CHAPTER 5

Energy and Emissions

Local and Global Effects of the Giants' Rise

Zmarak Shalizi

Sustainability issues normally do not manifest themselves for decades because either population growth rates or per capita income growth rates are relatively slow. But such issues become difficult to ignore when growth rates are not slow—as has been true in China in the last two decades. China's rapid transformation from an agriculture-based economy to the world's manufacturing workshop has been accompanied by a corresponding change in the spatial concentration and location of the population from relatively low-density rural areas to very high-density urban areas. This transformation is having a significant impact on the quantity and quality of natural resources available as inputs to the production process and consumption, and has affected the environment's ability to absorb the waste by-products deposited in the air, water, and soil. The recent acceleration of growth in India is beginning to generate similar problems.

Development strategies targeting high growth in gross domestic product (GDP) by relying on low-cost, low-efficiency, and highly polluting technology are likely to put pressure on available natural resources and natural sinks that absorb pollution and waste over time. Emerging in Asia is a major one-time opportunity to shift efficiently to a path that does not lock in inefficient resource use. This opportunity arises from the massive investments expected

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in the next 50 years (amounts on the order of trillions of dollars) to urbanize the population (and simultaneously reduce poverty and the backlog of service provision) (World Bank 2003b).

Addressing emerging domestic and local problems will be the primary national motivation for taking action. But there also is likely to be an international dimension to the problem if externalities are generated on international resources and sinks as needs grow beyond domestic capacity. This will generate costs for other countries, and may even provoke conflict, if domestic and international institutions for collective action do not emerge in a timely manner.[1]

Although this statement of the interaction between growth and natural resources applies to a wide range of natural resources and asset management issues in China and India, this chapter focuses exclusively on the issue of managing and meeting energy needs for growth so as to minimize negative consequences for health and the environment locally and globally. The objective of this chapter is to address the following questions:

- What is likely to be the Giants' demand for energy—particularly oil and coal—under a *business-as-usual (BAU)* scenario in 2020 and 2050?
- What are likely to be the associated levels of emissions that could have damaging consequences locally (such as particulate matter), regionally (such as ozone, sulfur, and acid rain), and globally (carbon dioxide [CO_2] in particular)?
- What domestic interventions in developing the energy-producing and energy-using sectors might make a significant difference in the energy path, relative to a BAU scenario?

Level and Composition of Energy Use and Emissions

For many reasons (such as the energy intensity of an economy and so forth), it is sufficient to focus on the level of aggregate energy use. Local and global

1. Developing the institutions to identify and enforce appropriate criteria (that take into account the scale and distribution of externalities, as well as the use of option values) for these investments will determine whether the cumulative investment program enhances welfare or not. Because of path dependency, there is the potential of locking into inefficient energy and emissions paths. However, the topic of institutional development is not covered in this chapter.

emissions from energy use, however, are sensitive to the composition of energy used and not simply to its level.

Emerging Concerns

There are many issues involved in managing energy supply and demand in China and India. However, a few broad concerns are emerging that are of particular interest.[2]

The Demand for Fossil Fuel

At the aggregate level, China and India currently account for about 12 and 5 percent of the world's energy use, respectively. In terms of composition, China consumes slightly less coal than it produces, and exports the balance (table 5.1). Its use of petroleum, however, is increasingly larger than its production—and the balance is imported. For most other fuels, domestic consumption and production are roughly in balance. India's domestic production of coal and oil satisfies an even smaller part of its consumption, and the imbalance is growing—particularly in oil (table 5.1). Both countries produce gas, but gas consumption does not yet account for a significant share of energy use.

At present, China is the second-largest energy consumer in the world, following only the United States. Its total energy use, however, is only half the U.S. use, and its per capita consumption levels are about 10 percent of those in the United States.[3] In 1980, China had one of the highest energy intensities in the world, using GDP at market prices (see table 5.2)—almost seven times as high as the United States and almost four times as high as India.[4] Using purchasing power parity figures lowers the relationship relative to the United States from 6.72 to 1.64, but increases it relative to India from 3.8 to

2. This review of problems is based primarily on secondary source literature. In the past few years, the International Energy Agency (IEA) in Europe, the U.S. Department of Energy, and others have produced many reports on energy in China and India to identify key drivers of energy and emissions trajectories and the role of different policy strategies.

3. Energy data is taken from the U.S. Energy Information Administration (USEIA) *International Energy Annual 2003* and population data comes from the World Bank's *World Development Indicators* (2005b).

4. *Intensity* is the amount of energy consumed per unit of economic output.

5.0. In fact, by 2003, measured relative to GDP in purchasing power parity, both China and India appear more efficient than the United States. Given that most energy use is in tradable/marketed sectors and considering the evidence of continuing inefficiency in industry (World Energy Council 1999), however, it seems that the scope for and returns to economizing on China's and India's energy use is still large.

Table 5.1 Energy Balance in China and India, 1980–2003

		Production and Stock Change (Mtoe)						
Country	Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
China	1980	316	107	12	5	180	0	620
	1985	405	130	13	8	189	0	745
	1990	545	136	16	11	200	0	908
	1995	691	149	19	16	206	3	1,084
	2000	698	151	28	19	214	4	1,115
	2003	917	169	36	24	219	11	1,376
India	1980	50	11	1	4	148	1	215
	1985	71	31	4	4	162	1	273
	1990	97	35	10	6	176	2	326
	1995	124	39	17	6	189	2	377
	2000	143	37	21	6	202	4	413
	2003	157	39	23	6	211	5	441
		Consumption (Mtoe)						
Country	**Year**	**Coal**	**Oil**	**Natural gas**	**Hydro**	**Biomass and waste**	**Nuclear**	**Total**
China	1980	313	89	12	5	180	0	599
	1985	401	93	13	8	189	0	704
	1990	535	110	16	11	200	0	872
	1995	673	158	19	16	206	3	1,075
	2000	664	222	26	19	214	4	1,149
	2003	862	270	35	24	219	11	1,421
India	1980	53	34	1	4	148	1	241
	1985	76	48	4	4	162	1	295
	1990	104	63	10	6	176	2	361
	1995	134	84	17	6	189	2	432
	2000	159	114	21	6	202	4	506
	2003	173	124	23	6	211	5	542

Source: IEA 2005a.
Note: Mtoe = million tons of oil equivalent.

Table 5.2 Changes in Energy Intensity in China, India, and the United States

		Based on GDP at market prices (constant 2000 US$)			Based on GDP at PPP (constant 2000 international $)		
Factor	**Year(s)**	**China**	**India**	**U.S.**	**China**	**India**	**U.S.**
Energy intensity[a]	1980	101,936	26,805	15,174	24,922	5,051	15,157
	2003	33,175	25,460	9,521	8,076	4,761	9,561
Growth rate (%)	1980–2003	–4.76	–0.22	–2.01	–4.78	–0.26	–1.98
Relative to U.S.	1980	6.72	1.77	n.a.	1.64	0.33	n.a.
	2003	3.48	2.67	n.a.	0.84	0.50	n.a.
Change in ratio	1980–2003	0.52	1.51	n.a.	0.51	1.49	n.a.

Sources: Adapted from USEIA 2005 and World Bank 2005b.
Note: n.a. = not applicable; PPP = purchasing power parity.
a. Total primary energy consumption (Btu) per unit of output.

Change over time is an important aspect of energy intensity in China and India. In the 23-year period from 1980 to 2003, energy intensity in China declined annually by an extraordinary 4.8 percent—more than double the 2 percent annual decline in the United States and almost 24 times faster than the anemic 0.2 percent annual decline in India.[5] As a result, China's energy intensity dropped by half that of the United States, whereas India's increased by 50 percent relative to U.S. intensity. This significant pattern of change over more than two decades (both within the two countries and relative to the United States) is the same whether one uses GDP at market prices or purchasing power parity prices (see last row of table 5.2).

Domestic Energy Resources

China's use of electricity more than doubled in the decade between 1986 and 1995 and then doubled again by 2003 (National Bureau of Statistics 2005). China has the fastest growing electric power industry in the world—fueled primarily by coal. Hydroelectric generating capacity is a particularly important source of electric power only in the central and western regions. Industry is the largest consumer of electricity, followed by the residential sector, and then the agricultural sector.

5. Most of the reduction in energy intensity in China since 1978 is attributed to technological change, not structural shifts from heavy to light industry (Lin 1996).

India has an installed electricity generation capacity of 112,000 megawatts, which is approximately 10 percent the capacity of the United States (USEIA 2005). Approximately 70 percent of India's electricity comes from coal. Unlike China, India does not have a large supply of high-quality coal nor of gas for generating electricity, so more and more coal and gas have to be imported. Industry is the largest consumer of electricity in India, followed by the agricultural sector, and then the residential sector.

As in China, India's power sector continues to face a considerable demand–supply gap and the supply it has is of poor quality (for example, low voltage and grid instability). Peak power shortage is estimated in the range of 13 percent (Government of India 2003)—probably lower than it would have been with more reliable supply. Transmission and distribution losses in some states (such as Maharashtra) amount to approximately 40 percent of total electricity generated centrally.[6]

Transportation

In the last decade, China has committed itself to a strategy of emulating U.S. dependence on motorization as the dominant mode of transportation. This strategy was determined only in part by mobility considerations; industrial policy considerations were the primary drivers.[7] The automobile industry is seen as a potential engine of growth for the economy as a whole because of its multiplier effect through buyer–supplier links.

With this strategy shift, less energy-intensive vehicles like bicycles and pedicabs have been replaced by more energy-intensive vehicles—motorcy-

6. The losses can be of a *technical* nature (such as line losses resulting from poor maintenance, overloading, poor equipment standards, low power factors at off-peak hours) or of a *commercial* nature (such as illegal tapping of low-tension lines, faulty energy meters, unmetered supply, and uneven revenue collection). Problems with loss reduction include lack of energy audits, no segregation of losses into technical and commercial categories, and little transparency in meter reading and billing. Available data cited above do not distinguish between the two types of losses even though the commercial losses, such as theft, are a loss to the utility but not to power available for consumption.

7. The 16th Conference of the National Congress of the Communist Party of China and the 8th Conference of the National People's Congress established the automobile industry as a pillar of the country's economy. For details, see the Web site of the Automotive Sub-Council of the China Council for the Promotion of International Trade, http://www.auto-ccpit.org/).

cles, cars, and trucks. The rate of growth of the vehicle fleet—which averaged 5.7 percent each year through 1999—accelerated dramatically to 26.5 percent a year in the last five years, although now there are signs that the growth rate is beginning to moderate. Automobile ownership in China is still only 8 to 10 per 1,000 people, in contrast to approximately 400 per 1,000 in Japan and about 500 per 1,000 in the United States.[8] A tenfold growth in ownership of automobiles over the next 30 years in China is quite conceivable, however, given the expected growth in household incomes and current government policies. The average number of vehicle miles traveled per household and the volume of freight transported by truck traffic is also expected to expand dramatically: within urban areas, as urban sprawl increases and jobs and residences disperse across a larger area, increasing distances between them, and between urban centers, as commercial and industrial entities increasingly rely on the flexibility provided by the growing highway network linking China's cities and connecting the coasts to the hinterlands. The penetration of fuel-efficient hybrid technology in the vehicle fleet is still very low.

Some cities in India, such as Delhi, have exhibited explosive growth in automobile ownership and use that is similar to China's. Overall, however, India's reliance on the road sector for passenger and commercial traffic is still much lower than in China because India started much later. But the recent growth of the middle class there and the government's decision to expand the highway network dramatically are likely to stimulate a growing dependence on the road sector. Both China and India have seen, in addition, an explosive growth in air traffic—a major consumer of oil products.

Energy Use and Emissions, 1980–2004

China is the largest producer of coal in the world. In 2004, its production was almost double that of the United States (2.2 billion short tons versus 1.1 billion short tons) (USEIA 2006). China's estimated total coal resources are second only to the former Soviet Union, although proven reserves ranked third in the world. China is a net exporter of coal and likely to remain so for at least another decade.

8. Vehicle ownership figures in Japan and the United States are higher, at 570 per 1,000 people in Japan and 780 per 1,000 people in the United States. Vehicle ownership includes not just automobiles but also buses, pickups, and trucks—but not motorcycles (World Bank 2005b).

In 2003, coal accounted for 67 percent of China's primary energy production of 1,216 million tons of oil equivalent (Mtoe), oil accounted for 12 percent, natural gas for 3 percent, hydroelectric power for 2 percent, and biomass and other waste for 16 percent (table 5.1). China has a growing nuclear power sector, but its output accounted for only 0.8 percent of energy production in 2003. More recently, China has moved aggressively to expand nuclear, wind, and solar power generating capacity, and to pursue new technologies for coal gasification and the like. In final energy consumption, coal also dominates other energy resources, accounting for 72 percent of fossil fuel consumption and 58 percent of total primary energy consumption.

In 2003, India's total primary energy production was estimated at 441 Mtoe, with coal accounting for 36 percent of the supply mix, oil for 9 percent, gas for 5 percent, hydroelectric power for 1 percent, nuclear for 1 percent, and biomass energy and other renewables for 48 percent (table 5.1).[9] The use of commercial fuels, such as coal and oil, is growing rapidly in tandem with the economic expansion (industrialization and growing per capita income). Nonetheless, unlike China, more than 60 percent of Indian households still depend on traditional energy sources such as fuelwood, dung, and crop residue for their energy requirements (TERI 2004).

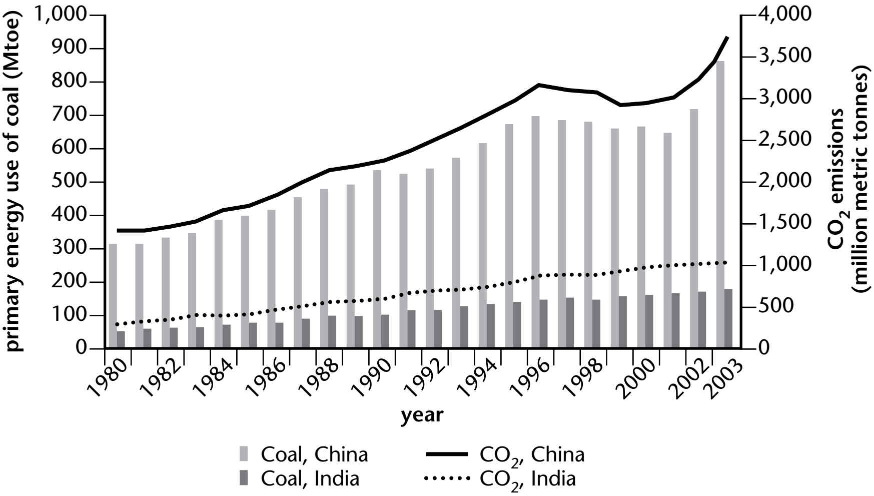
The increasing use of fossil fuels (particularly coal and oil) in both of the Giants is generating harmful emissions—particulates (with primarily local effects on health in urban areas), sulfur and nitrogen (with primarily regional effects via ozone and acid rain on agriculture and ecosystems), and CO_2 (with primarily global effects in the form of global warming).

Global Externalities

The United States is the world's largest emitter of carbon emissions from energy, but China is expected to overtake it in the next decade-plus. China's carbon emissions are driven by rapid growth in the use of fossil fuels—particularly coal and oil (gas not yet being a significant contributor). CO_2 emissions from India are a quarter of those from China, but also are growing as a result of the

9. Thirty years earlier, before the major expansion of commercial electricity production, traditional biomass accounted for 66 percent of India's total primary energy supply. At that time, biomass was also a major source of energy in China—approximately 30 percent (IEA 2005a).

Figure 5.1 Primary Energy Use of Coal and Total CO_2 Emissions from Fossil Fuel Consumption, China and India, 1980–2003



Sources: IEA 2005a, 2005b.
Note: CO_2 = carbon dioxide; Mtoe = million tons of oil equivalent.

dependence on fossil fuels, particularly for electricity production. As evident in figure 5.1, CO_2 emissions in both countries track coal use quite closely.

What socioeconomic factors are driving CO_2 emission changes in China and India? Recent literature covering the period 1980 to 1996/97 has suggested that economic growth was the single largest driver of increased emissions in both countries.[10] Over time the gross emission increases have been offset significantly by improved energy efficiency in China, but in India the offset has been much less sizable. Decarbonization (that is, lowering CO_2 emissions by reducing the emission factor through use of better technology and of lower-carbon fuels) was not a significant factor during this two-decade period in either country.[11] However, its importance in India has increased in the 1990s.

10. For China, see Sinton, Levine, and Wang 1998; Van Vuuren et al. 2003; and Zhang 2000. For India, see Paul and Bhattacharya 2004.

11. The emissions factor is calculated as emissions per unit energy.

Local Externalities

As noted earlier, not only is heavy reliance on fossil fuel (particularly coal) associated with the expansion of CO_2; it also is associated with the expansion of various types of local pollutants (such as suspended particulate matter, sulfur/sulfur dioxide, nitrogen oxides, and so forth) that contribute to health problems, particularly in cities, and to ground-level ozone and acid rain that particularly affect rural areas and natural ecosystems.[12]

Sulfur dioxide (SO_2) and soot released by coal combustion are the two major air pollutants that form acid rain, which now falls on approximately 30 percent of China's total land mass (USEIA 2003)—areas also affected by an ozone-generated natural haze. In India, too, acidic precipitation is becoming increasingly common. According to the Environmental Information System of India, soils in the northeast region, parts of Bihar, Orissa, West Bengal, and coastal areas in the south already have low pH values. If immediate mitigative measures are not taken, further aggravation from acid rain may cause these lands to become infertile or unsuitable for agriculture. Studies in India show a 13 to 50 percent decrease in mean wheat yield within 10 kilometers of thermal power stations with capacities of 500 to 2,000 megawatts, respectively (Mitra and Sharma 2002). Similar studies in China have concluded that the deteriorating air quality has reduced optimal yield by 5–30 percent for approximately 70 percent of the crops grown in China (Chameides et al. 1999).[13]

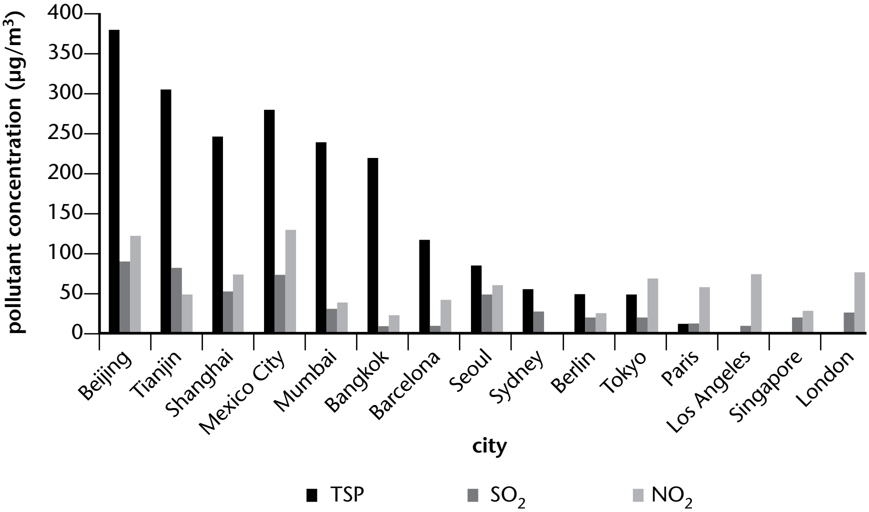
Industrial boilers and furnaces that use coal are the largest single-point sources of urban air pollution, and road transport is the main mobile source of air pollution.[14] Cities in developing countries tend to have higher pollution concentration than cities in industrial countries (see figure 5.2). Depending on what air pollutant one focuses on, a different set of 10–20 cities is among

12. Ozone and other photochemical oxidants are formed by the action of ultraviolet light from the sun on nitrogen. Ozone production and concentration is dependent on the presence of nitrogen oxides and ultraviolet light.

13. Assuming sufficient water and nutrients, simulations of the crop-response models demonstrate that atmospheric aerosols lead to lower crop yields through a decrease in total surface solar irradiance, thereby affecting the marginal productivity of other inputs.

14. China's State Environmental Protection Administration estimates that "industrial pollution accounts for over 70 percent of the national total, including 72 percent for sulfur dioxide emissions, and 75 percent for flue dust (a major component of suspended particulates)."

Figure 5.2 Air Quality Comparison, Selected World Cities, 2000
Average annual levels



Source: Hao and Wang 2005.
Note: NO_2 = nitrogen dioxide; SO_2 = sodium dioxide; TSP = total suspended particulates.

the most polluted in the world, and many Chinese and Indian cities are listed in these sets.[15]

One can speak meaningfully about pollution in a city, a locality, or a river because assessing pollution per unit area is a function of localized air sheds and watersheds. But there is no equivalent measure for an area as large as a country, so there is no such metric for the average level of pollution in China or India. Instead, it is more useful at the country level to estimate the total number of people exposed to different levels and types of pollution.

In 2003, more than half (58.4 percent) of China's urban population was exposed to average annual amounts of coarse particulate matter in excess of 100 micrograms per cubic meter, which is the Chinese standard (and twice the U.S. standard). Air pollution is estimated to have led to more than 427,000

15. Earlier studies include a report released in 1998 by the World Health Organization (WHO).

excess deaths and 300,000 cases of chronic bronchitis in 660 Chinese cities in that year (World Bank 2006a). In the case of India, Cohen et al. (2004) reported an estimate of 107,000 excess deaths in 2000.[16]

Attempts to reduce local emissions in China by curtailing coal production and consumption had some success in reducing SO_2 and other local emissions for a few years in the late 1990s (Hao and Wang 2005). Reduction in SO_2 tracked the apparent dip in coal consumption and CO_2 emissions in China (see figure 5.1). Even though GDP grew by a third (+33.7 percent) in the period 1997–2001, there was almost no increase in CO_2 emissions (+0.2 percent)—in contrast to a 14.0 percent increase that the 1980–97 emissions-to-GDP ratio would have predicted. SO_2 concentrations also dropped by approximately 40 percent. This drop gave rise to much optimism regarding the potential for "decoupling" the growth in emissions and energy requirements from the growth of GDP. Several factors—including faulty statistics—explain this apparent decoupling. The relative weights of these factors are being debated, but the closing of a large number of small and inefficient coal producers was also important (Sinton and Fridley 2000, 2003; Sinton, 2001).

This decoupling, however, could not be sustained. In the presence of low power tariffs, blackouts, and power shortages arising from 9–10 percent annual GDP growth, it has been necessary to use all power-generating capacity, no matter how inefficient. As a result, both SO_2 emissions (particularly in northern cities) and CO_2 emissions have resumed an upward trend.

International Energy Markets

Encouraging more reliance on roads for passenger and freight movements has prompted a surge in the demand for oil (gasoline, diesel, and other oil prod-

16. Other partial studies corroborate these findings. In China, the consequences of current air pollution levels are apparent in public health statistics for some cities: "approximately 4,000 people suffer premature death from pollution-related respiratory illness each year in Chongqing; 4,000 in Beijing; and 1,000 in both Shanghai and Shenyang. If current trends persist, Beijing could lose nearly 80,000 people, Chongqing 70,000, and other major cities could suffer tens of thousands in cumulative loss of human life through 2020. With industry expected to maintain rapid growth during the next 20 years, a steep decline in pollution intensity will be necessary just to keep emissions constant"(Dasgupta, Wang, and Wheeler 1997, p. 3). In India, Delhi has been identified as the city having the highest mortality figure—about 7,500 deaths a year (Brandon and Hommann 1995; WHO 2002; World Bank 2005a).

ucts) in both China and India. Oil imports have grown, and with them have come both national implications for balance of payments and energy security, and global implications for world energy markets. This section addresses the latter issue.

Recent growth in energy use by the Giants does account for a significant part of the incremental increase in global energy use, but the annual growth in global use has not been unusual, relative to the past. The Giants' energy use is not the key component in recent oil price surges. Rather, it is the tightening of oil supplies in the context of diminished spare capacity and growing geopolitical uncertainties that has driven up prices in the last couple of years.

Since the late 1980s, nominal oil prices have been relatively stable and flat.[17] There were two exceptions: a momentary spike (reflecting uncertainty) during the Persian Gulf crisis of 1990–91, with prices soaring 50 percent above the average price in the period May 1990–91; and a longer-lasting perturbation during the Asian financial crisis of 1997–98, when per-barrel prices dropped by $12.90 between January 1997 and December 1998. The drop in prices reflected a negative demand shock, caused mostly by the decline in oil demand in Asia and the modest slowdown of economic activity in Europe and Japan. The price drop also reflected a lag in the Organization of the Petroleum Exporting Countries' (OPEC's) downward adjustment of its production. This drop in price was followed during 1999 and 2000 by a symmetrical catch-up in prices under the combined effect of OPEC's successive cuts in production and the renewed growth in global economic activity. Between 2002 and 2004, oil prices entered a period of gradual but sustained increase and, since 2004, oil prices have surged. The time profile and determinants of the recent price trend have nothing in common with the two events in the 1990s, nor with either of the oil shocks in the 1970s (IMF 2005a) that were characterized primarily by abrupt geopolitical supply disruptions.[18]

Buoyant growth in global demand in the context of worldwide economic expansion has driven the more gradual but steady increase of oil prices in the period 2002–04. From 2002 to 2004, global GDP (in constant terms) has exhibited fluctuating but high annual growth rates in the range of 3–4 percent,

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17. For the purposes of this section (unless otherwise indicated), oil price is to be understood as crude oil spot price, in nominal terms. The (monthly averaged) arithmetic mean of Dubai, Brent, and West Texas Intermediate grades is used.

18. Average annual prices rose by 250 percent between 1973 and 1974 and by 133 percent between 1978 and 1979, in reaction to the abrupt and significant supply restrictions linked to geopolitical events.

with only a slight slowdown in late 2004 and throughout 2005 (World Bank 2006a). Global crude oil use grew from 77.6 million barrels a day (mbd) to 84.2 mbd between the first quarter of 2002 and the fourth quarter of 2004; and despite signs of a slowdown throughout 2005, it continued to increase over 2004 quantities (+1.1 mbd on average), indicating the relative inelasticity of oil use relative to higher prices in the short run (IEA "Oil Market Reports").

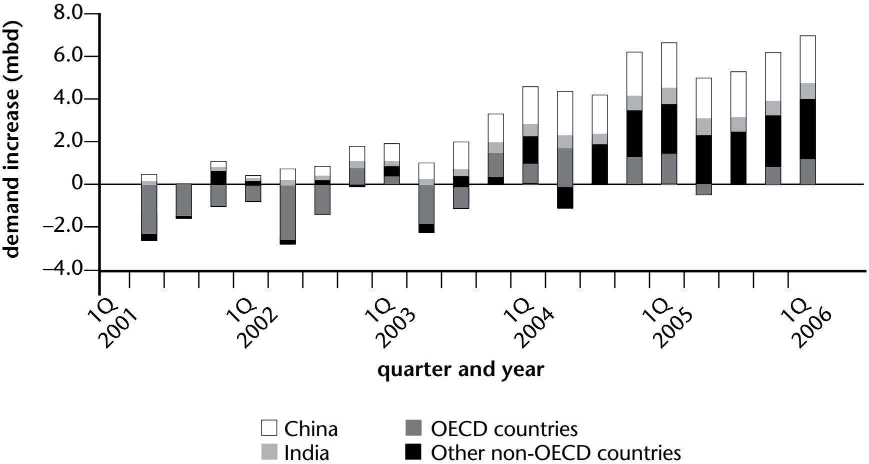
Organisation for Economic Co-operation and Development (OECD) countries are responsible for the largest share in crude oil use over this period (relatively steady at approximately 60 percent). China's share grew from 6.06 percent (first quarter of 2002) to 7.87 percent (fourth quarter of 2004) of global crude oil use. As such, it is responsible for the highest increase in global oil use over its early 2001 level, averaging 0.25 mbd initially and then expanding to 2.1 mbd (equivalent to 37 percent of the global increase). Furthermore, although crude oil use in industrial countries was decreasing slightly, parallel to a moderate slowdown of their economic activity in 2001, the Chinese economy's momentum was large enough to offset the decline and generate a net increase in oil use. Since 2005, as the world economy began slowing down (and oil use in industrial countries was levelling off), economic growth in China has continued to sustain some growth in oil use. A similar story applies for India, although it offers much less spectacular figures. India accounts for only 3–4 percent of global use and for 7 percent of the average increase in global oil use since early 2001.

Thus, China and India together account for a large portion (40–50 percent) of *incremental* global oil use this century (see figure 5.3), but they still account for only 9–10 percent of *aggregate* global oil use. In addition, recent growth in oil use in China and India has been offset partially by the deceleration or drop in the use of oil in traditionally oil-dependent countries. As a result, aggregate use of oil has not grown as dramatically in the past few years as it did in the 1990s.[19]

Until early 2005, the supply of oil (and drawdown of inventories) more or less kept up with rising demand. Since that time, however, with OPEC spare production capacity declining, the market has been under pressure, although this eased somewhat toward the end of 2005. All along the supply chain, this tightness has magnified many short-term developments and problems that were not concerns in a period of ample supplies, and has contributed to high

19. During the 1990s, overall crude oil demand increased 1.61 percent annually; by contrast, from 2000 to 2005, it increased by less than half that rate (0.74 percent).

Figure 5.3 Increase in Crude Oil Use Relative to First Quarter 2001, Various Countries

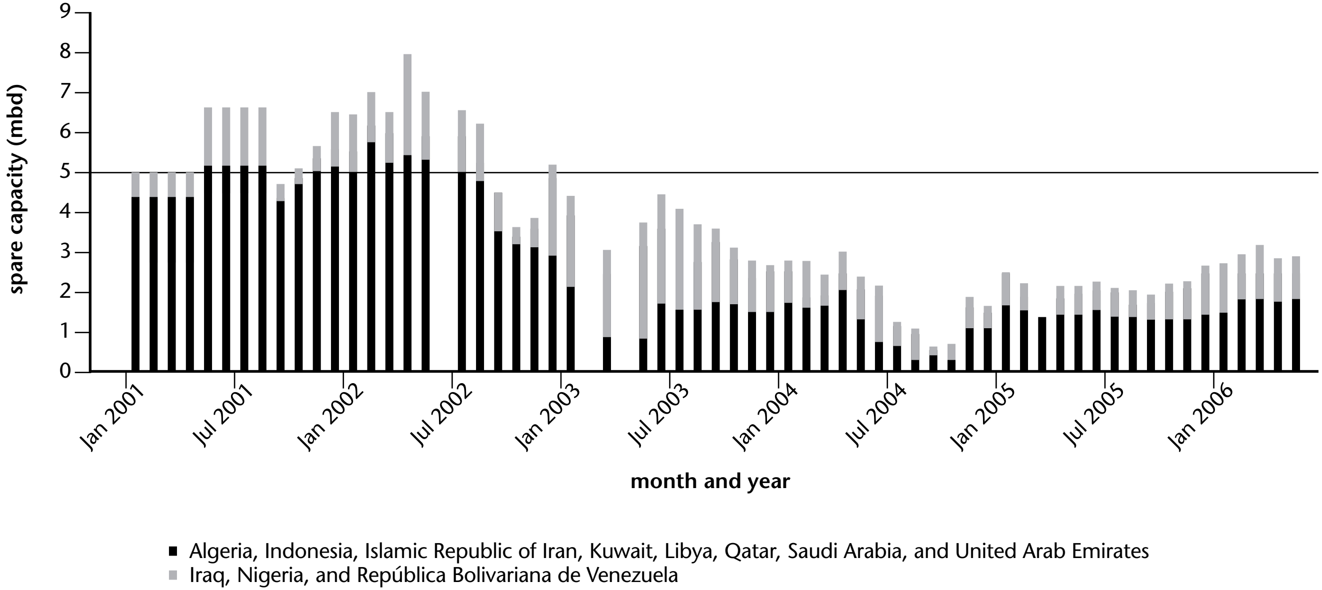


Source: IEA "Oil Market Report," various years.
Note: mbd = million barrels per day; OECD = Organisation for Economic Co-operation and Development.

volatility.[20] Figure 5.4 shows that OPEC spare production capacity started dropping steadily in mid-2002, bringing the market closer to binding constraints on the supply of cheap oil. Since January 2004, this spare capacity has been below 3 mbd. Rough calculations by the International Monetary Fund suggest that a level of spare capacity on the order of 5 mbd may help stabilize the market by halving volatility (IMF 2005a). With geopolitical uncertainties associated with output from Iraq, Nigeria, and the República Bolivariana de Venezuela (see figure 5.4), and underinvestment (both up- and downstream) in the supply chain, the extent of the drop in spare capacity is even higher. As a result, even when demand and supply were roughly in balance between mid-2003 and mid-2004, prices continued to increase significantly. This upward movement of prices has not slowed even after OPEC adopted an accommoda-

20. Inadequate investment in refining capacity over the past decade, combined with the refinery damage associated with hurricanes in the Gulf of Mexico, also have constrained the market.

Figure 5.4 OPEC Spare Production Capacity



Source: IEA "Oil Market Report," various years.
Note: mbd = million barrels per day; OPEC = Organization of Petroleum Exporting Countries.

tive stance in mid-2004—to enable OECD commercial crude oil stocks to be replenished fully and to ease the potential fear of supply shortages in the context of a slowdown of non-OPEC production. Thus, supply and demand equilibrium, as captured in the inventory model of the oil market, has ceased to predict crude oil prices fully in the past few years, with market fluctuations in excess demand but a steady rise in prices. The dramatic acceleration in oil prices since 2004 arose because supply was much more inelastic than it was in the past as a result of the decline in spare capacity combined with increased geopolitical uncertainties.

Prices currently are being formed in a setting increasingly driven by expectations of future tightness in a market fueled by concerns about medium-term prospects for cheap energy supplies, such as

- The slowdown of growth in non-OPEC production (despite high oil prices), which is expected to peak in 5–10 years
- The erosion of OPEC spare production capacity, which is already under pressure from increasing social unrest and political developments
- Inadequate spending on exploration and on maintenance of existing oil fields, as well as insufficient spending on appropriate refinery capacities in the context of a respecification of demand, causing extra pressure on demand for lighter products.

Simulation of Energy and Emissions Trajectories to 2050

Both China and India will have to maintain high GDP growth rates for many decades to improve the welfare of their citizens and to generate a steady stream of employment to accommodate the growing labor force. This growth will be fueled by energy. Many analysts of energy use in China and India note that the Giants' own production of fossil fuel energy is not likely to grow at rates equal to their consumption of fossil fuel energy. As a result, they are expected to become increasingly dependent on energy imports. How dependent will be determined by whether they stay with current low-cost but polluting energy options, or move aggressively to adopt a new, more balanced, and diversified energy strategy.

In forecasting energy use in the medium term (over as many as five years), it is common to take GDP growth and its underlying structure as exogenously determined, and use an econometrically estimated elasticity of energy use with respect to GDP to determine likely energy use. This parameter tends to have a value substantially less than unity for most high-income OECD countries. That is especially true since the 1970s when they started shifting to a postindustrial service-based economic structure (in part as a reaction to earlier oil price shocks in the 1970s). The value of the parameter is close to or greater than unity for most developing countries (Zhang 2000; Liu 2004). In the 1990s, however, the value of this parameter dropped to 0.7–0.8 for India—substantially lower than in the 1970s. The parameter has been even less stable for economies undergoing substantial structural changes, such as China, where it has varied from under 0.5 to over 1.0.[21] In fact, reliance on the extra-low numbers for China in the 1990s caused the IEA and other observers of the China scene to underestimate energy demand there dramatically in the post-2000 period (IEA 2002).[22] Based on more recent economic and energy statistics (for 2002–04), China again is exhibiting developing-country patterns of energy demand growth with an energy elasticity of GDP greater than one.[23]

To go beyond estimating aggregate energy needs within a five-year period requires use of more complicated models. To differentiate growth in various energy categories (for example, fossil fuel versus renewables, or subcategories of each), we need a more disaggregated model of the economy that provides structural detail on differential changes within the energy sector and shows how they respond to relative prices, changes in the technology and productivity of different sectors, and so forth. This requires a multisectoral simulation model. Many energy simulation models have a 20- to 30-year horizon because the underlying capital stock for energy production is long lasting and long-term implications of current investments do not show up in shorter time horizons. Even more detailed and longer time horizons are required to analyze the consequence of current investments for future emissions. Different fuels have different emissions coefficients, and fuel switching can affect aggregate emissions significantly even for the same level of energy use. The externalities associated with some energy-related emissions are also a function of the cumu-

21. As noted earlier, the anomaly of elasticities as low as 0.5 has not been explained satisfactorily. It appears to have resulted from a combination of faulty statistics, improved efficiency associated with new industrial technologies, plus some structural change/fuel switching ("low-hanging fruit"), and draconian command economy measures (closing profitable, employment-generating township and village industrial enterprises that were heavily reliant on producing dirty coal).

22. In IEA's 2002 *World Energy Outlook,* the projected total primary energy demand in China for 2010 was 1,302 Mtoe, whereas actual demand reached 1,422 Mtoe by 2003.

23. Elasticity of energy consumption averaged 1.47 over the period 2002–04, according to the National Bureau of Statistics of China (2005).

lative emissions (that is, concentrations of long-lasting pollutants, such as CO_2), not just annual emissions. This requires models with horizons of at least 50 years, which is what we use in this section.[24] It is important to note in analyzing the results of these models that they are neither forecasts nor probability distributions of likely outcomes. Instead, the results are heuristic illustrations of the consequences of selected types of actions. The usefulness of the results depends on the appropriateness of the models and scenarios selected to analyze a given problem.

Choice of Simulation Models

In simulating energy and emissions for individual countries, some analysts rely on top-down, economywide models, whereas others rely on bottom-up, sectoral/technological models. The former tend to generate a lot of trade-offs because they presume that all sectors are operating at their production frontiers, which often is not the case in developing countries. The latter models tend to generate more win-win opportunities, but do not take into adequate account the feedback effects or offsetting effects in the rest of the economy/ energy system. Because of the relative strengths and weaknesses of these two types of approaches, it is increasingly common to use a "system of models" that are "soft-linked"[25] (that is, top-down and general equilibrium economywide models are used in conjunction with bottom-up, partial equilibrium models that have more technological and sectoral detail) to simulate alternate scenarios for country-specific analysis.

Multiregional global models are used to simulate simultaneously the developments in large countries, such as China and India, and to trace the global consequences of these developments for different energy markets as well as global emissions. A number of such multiregional global models are available (such as MERGE, the Mini Climate Assessment Model [Mini-CAM], the Asian Pacific Integrated Model [AIM], and others).[26] This section uses esti-

24. Many climate change models operate with five-year increments over a couple of centuries.

25. In a "system of models," the output of one well-calibrated model is fed in as an input into another well-calibrated model instead of establishing a single set of internally consistent equations in a more comprehensive model that is difficult to calibrate.

26. For MERGE, see Kypreos (2000). The Mini-CAM is from the U.S. Pacific Northwest National Laboratory (Edmonds, Wise, and MacCracken 1994; Edmonds, Wise, and Barns 1995). AIM is from Japan's National Institute for Environmental Studies (Morita et al. 1994).

mates generated by the IMACLIM-R model at the International Research Center on Environment and Development.[27]

The IMACLIM-R model is a general equilibrium model with subsector detail on the energy-producing sectors (fossil fuels—coal, oil, and gas—and nonfossil fuels—nuclear, hydro, biomass, and other renewables), the energy-transforming sectors (such as electricity), and key energy-using sectors (such as industry, construction, transportation, and residential). For ease of analysis, the model collapses all other sectors into an aggregate composite sector. Growth is determined partly exogenously (population, savings), and partly endogenously (endogenous productivity growth, variations in the terms of trade, exhaustion of cheap fossil fuel resources, and so forth). Each year a static Walrasian equilibrium is solved and the structural evolution of the economy is endogenized (for example, a scenario in which there is a lot of investment on transportation and in which consumers have a strong preference for mobility will generate different structural growth over time than will a scenario with the opposite assumptions).

Compared with other existing economy–energy models, the IMACLIM-R model has a few advantages:

1. It explicitly incorporates technical information on the demand and supply sides of the energy sectors, including end-use efficiency (often neglected in models using elasticities applied to final energy demand), the ability to simulate "learning by doing," and the incorporation of capital stock vintages for long-lasting investments to trace the path of investment and technological adoption more realistically.
2. It ensures consistency between this technical information and the characteristics of the economic context, including the prevailing set of relative prices.[28]
3. It is based on a modeling compromise between models generating long-term optimal trajectories under perfect foresight (which tend to underestimate the role of social and technical inertia in economic adjustments) and models generating disequilibrium dynamics with a lot of knife-edge pathways and hysterisis.[29] IMACLIM-R is a growth model that allows transitional disequilibrium. The model has the abil-

27. For additional detail on this model, see Crassous et al. (2006).
28. In IMACLIM-R, the reaction to prices also depends on technical information, such as the existence of asymptotes in energy efficiency, which is more credible than constant coefficients in the production function, especially when prices move over a large range.
29. Hysterisis entails very slow adjustment and can result in large losses in terms of cumulative GDP.

ity to incorporate shorter-term transitional imbalances (resulting from the interplay of imperfect foresight at a given point in time and the inertia in the economic system) and the ability to adapt (see point [1] in this list). But it also contains all the feedback mechanisms required to enable it structurally to recover over the long run, a Solow-like long-term pathway that results from demographic changes, productivity growth, capital accumulation, and changes in the terms of trade. As such, long-term growth does not depend on intertemporal optimization with rational expectations;[30] rather, it relies on imperfect foresight about future prices and quantities explicitly modeled for investment allocation and technology choices in the electricity sector.

4. It allows international capital flows between regions as a function of the divergence between domestic savings and total desired amount of investments in each of nine global regions (with China and India each representing a separate region). The model is savings driven. A region's (country's) aggregate savings rate is determined exogenously by long-term demographic trends and age structure rather than by short-term interest rate adjustments. All savings are invested. Desired amounts of investment are computed from (imperfectly) expected increases in future demand. There is no reason for the two sides to be balanced within a region. As a result, a region with excess savings becomes a capital exporter, and a region with a deficit of savings to finance its investment needs becomes a capital importer. The international pool gathers the exports of regions with excess savings and reallocates the money to regions with insufficient savings proportional to the total amount of unmet domestic investment needs.[31]

Choice of Scenarios

A reference or base case, designated as the *business-as-usual scenario*, or BAU, is simulated for this chapter.[32] For convenience of exposition, only the results of

30. Although the model describes behavior in terms of current prices, this does not necessarily signify the absence of expectations. First, it is assumed that people react to existing prices as the best available information at the time decisions are made. Second, the elasticities that govern these reactions are supposed to mimic real behavior and incorporate implicitly a broader set of parameters, such as inertia, risk aversion, and the like.

31. In simulation, some countries can be modeled as having a fixed predetermined net export of capital.

32. The base year for the projections is 2001, rather than 2005 as used in other models in

this case are described in detail. All others are presented summarily and in relation to the BAU. On average, annual GDP growth rates assumed in the BAU are 6.5–7.5 percent in China over the next decade or two, and 5–6 percent in India with both rates tapering to 3–4 percent a year by 2050. These average growth rates for the future are somewhat lower than recent performance because of presumed institutional and technical constraints within the economies, resulting in inefficiencies in the allocation of resources and limiting their ability to sustain very high growth rates for a prolonged period. However, a variant of the BAU also is simulated. Designated as BAU-H, it assumes annual GDP growth rates that are approximately 1.0–1.5 percentage points higher for both countries (that is, 7.5–9.0 percent for China and 7.0–8.0 percent for India over the next decade or two). These more optimistic growth rates are based on recent performance and extrapolation of government assumptions for upcoming five-year plans. Both the BAU and the BAU-H assume continued heavy reliance on fossil fuels for the next couple of decades, with adverse consequences for local emissions (suspended particulates, sulfur, ozone, and the like) and for global emissions (greenhouse gases, particularly CO_2).

The policy-based *alternate scenarios* (ALTs) are designed to explore the extent to which a package of policies can result in two potential decouplings.[33] The first is decoupling energy growth from GDP growth through reduced energy intensity, either as a result of increased energy efficiency, a structural shift away from energy-intensive manufacturing in economic activity, or both. The second is decoupling emissions growth from energy growth through fuel switching from coal to gas (or clean coal), or from fossil fuels to nuclear energy or renewables (and associated simultaneous improvements in energy efficiency). The decouplings are not policies themselves nor are they totally independent of each other. Rather, they are analytically convenient ways of describing the extent to which policies have been effective in increasing the economy's energy efficiency and reducing its generation of harmful emissions.

Three sets of policy scenarios are simulated:

1. *Demand side scenarios* (designated with a D) that include additional actions geared toward improving end-use efficiency/energy saving,

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this book. The reason is that IEA data for country-specific energy details (used in the IMACLIM-R simulations) and Global Trade Analysis Project data for all regions are produced with a lag of a couple of years, and it was important to ensure that the economic parameters and energy details used in the simulations were mutually consistent in the base year and tested for a year or two out of sample.

33. For more information on policy options, see Shalizi (2005).

over and above the energy efficiency improvements already incorporated in the BAU case (as described later in the KAYA diagrams in figure 5.6).[34] The additional improvements are (a) a 25 percent improvement in overall energy efficiency in the "composite" sector (including both "pure efficiency" and structural change in the economy with an increase in the share of services in GDP), relative to the base case; (b) an additional 1.1 percent efficiency gain annually in residential/household energy-using equipment, leading to an eventual 60 percent improvement over the base case; and (c) a 50 percent improvement in the fuel efficiency of cars by 2050, compared with the base case.

2. *Supply side scenarios* (designated with an S) that include a higher share of hydroelectric and nuclear power in both China and India than under the BAU cases, which already incorporate some expansion of nonfossil fuels sectors.[35] The additional improvements include (a) a 20 percent increase in hydroelectric capacity, relative to the base case; (b) a 30 percent increase in the share of nuclear power in new investments for power generation; (c) the share of biofuels is increased progressively to 10 percent of the total amount of fuels produced by the Giants. The shares of wind and solar energy increase significantly from a very low base but not enough to offset the reduction in the use of traditional biomass; and (d) energy efficiency is increased by 15 percent in the use of coal for industry and by 8 percent in the use of coal for electricity generation in the new capital stock installed after 2005.
3. *Supply and demand side scenarios* (designated with S&D) that combine efficiency improvements and fuel-switching measures and are in line with Chinese and Indian energy strategies. (Sarma, Margo, and Sachdeva 1998; Liu 2003).

In the working paper version of this chapter, Shalizi (forthcoming), the BAU and ALT scenarios were simulated in two different contexts: (1) the

34. The IEA has suggested that end-use efficiency improvements hold the greatest potential for managing energy demand and mitigating CO_2 emissions. Over the 2002–30 period, such improvements could contribute more than 50 percent to reducing emissions for a group of 11 IEA countries (Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom, and the United States) for which IEA has complete time-series data (see Bradley 2006).

35. Note that fuel switching is often also accompanied by simultaneous improvements in energy efficiency.

base case used here, which assumes that there are no constraints to adjusting to short-term signals on energy markets; and (2) a context in which there are constraints to timely adjustment in response to growing energy needs either (a) on the deployment of domestic coal supply in China and India, or (b) on the evolution of future oil and gas markets, due to unexpected geopolitical or resource shocks in the global oil markets or to difficulties of the world oil and gas industry (including refineries) in developing the necessary production capacities in time. This introduces a number of refinements to the analysis given here.

These different scenarios generate a series of outcomes that can be compared. The particular outcomes of interest in this study are the energy requirements in the economy, the global emissions associated with these energy requirements (focused on CO_2), the local emissions associated with these energy requirements (focused on SO_2), and investment requirements associated with the different energy trajectories.[36] These simulations also enable us to compare the consequences of accelerated or delayed investments in shifting from the BAU to ALT scenarios, and to explore the potential for self-financing versus additional external financing requirements that might be needed.

Reference Scenarios—BAU and BAU-H

The two base scenarios reflect the rapid energy and emissions growth associated with fast and very fast GDP growth in China and India over the next few decades. These scenarios provide the benchmark energy and emissions trajectories against which the costs and benefits of additional policy interventions can be discussed in the next section.

Country Implications

In China, in terms of key energy-using sectors, industry and services account for the largest share of final energy use over the study period, increasing for the next two decades to more than 60 percent before declining below current

36. The variable total suspended particulates, which is used most often in health analysis ex post, is difficult to project ex ante and therefore not included. SO_2 emissions can be projected with the simulation model and are included in the findings. It is not possible, however, to assess their health implications because of the problem discussed earlier in the section on

Table 5.3 Sectoral and Fuel Shares of Energy Consumption in China and India

	China			India		
	2005	2020	2050	2005	2020	2050
Total final consumption (Mtoe)	921.7	1,683.2	2,685.1	400.3	609.4	1,268.1
Sector (%)						
Industry and services	58.5	62.2	54.6	32.7	39.3	48.3
Transportation	10.2	14.4	20.8	10.4	12.3	16.0
Residential use	31.2	23.5	24.6	56.9	48.4	35.7
Fuel mix (%)						
Coal	38.0	37.4	25.5	11.5	13.0	12.0
Refined products	25.0	27.4	27.8	27.5	27.7	25.7
Gas	2.6	3.4	4.4	2.7	3.0	3.3
Electricity	13.3	20.3	35.8	9.9	17.3	37.5
Renewables and biomass	21.1	11.5	6.6	48.3	38.9	21.5
Total primary energy use (Mtoe)	1,223.1	2,483.5	4,436.5	515.6	845.8	2,068.8
Coal (%)	54.3	58.9	62.7	29.2	37.8	57.9
Oil (%)	23.1	22.6	20.5	25.0	22.6	17.7
Natural gas (%)	2.5	3.5	3.4	3.8	5.3	4.5
Nuclear (%)	0.5	0.5	2.4	0.8	0.1	2.1
Hydro (%)	3.7	3.0	3.1	3.7	3.9	1.9
Renewables (%)	15.9	11.5	7.9	37.6	30.3	15.9

Source: Author's calculations based on simulation model.
Note: Mtoe = million tons of oil equivalent.

shares by 2050. The share of residential use also declines from 31 percent to 25 percent, and the share of transportation (relying almost exclusively on refined petroleum products) doubles to 21 percent (see table 5.3). In terms of fuels, electricity represents an increasing proportion of final energy use, with its share almost tripling. The shares of gas and refined petroleum products increase by 2 percentage points each. The shares of coal and traditional biomass drop substantially. The role of coal in final energy use declines as services grow, relative to industry, and the role of traditional biomass in final energy use diminishes as commercial electricity replaces it.

local externalities. Defining the implications requires projecting the spatial distribution of emissions and the density of the population exposed in different localities, and that is not possible at the level of aggregation used in IMACLIM-R.

Though electricity represents only a third of final energy use by 2050, the heavy reliance on coal (80 percent) for generating electric power at midcentury explains why coal retains a prominent share in China's energy balance. By 2050, China's reliance on coal for primary energy use remains high (63 percent in the BAU scenario, 65 percent in the BAU-H scenario). Primary energy use (not final energy use) determines the extent of polluting emissions. In the BAU scenario, primary energy demand in China will double in the 20-year period from 2001 to 2020 and quadruple by 2050.[37] In BAU-H (the higher-growth scenario), the increase in CO_2 emissions will be somewhat greater, at 2.5-fold by 2020 and 5.2-fold by 2050.

In India, final energy demand from industry and services grows from 33 percent to 48 percent, and energy demand for transportation rises from 10 percent to 16 percent. Final energy demand from the residential sector, however, drops from 57 percent to 36 percent (table 5.3).

Similar to the Chinese situation, the switch to electricity in India increases the share of coal in primary energy demand from one-third in 2001 to almost 58 percent in 2050. Coal's share expands relative to hydropower and traditional biomass. In the BAU scenario, there will be a 1.6-fold increase in primary energy demand in India by 2020 and a 3.8-fold increase by 2050.[38] In the BAU-H scenario, the increases will be significantly larger: 2.2-fold and 7.9-fold by 2020 and 2050, respectively.

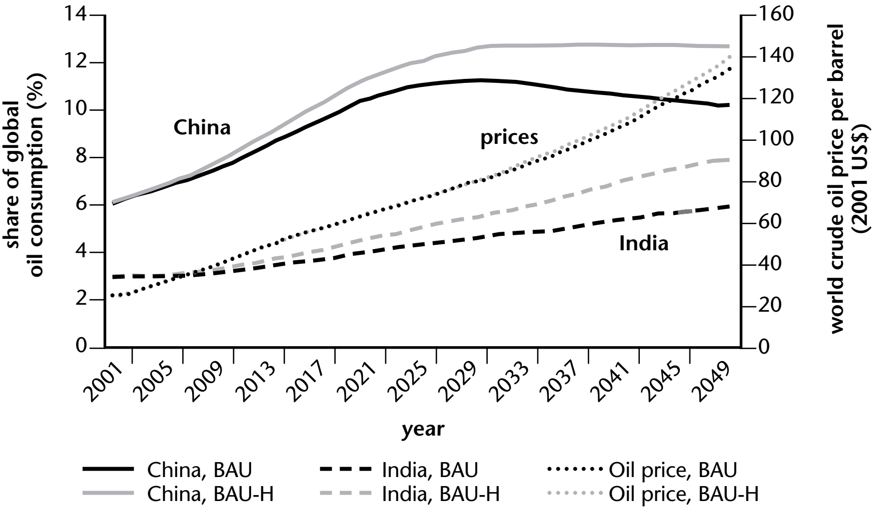
Global Implications

We look first at oil prices. At present, China accounts for 6 percent of world oil use; this share rises to 10 percent in 2050 in the BAU case. Note that the share of China's oil consumption in total world oil consumption stabilizes after 2030 because oil use in other developing countries grows faster. In the same period, India's global share increases steadily from 3 percent to 5 percent in the BAU scenario (see figure 5.5).

In the base case, the model simulations generate (in 2001 dollars) a price of oil in 2020 of \$61.90 (or \$62.47 in the BAU-H scenario), which is less than

37. These simulations follow official Chinese government estimates for the 11th five-year plan and beyond.
38. These simulations follow official Indian government estimates for the 10th five-year plan and beyond.

Figure 5.5 China's and India's Shares of World Oil Consumption and Trajectory of World Oil Prices, BAU and BAU-H Scenarios



Source: Author's calculations based on simulation model.
Note: BAU = business-as-usual scenario; BAU-H = BAU with high growth.

the actual price prevailing in 2006.[39] However, as noted above, the recent run-up in oil prices does not reflect a steady-state price. Thus, there is a big difference between the high value of oil prices during a short period of time and a steady, permanent high value. The $62 per barrel in 2020 (or the $133 per barrel in 2050, shown in figure 5.5) therefore should be compared with a counterfactual steady-state price independent of the recently observed short-term volatility. This normal price probably would be in the range of $40–$50 per barrel in 2006 (not $75 in July 2006).[40]

By 2050 there is a fivefold increase in crude oil price in the five-decade period between 2001 and 2050 (from $25 to $133 a barrel in 2001 prices). This

39. The conversion ratio from 2001 dollars to 2004 dollars is 1.065, and to 2005 dollars it is 1.092.

40. Oil price formation in IMACLIM-R does not incorporate a risk component (which has been shown recently to play a major role), so crude oil prices in the short run may be lower than prices observed recently on the oil market.

increase is significant but not outlandish relative to historical experience.[41] The price of a barrel of oil in 1970 was only $9.00 in constant 2004 dollars (or $1.80 in nominal prices of 1970) (BP 2006). In 2004, before the recent spike in oil prices resulting from tightness in the oil market and geopolitical uncertainties, the price was $36.40—that is, a fourfold increase in a little more than three decades.[42]

Is it plausible that alternate fuel technologies will not displace demand for oil at such high prices? This question cannot be answered definitively. The growth in oil prices by 2050 is driven by the continuing growth in demand for mobility (particularly road and air transportation) all over the world. This demand generates substantial growth in the use of oil for which there will be few substitutes (unlike in the power sector, where there are many renewable alternatives to fossil fuels). In simulating the model, the market penetration of biofuels or hydrogen as alternatives to oil for transport is assumed to be limited in the time period under review.[43] With the exception of ethanol from sugarcane (and to a lesser extent from corn), all other biofuels are at early stages of research and experimentation. Hydrogen and coal liquefaction are not yet commercially viable technologies and may not be so for another decade or two; it will take another couple of decades before the necessary infrastructure can be put into place to enable a substantial part of the fleet to convert to these alternate fuels. Thus, relying on knowledge of currently practical or likely to be practical technologies within the next two decades, the simulation clearly shows that the upward trend in oil prices will continue, linked to supply conditions.[44]

Because of the adaptation built into the model, a gradual price increase does not generate a significant loss in GDP, whereas a spike in oil prices will generate significant losses in GDP—at least in the short run, when the econ-

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41. Nor is it outlandish relative to some other projections. The U.S. Department of Energy's projections in its *International Energy Outlook 2006* includes a high scenario with oil prices reaching $96 a barrel (in 2004 prices) by 2030.

42. The 1970 price for Arab light crude was even less—$1.26 in 1970 prices, equivalent to $7 in 2005 prices. In 2003, its price was $40 or almost six times as much (IEA 2006).

43. As noted in the discussion on supply measures implemented in the model, biofuel penetration is assumed to reach 10 percent of fuels in China and India. For the world as a whole, the penetration rate is even lower (3 percent of fuels over the next 50 years, based on *World Energy Outlook* (IEA 2004).

44. Note that this oil price profile already incorporates an increasing role for nonconventional, more expensive petroleum sources.

omy does not have the requisite ability to adjust (Hamilton 2003). Over time, the economy returns to its long-run trajectory. As noted by Manne (1978), if there is either perfect expectation or progressive adaptation over the long run in a world with no erratic shocks, then one cannot expect large GDP variations because energy is a small fraction of the economy. This is no longer the case when there are shocks and surprises.[45] To analyze the behavior of IMACLIM-R in response to a spike in oil prices, a simulation was run assuming a world oil price increase of $35 a barrel over two years, relative to the long-term price trajectory. At the peak, GDP losses reach –3.2 percent in China (–1.6 percent in two consecutive years) and –7.0 percent in India (–3.5 percent in two consecutive years).

Now we turn our attention to emissions. In the BAU case, CO_2 emissions from energy use more than double by 2020, relative to 2005, and quadruple by 2050 to reach 3.6 giga tonnes carbon (GtC) in China. They almost double by 2020 and quintuple by 2050 to reach 1.6 GtC in India. The Giants' combined emissions in 2050 will be 44 percent of world emissions in that year, compared with approximately 20 percent in 2005. SO_2 emissions in both countries follow trajectories very similar to the CO_2 emissions.

The overall conclusion is that the high growth of energy use in China and India is not likely, *alone,* to cause structural imbalances in international energy markets. The main negative outcomes are in terms of local and global (CO_2) emissions (and, beyond 2050, in terms of the accelerated exhaustion of overall conventional and nonconventional oil reserves).

What happens to these variables when GDP growth rates are higher in China and India? In the BAU-H case, China's share in world oil use increases to 14 percent and India's to 8 percent by 2050. The price of oil, however, increases only marginally to $62.47 (relative to $61.90 in the BAU case) by 2020 and to $139.80 (relative to $133 in the BAU case) by 2050.[46] With the higher GDP growth rates in China and India (BAU-H), the rest of the world

45. As noted earlier, assuming "no surprise" and "no friction" in the BAU scenarios may not be realistic. However, these scenarios provide a useful benchmark against which to evaluate situations with adjustment problems (rigidity and friction) that prevent prices and quantities from adjusting rapidly and smoothly.

46. In the BAU-H scenario, oil prices are only $6.80 a barrel (+5.1 percent) higher than in the BAU scenario in 2050. This minimal difference is caused by the scenario's assumption that energy policies are deployed in a timely and efficient manner in the coal sectors of China and India to meet their growing energy needs. The rise in transportation demand for oil is significant but not enough to generate drastic imbalances on the oil market.

experiences a 2 percent higher GDP relative to the BAU scenario, induced by the faster economic growth in the Asian Giants.

In the BAU-H scenario, global primary energy requirements will be 16 percent higher by 2050. Carbon emissions, however, will be 19.8 percent higher. The faster growth in carbon emissions relative to primary energy reflects a 5.3 percent increase in the carbon content of the world aggregate energy supply because most of the regions in the world are not able to avoid a higher use of coal and other fossil fuels to meet their higher energy demands. In the higher-growth scenario, China and India's CO_2 emissions in 2020 more than double (to 2.2 GtC and 0.7 GtC, respectively), and by 2050 grow sixfold (to 4.9 GtC) and elevenfold (to 3.2 GtC), respectively. Together, the Giants will account for 60 percent of total world CO_2 emissions by 2050. Thus, comparing the BAU and BAU-H scenarios leads to this not-surprising result: in the absence of alternative policies to accelerate energy efficiency and decarbonization, energy use and CO_2 emissions will be higher, and the rate of GDP growth will be higher.

Because CO_2 persists in the atmosphere for very long periods, it is the cumulative emissions (that is, concentrations) that matter, not the annual emissions[47]—for example, for purposes of analyzing rising temperatures and global warming. It is in analyzing such issues that the advantage of using the 50-year time horizon becomes apparent. If the analysis were restricted only to the period up to 2020, we would see that the higher GDP growth rates in the BAU-H scenarios generate cumulative CO_2 emissions only 9 percent higher in China and 17 percent higher in India, relative to the BAU case. But by 2050 the differences are dramatic: 22 percent higher in China and 79 percent higher in India (or 34 percent higher combined)—and this with only an average 0.75–1.25 percent higher growth rate in GDP annually over the 50-year period 2001–50.[48]

The constrained adjustment scenarios in Shalizi (forthcoming) suggest that, if energy supplies do not expand as expected, GDP will be lower in India (by 8 percent in 2030) and China (by 2 percent) and that world oil prices are likely to be 15 percent higher than projected here. We cannot predict

47. This is less the case for SO_2 or other emissions that dissipate more rapidly over time.
48. The 1.0 to 1.5 percent higher growth rates (between the BAU and BAU-H scenarios) cited in the section on business-as-usual simulations refer to the first couple of five-year-plan periods after 2005. The simulation is frontloaded and the growth rates taper off to 3–4 percent by 2050. Thus, over the 50-year period the compound average growth rate (between the BAU and BAU-H scenarios) is only 0.75–1.25 percent.

whether the requisite investments to avoid the constraints will occur, but these results certainly suggest that they are an important element in the effects of Chinese and Indian growth.

Policy Intervention Scenarios—ALT-D, ALT-S, and ALT-S&D

The alternative policy intervention scenarios show that it is possible to increase energy efficiency and reduce emissions substantially without significantly compromising GDP growth.

Country Implications

The ALT (policy-based) scenarios result in a substantial reduction in energy use and CO_2 emissions in both China and India (table 5.4).[49] The combined effect of measures acting on demand and measures acting on supply is much stronger than the effect of either set of measures alone. More important, their positive effects on reducing annual energy use and emissions generated are significant and increase over time with marginal impacts on GDP.

Measuring the Extent of Energy and Emissions Decoupling from GDP Growth

KAYA diagrams provide a convenient way to present the time profile of the extent to which the two decouplings mentioned earlier are achieved. The horizontal axis of a KAYA diagram shows the extent of improvement in energy intensity in an economy (that is, energy used per unit of output) and is read right to left. The vertical axis shows the extent of improvement in carbon intensity (decarbonization) in the economy (that is, carbon emitted per unit of energy) and is read from top to bottom. In the KAYA diagrams presented here (figure 5.6), the lighter line refers to the BAU scenario; the dashed line refers to the scenario induced by measures acting on demand only (ALT-D); the dotted line refers to the scenario induced by measures acting on supply only (ALT-S); and the black line refers to the scenario induced by combining measures acting on supply and demand (ALT-S&D).

In the BAU strategy for China and India there is a strong reduction in energy intensity built in to reflect industry modernization and adoption of new

49. Reductions are even more substantial for SO_2 emissions that have local consequences but are not cited in the tables above.

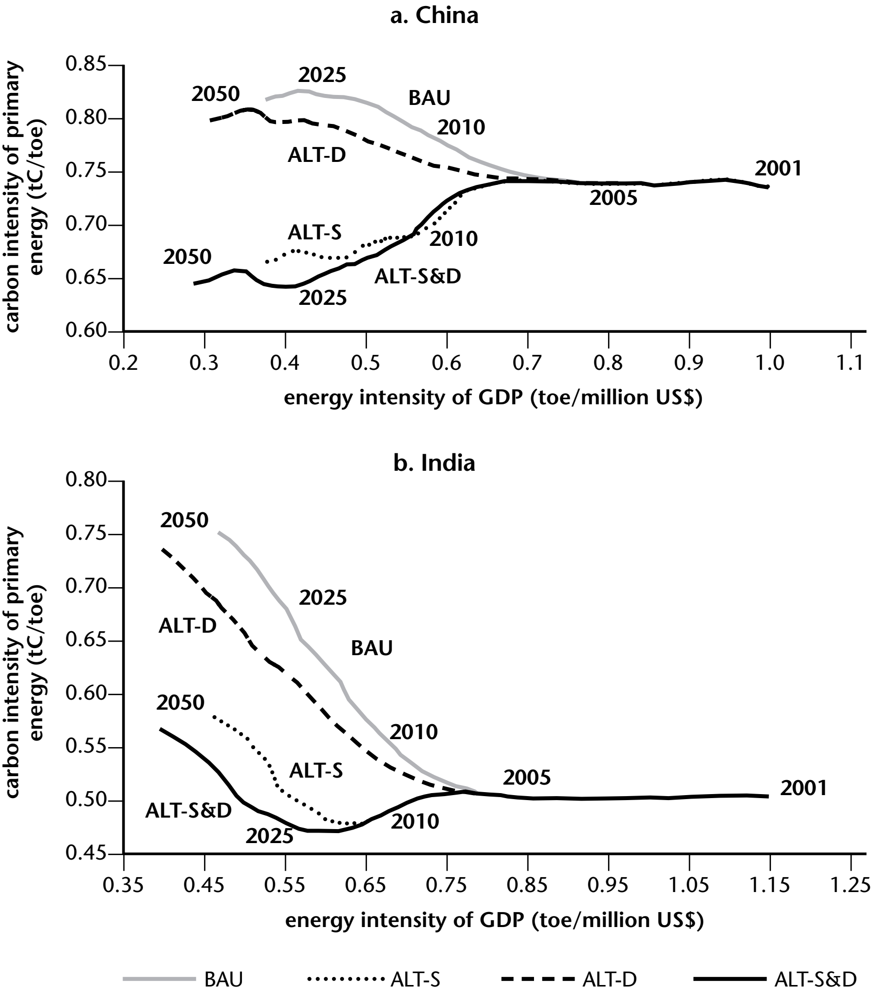
Table 5.4 Summary of ALT scenarios Relative to BAU for China and India, 2005–50

Country and scenario		GDP (2001 US$ trillions)			Primary energy use (Mtoe)			CO_2 emissions (GtC)			Energy investment (2001 US$ billions)		
		2005	2020	2050	2005	2020	2050	2005	2020	2050	2005	2020	2050
China	No change in policy—BAU	1.62	4.46	11.75	1,223.12	2,483.52	4,436.51	0.90	1.96	3.61	71.53	119.68	113.28
	Demand—ALT-D (%)	99.8	99.4	100.8	99.1	90.3	78.8	99.0	88.7	76.7	99.8	96.7	76.0
	Supply—ALT-S (%)	99.9	99.5	99.5	98.7	95.8	98.4	98.5	83.1	79.8	101.2	116.3	121.7
	Supply and demand—ALT-S&D (%)	99.7	98.6	99.2	97.8	86.7	75.9	97.6	72.8	59.9	101.0	114.3	92.2
India	No change in policy—BAU	0.61	1.35	4.59	515.61	845.84	2,068.79	0.26	0.49	1.56	18.44	36.64	74.13
	Demand—ALT-D (%)	99.8	99.4	100.9	99.1	94.1	84.8	99.1	92.8	82.9	99.9	95.2	84.1
	Supply—ALT-S (%)	99.9	99.8	101.4	98.4	93.8	99.3	98.1	77.3	76.4	102.2	113.4	124.9
	Supply and demand—ALT-S&D (%)	99.7	99.0	101.2	97.5	88.7	83.7	97.2	71.6	63.2	102.1	110.5	103.5

Source: Author's calculations based on simulation model.
Note: GtC = giga tonnes carbon; Mtoe = million tons of oil equivalent.

technology. However, carbon intensity increases in both countries—but more significantly in India. China shows a slight improvement in carbon intensity, but only toward the latter part of the 50-year period under review.

Figure 5.6 Extent of Energy and Emission Decoupling in the Case of Final Energy Consumption



Source: Author's calculations based on simulation model.
Note: tC/toe = tons of carbon to tons of oil equivalent.

Relative to the BAU case, ALT-D measures to reduce demand alone (by increasing energy efficiency), extend the degree to which the energy intensity of GDP is reduced (the line extends farther to the left), and ensure that carbon intensity does not grow as much as it does in the BAU cases. But the time profile of the two decouplings is very similar to the BAU cases in both China and India. In China, demand side policies reduce emissions by 0.84 GtC, relative to the 3.6 GtC of emissions in 2050 (a 23 percent reduction). In India, demand side policies reduce emissions by 0.27 GtC, relative to 1.6 GtC in 2050 (that is, they reduce emissions by 17 percent).

Relative to the BAU case, ALT-S measures to change only supply (that is, the structure of fuels supplied to the economy) do not extend the degree to which energy intensity of GDP is reduced (unlike the demand measures) in either China or India. However, in China they do significantly alter the time profile and the extent to which the carbon intensity is reduced. In India, after an initial shift away from carbon, the carbon intensity starts increasing again (unlike in China) because the share of traditional biomass for household residential use is much higher at the outset of the process in India than in China (48 percent versus 18 percent, respectively). Thus, the greater shift from traditional biomass to commercial electricity for household residential use results in a displacement of less carbon-emitting biomass by more carbon-emitting fossil fuel–based electricity—despite the increased penetration of nuclear and nontraditional renewables, such as wind and solar energy, for producing power. However, supply side policies bring emissions down by 30 percent in India (from 1.56 GtC to 1.19 GtC), a larger reduction than the 20 percent lowering in China (from 3.6 GtC in the BAU case to 2.88 GtC).

Combining demand-reducing measures with fuel-switching measures (ALT-S&D) results in both a lowering of energy intensity and a lowering of carbon intensity, relative to either set of measures alone, and quite significantly relative to the BAU scenario. By 2050, the combined measures reduce energy intensity of GDP by 24 percent in China and 17 percent in India, and reduce carbon intensity of energy by 21 percent in China and 25 percent in India compared with the BAU scenario.

Global Implications

The repercussions of these ALT policy scenarios on world energy prices are mixed. Improvements in transport fuel efficiency in China and India lower global oil prices by a couple of percentage points. The improved efficiency in coal use and the substitution toward nuclear and renewable fuels in generating electricity have a more significant impact on world coal prices, which drop by 5–10 percent by 2050. This has a positive impact on India, which may have to import more coal in the future. These effects are more pronounced in the scenarios with rigidity/friction.[50]

The ALT scenarios have a much more significant impact on emissions, and the effect grows over time and extends beyond 2050. In cumulative terms, however, even by 2050, demand side policies in China reduce CO_2 emissions by approximately 15 percent (18 GtC) and supply side policies produce reductions of approximately 18 percent (21 GtC). The combination of supply and demand policies reduces emissions by 32 percent (36 GtC) or almost one-third, compared with the 116 GtC cumulative CO_2 emissions in the baseline scenario. The overall impact of policies on CO_2 emissions in India is of similar relative magnitude. In cumulative terms, demand side policies in India reduce CO_2 emissions by approximately 12 percent (4.5 GtC) and supply side policies reduce them by about 22 percent (8 GtC). The combination of supply and demand policies reduces emissions by 31 percent (11 GtC) or almost one-third, compared with the 37 GtC cumulative CO_2 emissions in the baseline scenario.

Additional Investment and Financing Requirements

As noted earlier in the section on ALT scenario energy and emissions trajectories, implementing either demand side or supply side measures reduces energy and emissions, compared with the BAU case. The measures do not offset each other so implementing both sets of measures reduces energy and emissions substantially more than implementing either one alone. And this reduction continues throughout the period up to and beyond 2050. This is not the case for energy investments (see the final block in table 5.4).

Implementing measures only to reduce the demand for energy lowers investment requirements in all periods, relative to the BAU case, whereas measures to change only the structure of the fuel supply increase investment requirements substantially, relative to BAU. Combining the two sets of measures, however, results in an intermediate time profile of investment requirements that, in aggregate, are higher in the early period and lower in the

50. Note that the impact of the ALT scenarios relative to the BAU reference case is much lower than the effect of scenarios with rigidity/friction.

later period than is true in the BAU case.[51] That is, the requirement for additional energy investments drops by 2050 (and in China they drop to a level below the BAU equivalent). The reason for this drop is that a smaller amount of investment is required in fuel switching when demand is lower.[52]

A key point in this analysis is that net capital flows are fixed exogenously. Thus, the increases in investment in the energy sector must be financed either by reducing net capital outflows or by diverting other domestic investment. Our simulations assume the former for India, which permits its GDP growth relative to BAU, but at the expense of a deterioration in net assets—the welfare implications of which the model ignores. For the sake of illustration, we make the opposite assumption for China: investment is diverted and GDP falls marginally compared with BAU, but asset accumulation proceeds unchecked. The moral is that although the need for the extra investment in the ALT runs is real, the results given for GDP are very poor indicators of likely welfare consequences. The latter depend on the decline in output, on the decline in net assets, and, of course, on the benefits of curtailing emissions.

From a country perspective, the higher initial cost of investment in alternatives to fossil fuels is a concern, so the standard response is to delay adopting cutting-edge technologies until additional technological innovations reduce their costs.[53] Accordingly, another scenario was simulated to explore the consequences of delaying interventions (which is reported in the longer working paper version of this chapter). This shows that delaying policy interventions will save money now but will generate higher investment requirements in the future to reach a given target emissions level by a specified period. However, even these higher investment requirements will be more affordable because they will represent a lower share of a larger GDP, given the intervening growth in the economy. This supports the initial intuition regarding the economic benefits of delaying interventions. The downside of delaying interventions, however, is that the environmental benefits of these policies also will be delayed. What the scenarios show is that the latter never quite fully

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51. Investment requirements are 114 percent higher in China in 2020 (equivalent to an additional $13 billion in 2001 prices) and 110 percent higher in India in 2020 (approximately equivalent to an additional $4 billion in 2001 prices).
52. When friction and rigidities are introduced, the aggregate energy investment required in the BAU-f case also is lower than in the BAU case because GDP is lower.
53. In the IMACLIM-R model used for the simulations in this chapter, "learning by doing" is built in; therefore, earlier investments in novel technologies will speed up the rate at which one moves down the cost curve and thus reduce the aggregate financial burden.

catch up with the benefits generated by implementing policy interventions earlier. Even though the costs of investment and the benefits of emissions reduction are both shifted into the future, the net present value of the two policies is not the same. There is a price of carbon for which the two streams of costs and benefits will be equivalent. With early action, the implicit price will be lower than that currently observed (\$10–12 per tonne of CO_2) in the project-based segment of the carbon market (Clean Development Mechanism)—which means there is no reason to delay. Delaying action by a decade, however, requires a higher price of carbon today to generate the same returns. This higher carbon price will be above current market prices, and therefore will not be cost effective. As a result, the cumulative "financial cost-reducing" benefit of delaying investments does not offset fully the increased cumulative emissions cost associated with prolonged reliance on fossil fuels.[54,55]

Conclusions

This chapter has made a number of important points on the effects of Chinese and Indian growth on energy markets and emissions. Even at present, demand for electricity is growing very rapidly in both countries, and there are limited low-cost domestic energy resources other than coal for producing this electricity.

Demand for oil also is growing rapidly in response to the growing demand for mobility/transportation. This growing fossil fuel use is generating harmful emissions of greenhouse gas and increasing public health costs from severe local air pollution. The Giants, however, were not the principal drivers of high oil prices in 2006.

Turning to the future, energy externalities (local, regional, and global) are likely to worsen significantly, especially if there is no shift in China's and India's energy strategies.

Many developing countries worry that high energy demand from China and India will hurt their growth by forcing higher prices on international energy markets. This effect is likely to be small and to be offset partially or fully by the "growth-stimulating" effects of the larger markets in China and India.

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54. This chapter does not evaluate the extent of international carbon trading that might evolve post-Kyoto.
55. Fuller details of this example are available in Shalizi (2006).

The Giants themselves worry that shifting their energy strategies to fuels with lower emissions will reduce externalities and the pressure on world energy prices in world energy markets—but at the expense of their growth in incomes. In fact, the evidence suggests that improved efficiency leaves plenty of opportunities to reduce energy growth without adversely affecting GDP growth. Some of these entail extra costs, but the financing needs are well within the compass of domestic and world capital markets. Making these investments will have both global and local benefits.

Further research is required to link new generation multiregional global models with endogenous growth (such as IMACLIM-R) to more disaggregated models currently being developed or augmented in China and India. This will provide a richer framework to test specific policies tailored to the unique opportunities and constraints in each country. It also will enable analysis of equity issues as well as spatial consequences of different types of interventions.

Annex

Table 5A.1 Energy Balance, 1980–2003

a. China

	Production and stock change (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	316	107	12	5	180	0	620
1981	315	103	11	6	182	0	616
1982	332	104	10	6	184	0	636
1983	352	106	10	7	186	0	661
1984	387	116	11	7	187	0	708
1985	405	130	13	8	189	0	744
1986	423	131	14	8	191	0	767
1987	454	135	14	9	193	0	805
1988	488	140	15	9	195	0	847
1989	495	139	16	10	198	0	857
1990	545	136	16	11	200	0	908
1991	535	140	17	11	202	0	906
1992	555	143	16	11	203	0	929
1993	588	138	17	13	205	0	961
1994	630	144	18	14	205	4	1,015

Table 5A.1, *continued*

Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1995	691	149	19	16	206	3	1,084
1996	722	158	21	16	207	4	1,128
1997	707	156	21	17	208	4	1,113
1998	698	156	24	18	209	4	1,109
1999	685	161	26	18	213	4	1,106
2000	698	151	28	19	214	4	1,115
2001	705	161	31	24	216	5	1,142
2002	765	168	34	25	217	7	1,216
2003	917	169	36	24	219	11	1,377

	Consumption (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	313	89	12	5	180	0	599
1981	311	84	11	6	182	0	594
1982	329	83	10	6	184	0	613
1983	348	85	10	7	186	0	637
1984	384	88	11	7	187	0	676
1985	401	93	13	8	189	0	704
1986	418	98	14	8	191	0	729
1987	446	105	14	9	193	0	767
1988	478	112	15	9	195	0	809
1989	486	116	16	10	198	0	826
1990	535	110	16	11	200	0	872
1991	523	121	17	11	202	0	874
1992	541	132	16	11	203	0	904
1993	576	146	17	13	205	0	957
1994	615	145	18	14	205	4	1,002
1995	673	158	19	16	206	3	1,075
1996	700	172	19	16	207	4	1,119
1997	685	191	19	17	208	4	1,124
1998	678	188	22	18	209	4	1,119
1999	661	205	24	18	213	4	1,124
2000	664	222	26	19	214	4	1,149
2001	648	227	29	24	216	5	1,149
2002	716	244	32	25	217	7	1,241
2003	862	270	35	24	219	11	1,422

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Table 5A.1, *continued*

	Net export (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	3	18	0	0	0	0	21
1981	3	19	0	0	0	0	22
1982	3	20	0	0	0	0	23
1983	3	21	0	0	0	0	24
1984	3	29	0	0	0	0	32
1985	4	37	0	0	0	0	41
1986	5	33	0	0	0	0	38
1987	8	31	0	0	0	0	38
1988	9	28	0	0	0	0	37
1989	9	22	0	0	0	0	31
1990	10	26	0	0	0	0	36
1991	12	19	0	0	0	0	32
1992	14	11	0	0	0	0	25
1993	12	–8	0	0	0	0	4
1994	15	–2	0	0	0	0	13
1995	18	–9	0	0	0	0	9
1996	22	–14	1	0	0	0	9
1997	22	–35	2	0	0	0	–11
1998	20	–31	2	0	0	0	–9
1999	23	–43	2	0	0	0	–18
2000	35	–71	2	0	0	0	–34
2001	57	–66	2	0	0	0	–6
2002	49	–76	2	0	0	0	–25
2003	55	–101	1	0	0	0	–45

b. India

	Production and stock change (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	50	11	1	4	148	1	215
1981	56	17	2	4	151	1	230
1982	58	22	2	4	154	1	241
1983	63	27	3	4	156	1	254
1984	68	30	3	5	160	1	266
1985	71	31	4	4	162	1	274
1986	77	32	5	5	165	1	285
1987	82	32	6	4	169	1	294
1988	89	34	7	5	171	2	307

Table 5A.1, *continued*

Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1989	92	36	9	5	173	1	316
1990	97	35	10	6	176	2	326
1991	106	34	11	6	180	1	338
1992	111	30	13	6	182	2	344
1993	115	30	13	6	185	1	351
1994	118	36	13	7	187	1	362
1995	124	39	17	6	189	2	377
1996	131	37	18	6	190	2	384
1997	134	38	20	6	193	3	394
1998	131	37	21	7	195	3	395
1999	138	37	20	7	198	3	404
2000	143	37	21	6	202	4	414
2001	148	37	21	6	205	5	422
2002	151	38	23	6	208	5	431
2003	157	39	23	6	211	5	441

	Consumption (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	53	34	1	4	148	1	241
1981	60	36	2	4	151	1	253
1982	62	39	2	4	154	1	261
1983	66	40	3	4	156	1	271
1984	71	42	3	5	160	1	281
1985	76	48	4	4	162	1	296
1986	80	48	5	5	165	1	305
1987	86	50	6	4	169	1	317
1988	94	55	7	5	171	2	334
1989	97	60	9	5	173	1	346
1990	104	63	10	6	176	2	360
1991	112	65	11	6	180	1	375
1992	118	68	13	6	182	2	388
1993	123	70	13	6	185	1	398
1994	127	74	13	7	187	1	410
1995	134	84	17	6	189	2	432
1996	142	89	18	6	190	2	447
1997	147	94	20	6	193	3	463
1998	144	101	21	7	195	3	472
1999	152	113	20	7	198	3	494

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Table 5A.1, *continued*

Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
2000	159	114	21	6	202	4	506
2001	162	115	21	6	205	5	514
2002	168	119	23	6	208	5	527
2003	173	124	23	6	211	5	542

	Net export (Mtoe)						
Year	Coal	Oil	Natural gas	Hydro	Biomass and waste	Nuclear	Total
1980	–3	–23	0	0	0	0	–26
1981	–3	–20	0	0	0	0	–23
1982	–4	–17	0	0	0	0	–20
1983	–3	–13	0	0	0	0	–16
1984	–3	–12	0	0	0	0	–15
1985	–4	–17	0	0	0	0	–21
1986	–4	–16	0	0	0	0	–20
1987	–5	–18	0	0	0	0	–23
1988	–5	–22	0	0	0	0	–27
1989	–6	–24	0	0	0	0	–29
1990	–7	–27	0	0	0	0	–34
1991	–6	–31	0	0	0	0	–37
1992	–7	–38	0	0	0	0	–45
1993	–7	–40	0	0	0	0	–47
1994	–9	–39	0	0	0	0	–48
1995	–10	–45	0	0	0	0	–55
1996	–11	–52	0	0	0	0	–63
1997	–14	–56	0	0	0	0	–69
1998	–13	–64	0	0	0	0	–77
1999	–15	–75	0	0	0	0	–90
2000	–15	–77	0	0	0	0	–93
2001	–14	–78	0	0	0	0	–92
2002	–16	–80	0	0	0	0	–97
2003	–15	–85	0	0	0	0	–100

Source: IEA 2005a.
Note: Mtoe = million tons of oil equivalent.