00447) |
| **Destination Country Variables** | | |
| Landlocked | 0.234 | 0.0575 |
| | (0.220) | (0.192) |
| Suitable Nonforest Land | 0.525*** | 0.810*** |
| | (0.0748) | (0.0936) |
| Land Governance | −0.572*** | −0.165 |
| | (0.0957) | (0.108) |
| Law and Order | −0.265*** | −0.152 |
| | (0.0827) | (0.0958) |
| Weak Investor Protection | −0.00606** | −0.00913*** |
| | (0.00243) | (0.00256) |
| Net Food Exports (over GDP) | 5.757*** | |
| | (1.384) | |
| Food Security Index | | −0.0539*** |
| | | (0.00639) |
| Observations | 19,186 | 10,044 |
| Pseudo *R*-Squared | 0,217 | 0,283 |

Source: IMF staff calculations.
Robust standard errors are in parentheses.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

## WHAT ARE THE RISKS?

Indian economist Amartya Sen (Sen 1981) first highlighted the fact that hunger was not necessarily the result of a lack of food but a lack of the capability to buy food. Food security is a multidimensional concept. The Food and Agriculture Organization of the United Nations (FAO) (2015) concludes that food security rests on four pillars : (1) availability—the supply side, determined by production, stocks, and trade in food; (2) access—encompassing economic access, or the ability to purchase with one's disposable income, and physical access, the ability to reach food sources via transport infrastructure; (3) utilization—through diet diversity, intra-household distribution of food, and food preparation and consumption; and (4) stability—the constancy of the other three dimensions over time.

Because rapid urbanization and galloping population growth—especially in sub-Saharan Africa and Asia—have not been matched by commensurate increases in domestic food supply, there has been a growing dependency on imports in many countries (Table 6.4). In fact, an overwhelming majority of countries around the world are net importers of food (Table 6.5). Of course, some countries have always been food importers, but between 1990 and 2013 some 27 countries switched from being net food exporters to being net food importers. Nearly all of these countries are from sub-Saharan Africa, Latin America, and east Asia. The list includes Honduras, Vietnam, the Philippines, and Zimbabwe—all of which experienced major drops in net food exports of over 7 percentage points of GDP.

The high concentration of net food importers has led to further concerns about food security. Countries can achieve food security through imports, but whereas economically prosperous countries can easily finance such food imports, impoverished countries struggle to do so.[10] In Over the past few years, prices for most commodities have cratered, but food prices have not. This has rendered

**TABLE 6.4.**

Urban Population by Region
*(Percent of total population)*

| Region | 1990 | 2014 | 2050 | Change 1990–2014 | Change 1990–2050 |
|---|---|---|---|---|---|
| Africa | 31.3 | 40.0 | 55.9 | 8.7 | 24.7 |
| Asia | 32.3 | 47.5 | 64.2 | 15.3 | 31.9 |
| Europe | 70.0 | 73.4 | 82.0 | 3.5 | 12.0 |
| Latin America and the Caribbean | 70.5 | 79.5 | 86.2 | 9.0 | 15.7 |
| North America | 75.4 | 81.5 | 87.4 | 6.0 | 12.0 |
| Oceania | 70.7 | 70.8 | 73.5 | 0.1 | 2.8 |

Sources: United Nations, *World Urbanization Prospects*: *The 2014 Revision*; and IMF staff calculations.
Note: Oceania includes American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, and Wallis and Futuna Islands.

[10]The poorest population segments of some prosperous countries may also be subject to food insecurity.

**TABLE 6.5.**

Net Food Exports

*(1990 versus 2013, number of countries)*

| Region | Always Exporter | Always Importer | Exporter → Importer | Importer → Exporter | Total |
|---|---|---|---|---|---|
| East Asia and Pacific | 6 | 17 | 7 | 2 | 32 |
| Europe and Central Asia | 9 | 13 | 1 | 1 | 24 |
| Latin America and Caribbean | 12 | 14 | 8 | 0 | 34 |
| Middle East and North Africa | 0 | 17 | 2 | 0 | 19 |
| North America | 2 | 1 | 0 | 0 | 3 |
| South Asia | 1 | 6 | 0 | 1 | 8 |
| Sub-Saharan Africa | 4 | 29 | 9 | 3 | 45 |
| Total | 34 | 97 | 27 | 7 | 165 |

Sources: Food and Agriculture Organization of the United Nations; World Bank, *World Development Indicators*; and IMF staff calculations.

many developing economies—many of which are commodity exporters—more exposed to food price shocks by reducing their export receipts and putting increased demands on their overall budgets.[11]

Climate change affects agricultural production through economic losses resulting from reduced crop yields and livestock productivity, changing average temperatures and patterns of precipitation, and extreme weather events such as heat waves and severe storms. There are a host of other effects, too, including changes in pests, diseases, and atmospheric concentrations of carbon dioxide (Porter and others 2014). Generally, countries closer to the equator will be more vulnerable to the adverse effects of climate change than countries at higher latitudes (Rosenzweig and others 2014).[12] For example, Ethiopia recently experienced the most severe drought in decades in association with the 2015–16 El Niño weather phenomenon. Rainfall during Ethiopia's two main rainy seasons directly affects more than 80 percent of the country's agricultural yield and the more than 85 percent of the population engaged in agricultural production. The recent drought therefore caused a massive spike in humanitarian needs over several years (Government of Ethiopia 2015).[13]

Such extreme weather events and the resulting threats to food security are expected to worsen and increase in frequency (International Food Policy Research

[11]In principle, food terms of trade shocks can also lead a country to switch from being a food exporter to a food importer. In practice, fast population growth and urbanization, stagnating productivity, and poor infrastructure are key elements explaining many developing economies' dependence on food imports (Rakotoarisoa, Iafrate, and Paschali 2011).

[12]There is evidence to suggest that climate change affects different crops differently.

[13]Beyond Africa, the impact of the 2015–16 El Niño in Asia was even more severe in certain locations such as the uplands of Cambodia, central and southern India, eastern Indonesia, central and southern Philippines, central and northeast Thailand, Papua New Guinea, and other Pacific island countries. In India, severe floods were already been reported in several parts of Tamil Nadu during November and December 2015, and inundated inundating most areas of Chennai (UNEP 2015).

Institute 2016; UNEP 2016; and World Bank 2015a).[14] So-called climate-smart agriculture (CSA) can help mitigate the effects of climate change on agriculture by creating opportunities for smallholder farmers to sustainably and efficiently produce more nutritious crops (IFPRI 2016).[15] CSA is an integrative approach with three objectives:

To sustainably increase agricultural productivity in order to support equitable increases in farm incomes, food security and development; to adapt and build the resilience of agricultural and food security systems to climate change at multiple levels; and to reduce greenhouse gas emissions from agriculture (including crops, livestock and fisheries).

**TABLE 6.6.**

Share of Food and Beverages in Total Consumption, 2010 (Percent)

| Area | Share |
|---|---|
| High-Income Countries | 21.0 |
| Middle-Income Countries | 43.7 |
| Low-Income Countries | 56.6 |
| Guinea | 71.1 |
| Burundi | 71.0 |
| Dem. Rep. of Congo | 69.5 |

Sources: World Bank, Global Consumption Database; Organisation for Economic Co-operation and Development, National Accounts database; and IMF staff calculations.
Note: Includes processed food such as alcoholic beverages and catering services.

The FAO and the U.S. Agency for International Development (USAID) have established early warning systems to anticipate and prevent famines. The FAO hosts the Global Information and Early Warning System, which monitors the world food situation in 190 FAO member states and provides early warnings of impending crises (Groskopf 2016). The Famine Early Warning Systems Network (www.fews.net) set up by USAID helps anticipate and plan for humanitarian crises in 29 countries.

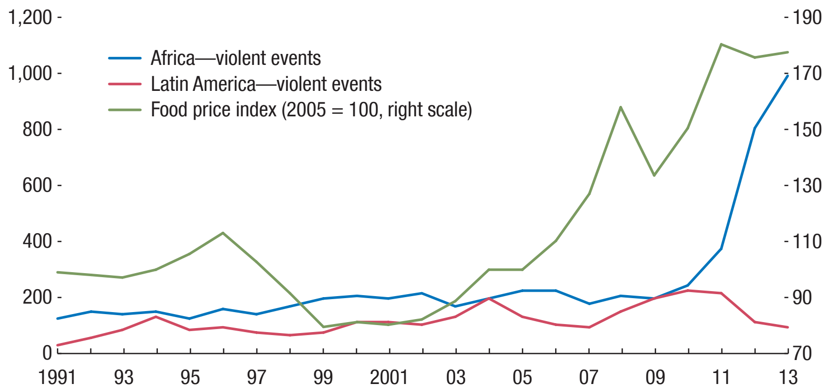
Volatility in food prices or outright food shortages have a crucial impact on the most basic aspect of welfare in poor countries, namely, survival. As shown in Table 6.6, the share of food and beverage consumption in the overall consumption basket is dramatically high for many low-income countries. It is even higher for fragile states, including Guinea and Burundi. For middle-income countries, the share is somewhat lower but still significant—approaching 50 percent of total consumption. Existing econometric evidence (Arezki and Brueckner 2014; and Bellemare 2015) suggests that food price volatility can cause enormous distributional challenges within and between countries and can lead to conflicts (Figure 6.5).[16] Existing indices (Figure 6.6) show that, as a region, Africa is the

[14]In Latin America and southeast Asia, floods and droughts during recent El Niño/La Niña episodes, which already cause heavy losses in agriculture, are likely to double in frequency (World Bank 2015b).

[15]For example, C4 rice has been found to increase yields by 50 percent as a result of doubling water use efficiency and increasing nitrogen use efficiency by 30 percent.

[16]Food production is endogenous to civil conflict: country examples are indicative that the presence of civil war may be associated with an increase is domestic food prices. For example, in

**Figure 6.5. Food Prices and Violent Events**
*(Number of events, unless noted otherwise)*




Sources: IMF, Primary Commodity Price System; Social Conflict Analysis Database 3.1; and IMF staff calculations.

most prone to such food insecurity, but pockets of vulnerability also exist in Asia, Central America, and South America.

Policy interventions can serve to amplify food price spikes. The price volatility of weather-dependent commodities like food is exacerbated by the tendency for both advanced and emerging and developing economies to alter their trade and domestic policies from year to year in an effort to stabilize prices and supplies in domestic food markets (Anderson 2016; FAO 2015). During periods of elevated food prices, as during 2007–08, net food exporting countries frequently implement export restrictions whereas net food importers lower import barriers, both in an attempt to increase domestic food supplies. Taken together, these two policy responses amplify the food price spike (Anderson, Rausser, and Swinnen 2013; Anderson 2016). An effective means of preventing such outcomes, as demonstrated in developing Asia, is to raise agricultural sector productivity and improve supply chains, as well as to promote regional coordination—including through maintaining and managing regional grain reserves (Jha and Rhee 2012).[17]

Overall, food markets are segmented due to distortions in trade and domestic impediments to investment in the agricultural sector. Demand for food has and will continue to grow at a rapid pace as a result of global population growth.

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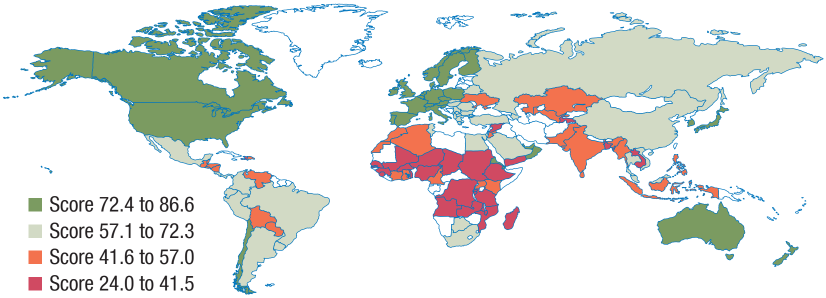
Darfur, Sudan, prices of the main food staples increased rapidly after widespread violence started in late 2003 and early 2004 (see for example Brinkman and Hendrix 2010).

[17]There are other means to alleviate food shortages, including: reducing excessive food consumption, which leads to obesity and associated negative health outcomes; and reducing food waste. The FAO estimates that one-third of food produced for human consumption is lost or wasted globally, which amounts to about 1.3 billion tons a year.

**Figure 6.6. Global Food Security Index, 2016**
*(Overall score 0–100; 100 = best environment)*




Source: Economist Intelligence Unit, Global Food Security Index 2016 Workbook.

Income growth also affects the composition of food demand. Accelerated urbanization trends in Africa and Asia will make even more countries dependent on trade to meet their domestic requirements. To meet these challenges and reduce food insecurity, advanced economies, emerging markets, and developing countries will need to continue to reduce barriers to trade. Low-income countries should also raise productivity in their agricultural sectors by attracting capital flows, but for that to occur, multifaceted institutional improvements are needed.

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ISBN-13: 978-1-48431-032-8
9 781484 310328

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