ENERGY SECURITY

Coping with Oil Price Volatility

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ESMAP
Energy Sector Management Assistance Program

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Abbreviations and Acronyms

ADF	Augmented Dickey-Fuller
ESMAP	Energy Sector Management Assistance Program
GARCH	generalized autoregressive conditional heteroskedasticity
GDP	gross domestic product
HHDI	Herfindahl-Hirschman diversification index
HP	Hodrick-Prescott
ICE	Intercontinental Exchange
IEA	International Energy Agency
IRR	internal rate of return
NYMEX	New York Mercantile Exchange
OPEC	Organization of the Petroleum Exporting Countries
PSA	production-sharing agreement
U.S. EIA	U.S. Energy Information Administration
WTI	West Texas Intermediate

Currency

B	Thai baht
₵	Ghanaian cedi
Ch$	Chilean peso
K Sh	Kenyan shilling
₱	Philippine peso
R	South African rand
Rs	Indian rupee
US$	U.S. dollar

Executive Summary

Oil prices have been variable since the large price increases of the 1970s and 1980s. The wide price fluctuations in 2007, when daily spot prices for marker crudes nearly doubled between January and November, and fluctuations by more than US$20 a barrel in early 2008 reinforce the idea that oil prices are volatile. Oil is important in every economy; when its prices are high and volatile, governments feel compelled to intervene. Because there can be large costs associated with such interventions, reserve banks, central planning institutions, and think tanks in industrial countries have been carrying out quantitative analyses of oil price volatility for a number of years.

This study is a sequel to *Coping with Higher Oil Prices* (Bacon and Kojima 2006) and is part of a broader assessment of energy security undertaken by the World Bank. The previous report dealt with higher oil price *levels*; this report focuses on *fluctuations* around trends in oil prices. It examines measurements of oil price volatility and evaluates several different approaches to coping with oil price volatility: hedging, security stocks, price-smoothing schemes, and reducing dependence on oil including diversification. It does not deal with the impact of oil price volatility on countries' macroeconomic performance or with macroeconomic policy responses; these generally have more to do with coping with higher price levels than with higher volatility per se. The study examines oil price volatility largely from the point of view of consumers and does not cover the management of revenue volatility by large oil exporters.

Statistical Analysis of Crude Oil and Oil Product Prices

The report begins by examining daily, weekly, and monthly prices of crude oil and oil products in the U.S. Gulf Coast between 1986 and 2007. The study period is divided into three subperiods, the first through end 1999, the second from 2000 to end 2003, and the third from 2004 to March 2007. In some cases, price data were extended to February 2008. The analysis of monthly prices also covers crude oil and oil products in five developing countries—Chile, Ghana, India, the Philippines, and Thailand—converted to local currency units to account for currency fluctuations in addition to oil price volatility. The statistical analysis suggests the following:

- With the exception of the first subperiod for some of the fuels, price *levels* are nonstationary—that is, the mean, the variance, or both were not constant over time. There are indications that shocks to the prices have both permanent and temporary (decaying) components. Some differences exist between local currency and U.S. dollar prices, whereby one would be stationary but not the other. Somewhat surprisingly, in two cases, gasoline prices in local currency were found to be stationary (and hence mean-reverting) between 2000 and 2007, but not in U.S. dollars.
- The recent depreciation of the U.S. dollar relative to other currencies means that the magnitude of the price increase has been less severe in many countries in which the exchange rate has strengthened against the dollar. An examination of international prices converted to local currency units in the five developing countries between 2004 and 2008 showed that nominal price increases were lower in local currency units in every country except Ghana. In real terms, price increases were lower in local currency in all five countries (table 1). Ratios greater than unity represent the offsetting effects of nominal

Table 1

Ratio of Price Increase in U.S. Dollars to Increase in Local Currency Units, January 2004–January 2008

Country	Nominal price	Real price
Chile	1.19	1.23
Ghana	0.92	1.27[a]
India	1.15	1.24
Philippines	1.36	1.50
Thailand	1.18	1.21

Source: Author calculations.

a. Real prices only through November 2007.

and real exchange rate appreciation against the dollar.

- When the variance of the volatility of daily and weekly prices is compared across different subperiods, the third subperiod is least volatile for crude oil. For some oil products, the reverse holds: volatility is higher after 2000 than before, but it appears to decrease slightly in the third subperiod without returning to the levels of the first. Most monthly price series—arguably the most important for policy consideration—do not yield statistically significant results. Table 2 takes the marker crude Brent, gasoline, and gasoil in Europe and shows the mean of the monthly price levels, the standard deviation (the square root of the variance) of returns (the change in successive prices), and the standard deviation of returns based on logarithms of prices (which approximate fractional changes between successive prices when the changes are small, as in table 2). The lowest volatility is observed for the period since 2004 for crude oil and gasoil, and in the period up to 1999 for gasoline (although these differences are not statistically significant with monthly prices).
- Tests were carried out to determine whether historical price volatility was stationary, and, if so, how long the reversion to the historic mean took. The volatility of daily prices tends to be stationary, and the half-life for mean reversion ranges from 2 to about 100 days. The results with weekly prices are less conclusive, but there are two cases where price volatility is not stationary and grows without bound. Analysis of monthly prices is the least conclusive and does not yield meaningful results for the most part, especially during the last subperiod. The price volatility data are not "well behaved" for the purpose of statistical analysis, indicating the randomness of their temporal movements.
- The variance of price volatility in local currency units in the five developing countries showed

Table 2

Statistics on Monthly Spot Oil and Oil Product Prices

	Brent[a]			Gasoline			Gasoil		
Period	Mean	SD returns	SD log returns	Mean	SD returns	SD log returns	Mean	SD returns	SD log returns
1987–99	$18.06	$1.68	0.085	$21.94	$2.06	0.084	$22.24	$2.10	0.084
2000–03	$26.65	$2.54	0.096	$31.32	$3.27	0.107	$31.32	$2.87	0.087
2004–08[b]	$59.01	$4.53	0.079	$66.62	$6.75	0.102	$70.83	$4.96	0.071
1987–08	$27.75	$2.68	0.086	$32.50	$3.70	0.092	$33.52	$3.06	0.083

Sources: Energy Intelligence 2008; author calculations.

Note: SD = standard deviation. Prices are in U.S. dollars.

a. Mean = monthly average spot prices of Brent crude; SD returns = standard deviation of differences in two consecutive monthly Brent crude prices; SD log returns = standard deviation of returns on logarithms of consecutive monthly average prices.

b. January 2004 to February 2008.

that currency appreciation against the dollar did not reduce volatility except in Chile prior to 2000. In both nominal and real terms, local currency prices were the same as, or slightly more volatile than, prices denominated in U.S. dollars in all other cases.

Hedging

Hedging is a strategy intended to reduce the risk of adverse price movements (future oil prices increasing for an oil purchaser, declining for an oil seller). A government of a major oil exporter may wish to hedge future oil revenues; a state-run transport company may consider hedging the purchase of diesel for its fleet. In the futures oil markets, a contract can be entered into at a known price to purchase oil in a given number of months, enabling the purchaser to lock in the future price of oil and eliminate price uncertainty. If the price at the future date turns out to be higher than the futures contract price, the purchaser clearly benefits. If it is lower, the purchaser would have been better off not having entered into the contract. A seller of oil participates in the futures markets in the same way, with the impact of the difference between actual and futures prices reversed. There are variants of this basic setup with varying degrees of sophistication and cost.

This study took WTI crude futures contract prices of varying duration on the New York Mercantile Exchange (NYMEX) between 1987 and 2007, and carried out an ex post analysis to calculate the percentage of physical oil for sale that should be hedged to minimize overall risk (risk-minimizing hedge ratio) and the percentage reduction in the risk compared to not hedging (hedging efficiency), and compared returns on a hedged portfolio with those on an unhedged one. For a buyer, the risk-minimizing hedge ratio and hedging efficiency tends to increase with the duration of the futures contract. Hedged and unhedged returns are closer for the short-duration hedges; but for 24-month futures contracts, the unhedged return is much lower than the hedged return, indicating a loss on the unhedged portfolio. The hedging performance of gasoline and diesel on NYMEX is similar.

A comparison of spot prices and 6-, 12-, and 24-month futures contract prices for WTI crude between 1986 and 2007 shows that futures prices were lower than current spot prices more than half the time and that the degree of underprediction of future prices on NYMEX increased with increasing contract duration. Since January 2004, futures contract prices underpredicted the actual prices three-quarters of the time or more, and 100 percent of the time in the case of 24-month futures contracts.

These ex post findings, however, should not be taken as an endorsement of the use of futures markets to mitigate the adverse effects of large price volatility. At any given time, futures prices are probably the best estimates of the spot price at the time of closing out the futures contract. Governments or their agents are unlikely to be able to make a systematically better estimate of prices in the coming months than the market itself. Hedging is designed to remove risk, not increase returns; and the ex post experience of a period of unhedged returns exceeding hedged returns is no gauge as to whether this will continue.

There are several considerations to note before a government agency or state-run company embarks on hedging. There are financial costs associated with futures contracts and their variants—sometimes requiring financing on a daily basis—even if most of these costs are eventually returned to the hedger. This financing requirement could lead to cash flow problems and could even prove to be unmanageable. There is a basis risk, which is the difference in price between what is hedged and the crude oil or oil product as traded on the futures markets, arising from the difference in quality and the location and timing of delivery. The public typically holds the government accountable for the success or failure of a hedge program; when the hedging strategy results in financial losses, political support for the strategy may evaporate rapidly. For some governments, the lack of well-known and successful examples in other countries that could be studied and copied is a considerable drawback. Governments have hedged sales or purchases at various times, but do not appear to be doing so on a broad scale today. Such caution would suggest that hedging is not a simple solution for dealing with oil price volatility.

Security Stocks and Price Hikes

Between 1950 and 2003, there were 24 major disruptions to world oil supply, each lasting on average about half a year and affecting about 4 percent of world supply. Security stocks can be used to help reduce the magnitude of sharp price spikes due to physical disruptions to supply. A virtual security stock scheme—by which no physical stocks are held and cash is instead transferred to consumers in times of sharp price spikes—can protect consumers, but a simulation in this study shows that a virtual stock will be more expensive to the government in times of rising oil prices, which is when such a scheme is needed.

Certain decisions need to be taken as inputs for the design of a security stock scheme to be used to combat price spikes: (1) the nature of the price event to be ameliorated, (2) the maximum size of the stock, (3) the floor trigger price below which purchases would be made if the stock is not full, (4) a ceiling trigger price above which sales from the security stock would be made, and (5) the maximum allowable sales volume per time period when the ceiling trigger selling price is exceeded. One indicative guide for the size of security stocks is the requirement by the International Energy Agency (IEA) that each member hold stocks equivalent to at least 90 days use of net imports. Such stocks may be held by the government directly, or companies can be mandated to hold certain amounts of stocks beyond their normal commercial levels, as in Japan and the Republic of Korea.

This study carried out a simulation of a security stock scheme between 1986 and 2007. The years were divided into two subperiods: the first from 1986 to end 1999, and the second from January 2000 to March 2007. Different release criteria were applied to the two subperiods, with much lower floor trigger purchase and ceiling trigger selling prices in the first subperiod. Based on the release criteria, there would have been just one release taking place from September to November 2000 during the first subperiod. The net cost to the government would have been about three times the net benefit to consumers. In the second subperiod, several combinations of floor and ceiling prices as well as different maximum allowable sales volumes were examined. As expected, the larger the maximum allowable monthly sales volume or the lower the ceiling trigger selling price, the greater the benefit to consumers. However, the cases with the two greatest benefits to consumers found strategic stocks exhausted at the end of the simulation period, thereby leaving the country unprotected against subsequent price spikes. Terminal net costs to the government were lower than during the first subperiod, in large measure because the government was able to benefit from a generally increasing oil price by buying low and selling high.

The simulation results suggest that using a fixed set of rules for purchases and sales would limit the effectiveness of the scheme. The trigger prices would need to be updated, as the mean price forecast changes significantly. The rules that were adequate during the first subperiod would have been inadequate after 1999, because they would never have permitted any purchase of stock, and the stock left over from the first subperiod would have been exhausted before the price increases of the second subperiod. The simulation of the second subperiod shows that it is possible to operate a security stock scheme at a relatively low net cost to the government even when prices follow a generally rising path for much of the period. A challenge is to determine beforehand when prices are likely to follow a rising pattern. One conventional tool for assessing market views of likely price trends is futures prices for crude oil and oil products.

The simulation illustrates that, when prices fluctuate around a fairly constant mean, the period during which stocks have to be stored will be lengthy. Moreover, if refilling takes place, the government will be holding stock throughout the period, except for a few months when prices are abnormally high. Where variability around the mean is low, stocks would be used only rarely, and the operation of security stocks will be costly. For high-income countries, the costs of filling and running security stocks that are rarely used will be affordable; for lower income countries, the costs may be too high, and the number of days covered may need to be fewer than the 90 days of imports mandated by the IEA.

Price-Smoothing Schemes

Many governments have operated schemes designed to smooth the variation in domestic oil prices to consumers. The success of a price-smoothing scheme can be judged on (1) the reduction in the volatility of domestic prices; (2) the reduction, if any, in the overall level of domestic prices; and/or (3) the fiscal cost or revenue forgone. One commonly adopted approach of price-smoothing schemes is to set the domestic price by averaging past, and possibly futures, prices over several months. An analysis of historical spot and futures WTI crude prices shows that, as expected, volatility declines with increasing averaging period. Additionally, the volatility of the target domestic price based on averaging spot prices from the past three months is about the same as that based on averaging spot prices during the past three months and the futures contract prices during the next three months. Similar calculations in local currency in Kenya and Ghana (which experienced high levels of depreciation during the study period) show that volatility is somewhat higher than in U.S. dollars, but, despite much larger depreciation in Ghana, there is essentially no difference between the two countries.

This study carried out a simulation of a price-smoothing scheme between 1986 and 2007 using the target domestic price based on averaging WTI crude prices over varying durations. The results show that, even between 1986 and 2000 when prices were fluctuating around a reasonably constant mean, the cumulative balance for the scheme would have been negative most of the time and would have been consistently negative after 2000 when the negative cumulative balance grew sharply. Allowing a band around the target price—whereby the government does not adjust the domestic price as long as the current price is within a certain percentage of the computed target price—would have reduced the cumulative cost to the government markedly, albeit with some increases in price volatility.

Oil Intensity and Diversification

Another way of coping with oil price volatility is to reduce the importance of oil consumption relative to gross domestic product (GDP) or total primary energy demand by lowering the demand for oil through energy efficiency improvement, demand restraint, and diversification away from oil. The greater the amount of oil a country consumes relative to its current GDP, the larger will be the consequences throughout the economy. To that end, the study examined global historical trends in the following:

- The percentage of GDP spent on oil consumption valued at the market price, both expressed in current U.S. dollars (oil share of GDP)
- Barrels of oil consumed per unit of GDP in constant U.S. dollars (oil intensity)
- Oil consumption as a percentage of primary energy demand, both measured in common energy units (oil share of primary energy)
- An energy diversification index based on six energy sources (oil, gas, coal, nuclear power, hydropower, and renewable energy)

Of the 163 countries in the sample, half spent more than 6 percent of their GDP on oil in 2006, and 16 countries spent more than 15 percent of GDP. All countries with a high oil share of GDP were developing countries. The oil share of GDP had generally been declining until the late 1990s, but has been rising this decade and almost universally in the last few years. About 40 percent of the countries experienced the highest oil share of GDP in 2005 or 2006. For about half the countries, oil intensity was at its highest in the early 1980s; in more than 30 percent of the countries, oil intensity was at is lowest in 2006. Therefore, the high oil share of GDP in 2006 largely reflects high oil prices and not high oil intensity.

Energy diversification could help mitigate the adverse effects of energy price increases and fluctuations if prices levels and price volatility of different energy sources are not well correlated. The price gap between coal and hydrocarbons (oil and gas) has been widening since 2000, making switching to coal financially attractive. Among energy sources, spot natural gas prices in the United States have had the highest price volatility in the last two decades, and the average of contract prices for natural gas imported to Europe the lowest. The volatility of spot Australian coal prices was much lower than that of spot crude oil prices until 2004. Since then, the volatility of these two fuels has been almost the same. The correlation between oil price volatility and the volatility of other fuels has been weak. Diversification away from oil to other fuels—even if their price volatility is not any lower—may be attractive. Weak correlation has interesting consequences. The price volatility of a mix of 25 percent coal and 75 percent oil was lower than that of either oil or coal alone in 2004 to 2007. This illustrates that diversifying into a more volatile fuel (in this case, from 100 percent coal to 75 percent coal and 25 percent oil) could decrease, rather than increase, the overall price volatility of the fuel mix.

Small island nations, several small African countries, and a few other small countries are entirely dependent on oil for their energy. The oil share of primary energy around the world has been generally declining since the early 1980s. In 2005, a quarter of countries had an oil share of energy less than 25 percent. However, a third had a share larger than 75 percent. More than half the countries had an energy diversification index equivalent to dependence on two or fewer energy sources with equal shares.

Concluding Remarks

Statistical analysis of price volatility appears to show that volatility does not follow any systematic path, especially when monthly prices are tracked. Where analysis suggests that oil price volatility appears to grow without bound, attempts at stabilizing oil prices would not be successful, and even smoothing oil price fluctuations should be approached with care. Under these circumstances, a policy that relies on a systematic formula—such as formula-based price smoothing or strategic stock operation—carries a large risk and could even become fiscally unsustainable.

Oil intensity peaked in this decade in close to one-fifth of the countries in the sample. In virtually every country, the oil share of GDP has been climbing in the last three years, making what was a lesser problem a decade ago a much more serious concern today. The rapidly rising oil share of GDP would seem to suggest that countries apparently have not been able to do enough to address what now looks like a long-term issue. If oil price volatility continues at the present level—which is a highly likely scenario—the economic effects could become substantial, unless governments are able to reduce oil use, especially in those countries with rising oil intensity. Given the difficulties of diversifying away from oil, the importance of fuel conservation through energy efficiency improvement and demand restraint measures cannot be overemphasized.

1 Context

Oil prices have been variable since the large price increases of the 1970s and 1980s. The perception that oil prices are more volatile than those of most other commodities has prompted governments—especially in developing countries—to intervene in the oil market in various ways, including price-smoothing schemes for end users, fuel tax adjustments, price controls, and incentives for diversification away from oil. While there are other commodities whose prices are just as volatile, if not more so, oil price volatility is considered especially deleterious because of oil's importance in every economy. In the transport sector in particular, there are no suitable substitutes for gasoline and diesel on a large scale. Oil price volatility affects the cost of freight transport, on which virtually all commodities depend, as well as that of passenger transport.

Quantitative studies have not necessarily supported the widely held belief that oil prices are more volatile than those of most other commodities. Clem (1985) found that agricultural commodity prices were the most volatile between 1975 and 1984, a period that included the second oil shock. More recently, Regnier (2007) examined commodity prices between January 1945 and August 2005. The study found that the prices of crude oil, refined oil products, and natural gas were more volatile than those of about 95 percent of products sold by U.S. producers. Compared to the prices of other primary commodities, oil price volatility was found to be greater than that of 60 percent of primary commodities (including farm products, foods, and feeds) but less volatile than those of 21 percent of primary commodities.[1]

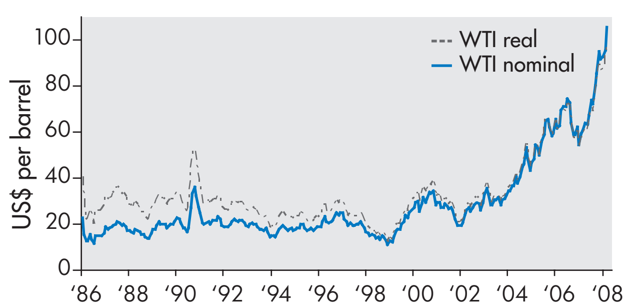
Oil Price Trends

Figure 1.1 provides a starting point to the analysis of oil price behavior over the last 20 years. The graph shows that monthly prices of West Texas Intermediate (WTI) crude—one of the marker crudes—have varied continuously, with a spike between August 1990 and January 1991 related to the first Persian Gulf War, and a large run-up in prices starting at a low of US$19.39 a barrel in December 2001 and reaching a peak of US$95.39 in February 2008.[2] Discounting the exceptional circumstances of the first Persian Gulf War, prices had tended to fluctuate within a narrower band for most of the 1990s.

Recent events, which have followed a period of relative stability, have renewed interest in oil price behavior as governments and individuals have had to adjust their policies in an effort to cope with rapid

Figure 1.1

Monthly Average Spot Price of WTI Crude



Source: U.S. EIA 2008a.

Note: Real prices are in January 2007 U.S. dollars, adjusted using the consumer price index.

[1] The reason these two percentages do not total 100 is that the difference in volatility for the two sets of commodities mentioned is statistically significant, which is not true for the remaining 19 percent of commodities.

[2] Throughout this report, real prices are defined in terms of the consumer price index in January 2007.

changes. The history of price movements illustrates that policy makers are faced with two separate but linked uncertainties. The first is the trend of prices themselves; the second is the extent to which prices have varied around this trend. Even if prices had moved with a smooth progression, policy makers would still have to take into account the change in price level and would have to adjust behavior to substantially new circumstances and expected future price levels. The second uncertainty arises from the large variation around the medium- to long-run trend in price level. Policy makers need to recognize that some price movements are temporary and may be reversed—at least in part—but the economy is affected by price movements (whether the country is buying or selling oil or its products). The larger these variations, the more important it may become to have a strategy to manage or cope with the price variations.

Effects of Oil Price Volatility

Volatile oil prices may have a number of adverse effects on an economy. Some of these directly affect the economy as a whole, some affect the government and hence the economy through the government's reactions, and some affect individual firms and consumers directly.

Balance of Payments

In the face of rising oil prices, the balance of payments will worsen as the import bill rises. This effect will be offset by any currency appreciation against the U.S. dollar in which international oil sales are priced. At the same time, there may be other reinforcing import cost increases (such as food prices) or offsetting benefits from a simultaneous increase in the price of export commodities (especially minerals) for those countries that are net exporters. A worsening of the balance of payments may be accommodated in the short run through currency reserves or international borrowing, but this would not be sustainable in the long run against persistent oil price increases, such as those that have occurred since 2004. Governments may be forced to deflate the economy in order to reduce import demand, especially for oil, and this would affect all segments of society. Volatility can exacerbate this problem because temporary price increases above trend cannot be easily distinguished from the trend itself, especially when prices are not fluctuating around a nearly constant value. An increase in the oil import bill may force a government into action for fear that it is permanent, while in fact it later turns out that the increase had been temporary. Thus, for example, the institution of a subsidy program might be triggered by a very sharp rise in prices, but such a program cannot, from a political point of view, be withdrawn easily if prices fall back to their trend. This applies equally to price falls that turn out to be only temporary; these can lull a government into a false sense of security and cause it to take actions that it later regrets, such as slowing down on programs to reduce energy and oil intensity.

Budget Surplus or Deficit

For those governments that are subsidizing domestic oil prices, the volatility of international prices is transmitted into volatility in the actual government spending stream. This circumstance can lead to difficulties in managing fiscal programs, which tend to be planned a year ahead and are based on estimates of average oil price. Sudden but temporary increases that cannot be distinguished from permanent increases may lead a government to change its fiscal policy for fear that the changes are permanent.

Domestic Economic Output

Volatile oil prices, as may be experienced in the absence of price smoothing by the government, have been linked to lower output. There appear to be three reasons for this linkage. First, volatility tends to delay investment as firms wait to see where price levels settle in order to justify their investment decision. Second, as oil prices rise, sectors where oil use is more intensive should see resources shift away to those sectors where it is less intensive, but lack of labor mobility may merely result in unemployment in the oil-intensive sectors as workers who are laid off do not readily move to other sectors. If real wages are sticky downwards (they do not fall even when demand for labor is declining), this will also hamper intersectoral adjustment. Third, constantly adjusting prices and outputs in response to changes in input costs leads firms to incurs costs of adjustment, slowing short-run responses to changing prices. This in turn leads to suboptimal output decisions, an effect that would be exacerbated by increasing oil price volatility.

Household Behavior

Households facing volatile prices normally attempt to smooth real expenditures. Consumption smoothing is the welfare-maximizing response to fluctuations around expected income or price trajectories. However, at times of higher prices for oil (or other important consumer goods), it may not be possible for households to maintain their consumption levels. If households need to borrow or run down savings to maintain expenditure patterns at times of higher prices but are credit-constrained or lack assets that can easily be drawn down, then they will need to reduce consumption, which would result in a loss in welfare. The lowest income groups may therefore be most hurt by price volatility. The share of direct and indirect expenditures on oil may very well be larger for them than for higher income groups, thus magnifying the adverse effects of any given swing in oil prices, because their coping mechanisms are weakest.

Government Response

Many governments have attempted to reduce the adverse effects of oil price volatility on the economy. Where these policies are designed to shift risks to a party outside the country, any costs of such a program will still be borne through the budget and thus affect current or future generations of its citizens. The trade-offs of such a program may be large, and the gains from reduced volatility may not be worthwhile. Moreover, since the total balance of payments or the government deficit is affected by volatility from a number of sources, focusing on reducing only the effects of volatile oil prices may provide just a partial remedy.

Where governments have attempted to shift the adverse effects of volatility from consumers to the government itself through price-smoothing and other schemes, the costs of such a program will eventually also have to be borne by consumers. However, the incidence of changed expenditure (or tax) policies required to finance these budgetary costs may be different from the incidence of price volatility on consumers, making a redistribution of welfare possible. This effect is most clearly seen where oil price smoothing results in large temporary subsidies that benefit consumers proportionately to their oil use, while the costs of the policy are borne by all households through reduced fiscal spending.

Report Structure

This study is a sequel to the Energy Sector Management Assistance Program (ESMAP) report *Coping with Higher Oil Prices* (Bacon and Kojima 2006) and is part of a broader assessment of energy security undertaken by the World Bank. The previous report dealt with higher oil price *levels*; this report focuses on *fluctuations* around trends in oil price levels. It asks if the nature of oil price volatility has changed in recent years and examines different policy options governments may consider in response to oil price volatility.

The next three chapters employ statistical techniques to examine oil price volatility in an important reference market—the U.S. Gulf Coast—as well as in five developing countries in different regions of the world—Chile, Ghana, India, the Philippines, and Thailand. The report then discusses several strategies designed to cope with oil price volatility: hedging, strategic petroleum reserves, price-smoothing schemes, and energy conservation and diversification measures.

Two caveats are in order. To narrow the focus of the study, this report considers oil price volatility primarily from the point of view of oil consumers and oil importers. For a significant oil exporter that depends on oil sale receipts for much or even most of its government revenue, oil price volatility is closely linked to revenue volatility and presents unique challenges related to government budget planning and execution. This report touches upon revenue volatility in two places:

- In annex 1, the impact of varying fiscal parameters on smoothing revenue is examined. This examination concludes that adjusting fiscal parameters is not a good way of smoothing oil revenue and that other means are likely to be needed to manage revenue volatility.
- Chapter 5 discusses hedging. Hedging can provide greater certainty to prices received for selling oil, which can help manage the budget process for major oil exporters. For ease of exposition, the analysis in chapter 5 focuses on oil producers that sell crude oil on the international market. By symmetry, the case of an oil purchaser is the reverse of that of an oil seller.

The second caveat is that the report does not consider the use of macro-level policies to cope with the impact of oil price volatility on the macroeconomy (which in any event have to do largely with coping with higher oil prices rather than higher oil price volatility), nor the measurement of the impact of oil price volatility on the macroeconomic performance of countries. The report is focused primarily on sector-level issues.

2 Measurement of Oil Price Volatility

In examining oil price volatility—the focus of this and the next two chapters—this study extends the analysis carried out by other researchers by including recent price data and applying widely used statistical techniques to prices in local currency in developing countries. The recent history of oil prices raises a number of questions that need to be answered before policies to cope with volatility can be analyzed:

- Is there a trend or pattern in the development of oil prices over time, or are they random?
- How much variability is there around any trend in prices that can be identified, and has the variability changed over time?
- Is the variability similar for series measured over different time intervals (daily, weekly, monthly), for prices expressed in nominal and real terms, and for prices of crude oil and different oil products?
- In non-U.S. markets, how does the variability of oil and oil product prices behave in local currency terms?

Before moving to analysis of these issues, this chapter presents a brief description of the standard statistical methodology used to address questions of this nature. Only those concepts essential for understanding the rest of the main report are given below. Further details are provided in annex 2.

Trends, Cycles, and Volatility: Measurement and Statistical Analysis

The statistical behavior of oil prices has received a great deal of attention over the years as has that of many other commodities and financial assets, and there is a large technical literature on various aspects of the subject. This section does not aim to provide a review of this literature, but rather to introduce the particular approaches and statistical tools used in this report.

Prices and Time Interval of Measurement

Oil price data are available as daily quotations and weekly, monthly, and annual averages. The level and fluctuations of these different measures are relevant to different agents for different purposes. Oil traders (which can include large exporting countries) will need to follow daily movements; at the other extreme, governments making annual budget plans will relate these to annual prices or to price changes. In between, smoothing schemes—by which the government regulates prices to consumers—are usually updated monthly, or on occasion fortnightly, to ensure that international price changes are tracked to some extent by domestic prices. The statistical analysis of this report focuses primarily on fluctuations at monthly or shorter intervals because there are too few annual observations available to carry out any robust statistical analysis.

Prices and Stationarity

Statistical analysis of the behavior of prices depends on whether they are stationary. If the mean and variance of a series remain constant as more data are added, then the series is stationary and conventional statistical models are appropriate. A series of prices that grow without bound in time is not stationary, and, in this case, the mean is not constant. Even if a price series has a constant mean, if fluctuations around that mean become increasingly larger with time, the series is again not stationary: in this case, because the variance, which is a measure of volatility, is not constant. A price series can be fitted by a trend, but, even having made this adjustment, the variance may still not be constant over time. An important example of nonstationarity occurs when a series follows a so-called random walk. In this case, each successive price is equal to the previous price—that is, multiplied by a coefficient equal to one (unity)—plus a new random shock, so that after a number of time periods k the price is equal to the price k periods before plus the sum of k random variables. A price series exhibiting this behavior has a variance that tends to grow over time. Series where the current price is equal to the previous price plus other factors are said to exhibit a unit root. If the series does not have a unit root, the impact of the previous price on the current price is less than unity, and the variance tends to a constant value.

The standard test for the presence of a unit root is the Augmented Dickey-Fuller (ADF) test, which can allow for a mean and a linear trend in the price series, as well as a number of previous (lagged) values. This test was carried out on all the series used in this report. As detailed in annex 2, standard ADF tests can have very little power under certain conditions. To provide more evidence on whether variances are constant over time, variance ratio tests introduced by Cochrane (1988) were also carried out.

Establishing Series Trend Values

It is important to establish the value or trend to which prices tend to revert. In the simplest case where there is no trend, the mean of the series is the value to which prices tend to revert and can serve as the best forecast of future prices. As is evident from figure 1.1, it is unlikely that the mean price has stayed constant for the whole of the last 20 years. Models with structural change can allow for one or more changes in the mean at various specified dates relating to well-known and understood external events that explain why the general level of prices shifted at certain times. Tests of *equality of means* for subsamples (containing price data from different time periods) can be carried out to check if the mean has shifted over time.

The movement of the price level since 2000 indicates that a mean-reversion model—one postulating that prices always return toward the same value in time—would be inadequate to describe the general behavior of oil prices since that date. A standard technique for constructing a trend in prices without using a formal model based on supply and demand to explain the sequence of prices is to use a *filter* that smooths price fluctuations. The Hodrick-Prescott (HP) filter creates a series whose period-by-period changes are fairly smooth, while staying close to the actual data. The differences between the filtered series and the actual data—more specifically, actual data minus filtered series—are referred to as the *cycle* component of the data, although they may not contain any obvious regular cyclical pattern.

Establishing a Series for Volatility

The analysis of the volatility of a price series is based on the *returns* of the data, which are the period-by-period changes in the data. For example, returns on monthly prices are the differences between prices in two consecutive months. In this study, as in many others, the preferred measure of the return is the difference in the logarithms of prices over two consecutive periods. Such a calculation gives an approximate percentage change in price when the magnitude of variation from one period to the next is small compared to the price levels themselves. Differences in logarithms are conventionally preferred because they are dimensionless: thus, the statistical measures used to summarize their behavior (such as the variance) can be compared directly with those of other series where the price data may be given in different units.

The historical volatility of a series is based on the sequence of squared returns, while a summary measure of the volatility over a period is either the variance or the standard deviation (the square root of the variance) of the series of returns. This forms a measure of the degree of unpredictability of prices, which enters into policies designed to cope with volatility.

When a trend can be fitted to the price level, some of the period-to-period changes are due to the increment in the trend. An alternative measure of volatility is based on *cycle returns* from the HP filter. A cycle return is the change in the differences between actual and filtered values (which form a trend curve for the price level). The nearer the change in filter values are to zero, the closer will be the cycle returns to the returns in the foregoing paragraph.

Testing for Changes in Volatility

One of the study's central concerns was whether volatility has increased or shows any systematic pattern that would need to be taken into account in designing policies to cope with it. Several statistical tools can be used to investigate the question of whether volatility is itself random or exhibits some underlying pattern. The simplest technique is to split the returns data into subperiods and compare the variance for the subperiods. The standard test for checking if variances from two different periods are not statistically different (that is, are essentially the same) is the F-test.

A substantial body of literature is devoted to the question of whether the variances of returns tend to be *clustered*. In such a case, a large squared return is likely to be followed by another large squared return (even if the actual returns are of opposite signs) and a small value by another small value. If this occurs, a sudden increase in volatility due to an external event will be followed by high volatility for several periods—shocks to the variance do not die out rapidly. The model used to test this hypothesis is the generalized autoregressive conditional heteroskedasticity (GARCH) model, described in annex 2. The period-by-period variances themselves could be nonstationary, showing no tendency to return to a constant value. If variances are nonstationary, measures of volatility based on the variances themselves would tend to exhibit increasing values over time, and the best predictor of future volatility (as measured by the variance) would be the most recent value. The GARCH formulation used in this study consists of up to two terms in the *conditional variance equation* (conditional because the equation for the one-period-ahead forecast variance is based on past information):

- News about volatility from the previous period (previous day, week, or month, depending on the time aggregation for the price series)
- The forecast variance from the previous period

The first term, called ARCH, is always present; while the second, called GARCH, may be omitted. An equation with only the first term is denoted by GARCH(1,0); that with both terms present is denoted by GARCH(1,1). A Wald test is used to check for nonstationarity of the conditional variances. If the process is stationary, an estimate of the half-life of the duration of a shock to the variance can be estimated from the GARCH equation.

Testing for Sequential Patterns in Returns

In designing policies to cope with the volatility of oil prices, agents may also be concerned with the temporal patterns of returns. A series of positive returns with a given variance (price levels going steadily up) may be more difficult to accommodate than a series of positive and negative returns (price levels moving up and down) with the same variance. Tests for sequential patterns can be used to check this characteristic of the prices.

Because there are periods when prices move mainly upward, returns based on prices themselves could well show a sequence of largely positive values. Distinguishing longer term sequences of price increases from temporary sequences around the trend thus becomes important. For this purpose, tests should be based on cycles, which have removed the filtered trend from the data.

The Wald-Wolfowitz test focuses on the signs of successive returns; more specifically, on *runs*. A run is a consecutive sequence of values with the same sign (positive or negative). For example, the sequence [+ + − − − +] commences with a run of two positive signs, followed by a run of three negative signs, and concludes with a run of one positive sign. There are three runs in the sample of six observations. Because the mean cycle as fitted by the HP filter is, by virtue of the calculation procedures used, zero, the set of sequences of positive and negative runs should be random. In a given sample, too large a number of runs would indicate constant switching of sign, pointing to nonrandom behavior; a very low number of runs would point to long duration at the same sign, which would again suggest nonrandom behavior.

A descriptive statistic that can be used in conjunction with investigating the patterns of runs is the distribution of *sojourns* of a series, which are useful in evaluating price-smoothing schemes. Starting at the beginning of the sample period, successive cycle values can be cumulated to give a new series. Since the mean cycle is zero, the final value of the cumulated cycle series will also be around zero. However, the cumulated series will have periods when it remains positive before going back to a negative value, and other periods when it remains negative. The period during which it remains the same sign is a sojourn. The distribution of the lengths of sojourns has a relation to the arc-sine law, as analyzed by Feller (1950) and utilized by van Marrewijk and de Vries (1990). The arc-sine law indicates that reversions to the origin of a cumulated series based on random, equally probable events are surprisingly infrequent. This means that sojourns can be lengthy, which has implications for policy makers contemplating price-smoothing schemes (discussed in chapter 6).

Statistical Analysis of Oil Prices

The statistical testing documented in this report was carried out on a number of time series and on various time aggregates and time periods. All the tests were carried out using data up to the end of March 2007. GARCH analysis was repeated using data through November 14, 2007, and equality of means tests were repeated through the end of December 2007, to compare the results. In addition, out-of-sample testing was performed using price data between April and November 2007. Extrapolation beyond March 2007 enables comparison of model predictions with actual price movements and assessment of the predictability of the statistical models.

All statistical analysis in this study was carried out in Eviews. In chapter 3, prices of crude and oil products on the U.S. Gulf Coast are studied in detail. The price information is available on a daily, weekly, monthly, and annual basis from 1986 (later for oil products) to date. Annual prices were not examined because there were too few annual observations in the period in question to be used for formal statistical analysis. In chapter 4, monthly prices in northwestern Europe, the Persian Gulf, Singapore, the U.S. Gulf Coast, and Africa (for crude) are examined in U.S. dollars and in the local currencies of five developing countries.

3 Statistical Analysis of U.S. Gulf Coast Prices

Statistical tests were carried out for the whole of the period as well as for three subperiods: (1) from January 1986 (or later for oil products) to the end of 1999, (2) from the beginning of 2000 to the end of 2003, and (3) from the beginning of 2004 to March 2007. The first subperiod, which includes the first Persian Gulf War, covers a period of fairly stable price behavior barring the war. The second reflects a transition period in which prices were less stable but did not exhibit a steadily increasing trend. The third corresponds to the recent past during which, up to July 2006, prices fluctuated around a rising trend, followed by a downward trend of a few months, and, since January 2007, another rising trend. These periods are different from those identified by Lee and Zyren (2007), who divided the data between 1990 and 2005 into four subperiods, the last one of which began in March 1999, when the Organization of Petroleum Exporting Countries (OPEC) changed its pricing strategy. The initial statistical tests investigated whether crude oil and oil product prices on the U.S. Gulf Coast were stationary (thereby following mean reversion). Tests on the crude oil price series were followed by similar tests on the oil product prices. The study then conducted GARCH analysis, runs tests, and other statistical tests described in chapter 2 to examine volatility.

Are Crude Oil Prices Stationary?

An ADF test was applied at a one-sided 5 percent confidence level to nominal and real crude oil prices. The results are shown in table 3.1 for WTI crude. The null hypothesis was that the price series has a unit root and is thus not stationary. If the ADF test statistic is larger than the critical value (shown for 5 percent), then the null hypothesis holds and prices are not stationary—the mean, the variance, or both grow without bound over time.

In all cases except the first subperiod, the nominal prices are consistent with there being a unit root. Real and nominal prices yielded similar results. During the first subperiod, with the exception of weekly nominal prices, prices appeared stationary. Data

Table 3.1

ADF Test Results for WTI Crude Oil

Averaging period	Jan. 1986–Mar. 2007	Jan. 1986–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Daily, nominal	Not stationary	Stationary	Not stationary	Not stationary
Daily, real	Not stationary	Stationary	Not stationary	Not stationary
Weekly, nominal	Not stationary	Not stationary	Not stationary	Not stationary
Weekly, real	Not stationary	Stationary	Not stationary	Not stationary
Monthly, nominal	Not stationary	Stationary	Not stationary	Not stationary
Monthly, real	Not stationary	Stationary	Not stationary	Not stationary

Source: Author calculations.

are not presented for other time intervals since the results for crude oil indicate that the degree of time aggregation does not markedly change the picture on the presence of a unit root in the oil markets.

Are Oil Product Prices Stationary?

ADF tests were applied to nominal and real daily, weekly, and monthly oil product prices. The results for monthly prices are shown in table 3.2; detailed results for monthly prices—as well as for daily and weekly prices—are given in annex 3. The results for oil product prices are largely similar to those for crude oil prices. There is again little difference in behavior in nominal versus real terms. With the exception of the first subperiod, oil product prices, whether nominal or real, are mostly nonstationary. Time averaging was found to affect the results for gasoline. Weekly gasoline prices are stationary in every subperiod, which is not true for either daily or monthly average prices. In the first subperiod, both heating oil and jet kerosene are stationary when weekly and monthly average prices are considered; for the entire period, the statistics for diesel, residual fuel oil, and propane (an important component of liquefied petroleum gas) are consistent with the price series being nonstationary, with the exception of nominal residual fuel oil prices.

Construction of Filtered Series

The data on crude oil prices indicate the presence of a notable trend at the end of the period considered. Rather than create arbitrary subperiods, which still would not produce trendless data in each, a Hodrick-Prescott filter was used to produce a smoothly evolving trend. Such a trend may correspond to a forecast of the trend in prices made by an agent in the market (see Ash and others 2002). Filtered data are shown in figure 3.1 using nominal weekly prices. The general shapes of filters for daily and monthly prices are similar. The filter method used requires that the data for the period of the first Persian Gulf War be included. The results reveal a fairly constant price level during the late 1980s and the 1990s, with a steady upward climb since 2002.

Figure 3.2 shows the same results in real terms. They show a fall in trend prices until the end of the 1990s, with a steep trend increase thereafter. The

Table 3.2

ADF Test Statistics for Monthly U.S. Gulf Coast Oil Product Prices

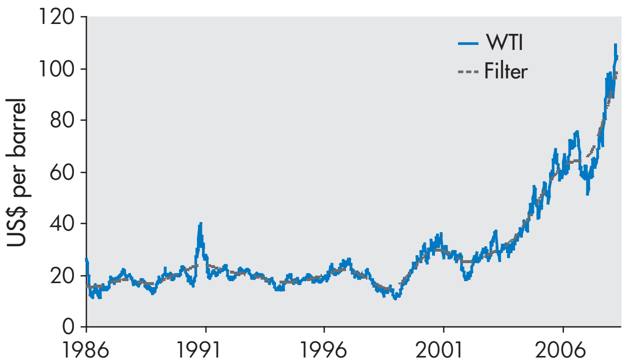
Fuel	Beginning–Mar. 2007	Beginning–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Gasoline, nominal	Not stationary	Not stationary	Not stationary	Not stationary
Diesel, nominal	Not stationary	Not stationary	Not stationary	Not stationary
Heating oil, nominal	Not stationary	Stationary	Not stationary	Not stationary
Jet kerosene, nominal	Not stationary	Stationary	Not stationary	Not stationary
Residual fuel oil, nominal	Not stationary	Not stationary	Not stationary	Not stationary
Propane, nominal	Not stationary	Not stationary	Not stationary	Not stationary[a]
Gasoline, real	Not stationary	Not stationary	Not stationary	Not stationary
Diesel, real	Not stationary	Not stationary	Not stationary	Not stationary
Heating oil, real	Not stationary	Stationary	Not stationary	Not stationary
Jet kerosene, real	Not stationary	Stationary	Not stationary	Not stationary
Residual fuel oil, real	Not stationary	Not stationary	Not stationary	Not stationary
Propane, real	Not stationary	Not stationary	Not stationary	Not stationary

Source: Author calculations.

a. The null hypothesis narrowly escapes being rejected at 5 percent.

Figure 3.1

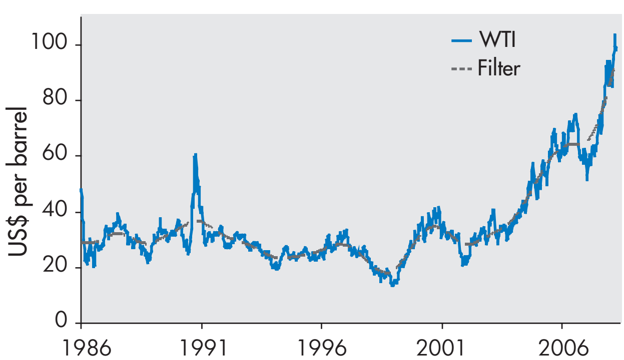
Weekly Nominal Prices of WTI Crude and HP Filter



Sources: WTI crude prices from U.S. EIA 2008a; author calculations.

Figure 3.2

Weekly Real Prices of WTI Crude and HP Filter



Sources: WTI crude prices from U.S. EIA 2008a; author calculations.

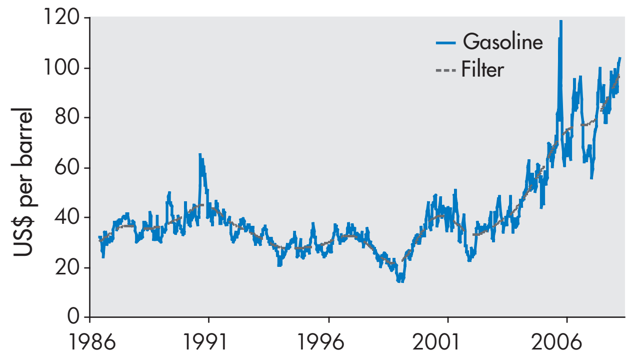
trend is steep, and its rise in both real and nominal terms is similar.

The filtered series for gasoline is shown in real terms in figure 3.3. Other fuel prices and nominal prices show trends similar to those for crude and gasoline.

Examination of the actual data and the filtered series reveals that there is a close correlation between the different series, and that all exhibit similar trend behavior. A feature of the product prices not existing in the crude prices was the exceedingly sharp spike in product prices in the first week of September 2005. In that week, gasoline reached US$110 a barrel, while crude reached a peak for that year of US$68 a barrel.

Figure 3.3

Weekly Real Prices of Gasoline in the U.S. Gulf Coast and HP Filter



Sources: Regular gasoline prices from U.S. EIA 2008a; author calculations.

Volatility of Returns

Returns data, which form the basis of the measurement of volatility of a price series, are calculated in two ways.

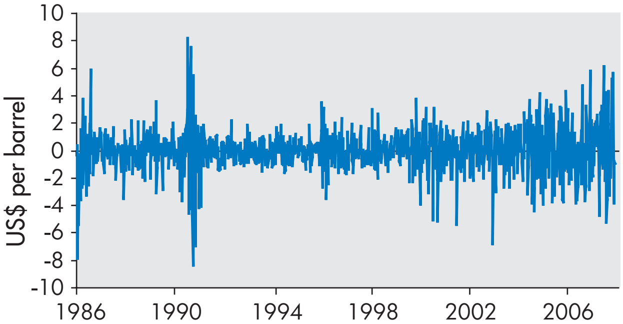
- Basic returns are calculated as the first differences of prices (price at period [N + 1] – price at period N).
- Cycle returns are the first differences of cycles (actual series – filtered series).

Returns on weekly WTI crude and gasoline prices in real terms are shown in figures 3.4 and 3.5, respectively. For the most part, returns and cycle returns track each other closely: there are only four data points for which the difference between the return and the cycle return is more than US$0.40 per barrel. All the graphs of returns show a few observations where there were extremely large changes from week to week. Changes of more than 20 percent have occurred for all products and for crude; for gasoline, residual fuel oil, and propane, there are weekly changes of more than 30 percent.

The standard deviation of the returns series serves as a measure of the average volatility of that series during the measurement period. Table 3.3 presents the standard deviations for returns (based on logarithms of prices) on nominal crude and product prices for the whole period and the three subperiods. As long as the standard deviations

Figure 3.4

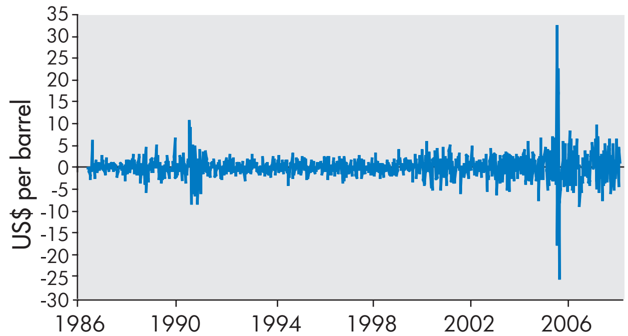
Returns on Weekly Real WTI Crude Prices



Sources: WTI crude prices from U.S. EIA 2008a; author calculations.

Figure 3.5

Returns on Weekly Real Gasoline Prices in the U.S. Gulf Coast



Sources: Regular gasoline prices from U.S. EIA 2008a; author calculations.

Table 3.3

Standard Deviation of Returns for Logarithms of Nominal WTI Crude and U.S. Gulf Coast Oil Product Prices

Fuel	Beginning–Mar. 2007	Beginning–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007[a]
WTI crude, daily	0.025	0.026	0.027	0.021 (0.021)
Gasoline, daily	0.029	0.025	0.034	0.035 (0.033)
Jet kerosene, daily	0.027	0.025	0.028	0.030 (0.028)
Heating oil, daily	0.026	0.025	0.029	0.027 (0.026)
Diesel, daily	0.027	0.023	0.028	0.031 (0.029)
Residual fuel oil, daily	0.018	0.014	0.021	0.020 (0.019)
Propane, daily	0.025	0.020	0.032	0.024 (0.022)
WTI crude, weekly	0.043	0.044	0.046	0.036 (0.035)
Gasoline, weekly	0.052	0.046	0.059	0.066 (0.063)
Jet kerosene, weekly	0.047	0.043	0.050	0.052 (0.049)
Heating oil, weekly	0.044	0.042	0.050	0.045 (0.043)
Diesel, weekly	0.046	0.040	0.048	0.050 (0.047)
Residual fuel oil, weekly	0.043	0.038	0.051	0.043 (0.041)
Propane, weekly	0.048	0.037	0.064	0.047 (0.043)
WTI crude, monthly	0.084	0.087	0.082	0.074 (0.071)
Gasoline, monthly	0.106	0.095	0.124	0.125 (0.117)
Jet kerosene, monthly	0.091	0.089	0.089	0.099 (0.091)
Heating oil, monthly	0.085	0.083	0.090	0.086 (0.080)
Diesel, monthly	0.086	0.078	0.089	0.094 (0.087)
Residual fuel oil, monthly	0.094	0.093	0.098	0.093 (0.090)
Propane, monthly	0.090	0.074	0.119	0.087 (0.079)

Source: Author calculations.

a. Standard deviations for January 2004 to December 2007 are shown in parentheses.

are small, multiplying them by 100 when taking logarithms of prices gives the percentage change from period to period. The standard deviations of returns based on real prices are almost identical to those for nominal returns and are thus not shown. The standard deviations are also calculated for the period January 2004 to December 2007 (shown in parentheses in the last column of table 3.3) as a check on whether volatility increased because of the large increase in prices during the latter half of 2007. The standard deviations were slightly smaller when the price series was extended to the end of 2007.

Most oil products had an average volatility of between 4 and 5 percent, with gasoline exhibiting the greatest volatility and crude oil the least. The first subperiod shows the lowest volatility, with a substantial increase in the second subperiod for all products. The most recent subperiod shows lower volatility in percentage terms than the second or the first for several products and for crude; this effect was more marked when the data set was extended until the end of 2007. Gasoline prices are the most volatile, showing an average daily, weekly, and monthly price variation of 3.5, 6.6, and 12.5 percent, respectively.

Since an important consideration in analyzing the volatility of oil prices is their degree of constancy over time, a series of F-tests for constant variance across subperiods was carried out. The results are shown in table 3.4 for daily, weekly, and monthly prices. The tests on daily and weekly data indicate that the returns are more variable in the second subperiod than in the first for every oil product. However, crude variability is not significantly different between the first and second subperiods. Daily prices show greater variance in the third subperiod than for the first for every fuel, but this trend is not observed for heating and residual fuel oil when weekly prices are examined. Comparing monthly prices in the third subperiod to those in the second or first reveals that in no case are the recent returns significantly more variable than in the first two periods; the returns for gasoline and propane are more variable in the second subperiod than the first. Extending the price series to the end of 2007 did not change statistical significance or conclusions.

The variance equality tests for daily and weekly prices indicate that volatility is higher after 2000 than before for all oil products, but volatility appears to decrease slightly in the period from the beginning of 2004, without returning to the levels before 2000. One exception is crude oil, for which the price volatility before 2000 is greater than in the subsequent years. This change in the variance of the returns points to the possibility that the pattern of returns does not simply relate to a permanent structural change, as is implicit in the use of a variance ratio test, but is more systematic. Several studies on oil price returns, including Wickham (1996) and Kuper (2002), have found evidence that there is clustering of volatility. Large returns (whether positive or negative) tend to be followed by large returns, and small values tend to be followed by small values.

The foregoing suggests that shocks to the variance of returns persist rather than rapidly die down. A GARCH formulation was used to test whether the variance of returns is stationary and if price levels eventually revert back to a mean and, if they do, over what time period. The GARCH formulation tests an equation specification for the mean of the return series (in logarithms) and an equation for the conditional variance of the returns. The first equation for the mean, called the conditional mean equation, relates the return to a constant and several lagged values, while the conditional variance equation utilizes a GARCH(1,1) or GARCH(1,0) formulation. Price volatility is classified based on GARCH test results as follows:

- *Category A:* The conditional variance, and hence price volatility, is not stationary but grows over time without bound.
- *Category B:* The conditional variance is stationary, and the half-life for mean reversion can be calculated.
- *Category C:* No statistically significant equations can be found, suggesting that the conditional variance may be constant.
- *Category D:* Statistically significant equations can be found but fail to meet one or more criteria: one or more coefficients in the conditional variance equation have the wrong (negative) sign, or

Table 3.4

Variance Equality Tests for Returns for Nominal WTI Crude and U.S. Gulf Coast Oil Product Prices

Averaging period	Fuel type	Subperiod 1/2	Subperiod 2/3	Subperiod 1/3
Daily	WTI crude	0.92	**1.63 (1.72)**	**1.50 (1.59)**
	Gasoline	**0.56**	0.95 (1.03)	**0.54 (0.58)**
	Jet kerosene	**0.77**	0.91 (1.03)	**0.70 (0.80)**
	Heating oil	**0.75**	**1.14 (1.26)**	**0.86 (0.95)**
	Diesel	**0.67**	**0.81 (0.90)**	**0.54 (0.60)**
	Residual fuel oil	**0.45**	1.10 (1.19)	**0.50 (0.54)**
	Propane	**0.40**	**1.77 (2.02)**	**0.70 (0.80)**
Weekly	WTI crude	0.92	**1.69 (1.76)**	**1.55 (1.61)**
	Gasoline	**0.59**	0.81 (0.90)	**0.48 (0.53)**
	Jet kerosene	**0.74**	0.92 (1.07)	**0.68 (0.79)**
	Heating oil	**0.71**	1.21 (1.38)	0.86 (0.98)
	Diesel	**0.67**	0.92 (1.05)	**0.61 (0.70)**
	Residual fuel oil	**0.54**	**1.43 (1.57)**	0.78 (0.85)
	Propane	**0.33**	**1.87 (2.18)**	**0.62 (0.72)**
Monthly	WTI crude	1.13	1.23 (1.31)	1.40 (1.49)
	Gasoline	**0.59**	1.00 (1.13)	0.58 (0.66)
	Jet kerosene	1.01	0.81 (0.95)	0.82 (0.96)
	Heating oil	0.86	1.10 (1.25)	0.94 (1.07)
	Diesel	0.77	0.91 (1.06)	0.70 (0.81)
	Residual fuel oil	0.90	1.12 (1.21)	1.01 (1.08)
	Propane	**0.38**	1.84 **(2.24)**	0.71 (0.86)

Sources: Prices from U.S. EIA 2008a; author calculations.

Note: Subperiod 1 is from the beginning of the price data series to end of 1999, subperiod 2 is from the beginning of 2000 to end of 2003, and subperiod 3 is from the beginning of 2004 to end of March 2007. Subperiod 1/2 is the ratio of the variance of returns in subperiod 1 to that in subperiod 2, and so on. Ratios that are different from unity using a two-sided test at 2.5 percent are in **bold**. Results for January 2004 to December 2007 are shown in parentheses.

there is serial correlation in the conditional mean equation, typically because of omitted variables. In this case, the conditional variance is unlikely to be constant, but it is not possible to determine how the variance changes over time.

The above categories of results carry policy implications. If oil price volatility is found to grow without bound, attempts at stabilizing oil prices would not be successful. Even smoothing oil price fluctuations should be approached with care. If oil price volatility is stationary but has a long half-life for mean reversion, stabilizing or smoothing prices could be costly, and alternative ways of mitigating oil price volatility may have to be found.

GARCH modeling was carried out using nominal daily, weekly, and monthly prices. The analysis enabled determination of whether historical oil price volatility has exhibited stationarity and, if so, how long the reversion to the historic mean takes. The results show that the explanatory power of GARCH modeling is, on the whole, weak. Many data series are not "well behaved," in that eliminating statistically insignificant coefficients one by one sometimes leads to the statistical significance of the remaining coefficients varying widely from one equation specification to the next. This problem becomes pronounced with decreasing sample size (for example, with monthly data or data from a subperiod). The systematic, predictable component of the variance (calculated from the conditional variance equation) has a weak correlation with historical variance and makes only a small contribution to the overall price volatility at each point in time in every case.

The results for daily prices are shown in table 3.5. For the entire time period, the variance equation includes a time-trend term with a positive coefficient, which means that the constant term (the intercept) in the conditional variance equation increases with time. The conditional variance is stationary and has a half-life of 101 days or shorter in all cases, except for WTI crude in the last subperiod, where it is found to grow without bound. Annex 3 provides more detailed results, including several cases in which GARCH(1,0) and GARCH(1,1) give seemingly valid results but with GARCH(1,0) giving a markedly shorter half-life.

The results of the estimates suggest that there is a substantial degree of persistence in shocks to the variance of returns when the entire period is considered. This phenomenon is particularly marked for crude oil and gasoline; the results are less pronounced for the subperiods. In particular, the persistence of shocks to the variance is low for crude oil, gasoline, residual fuel oil, and propane in the second subperiod, suggesting little clustering of daily price volatility. In several cases, the sum of the ARCH and GARCH terms is near unity, and even small changes in this sum from subperiod to subperiod produce large changes in the estimate of the half-life of shocks. As annex 3 shows, these results remain essentially the same when the data are extended to include prices to November 14, 2007.

Also shown in annex 3 is out-of-sample testing using the equations derived for WTI crude from table 3.5. Model predictions are compared with actual prices between the beginning of April and November 14, 2007. The model predicts that the conditional variance would nearly double during this period, but statistical analysis of the results shows that the greatest difference by far between predicted and actual returns is due to the difference between the variances of the forecast and the actual price return series.

The results for weekly prices are given in table 3.6. The correlation with the results based on daily prices is not particularly strong, and there are several cases where an equation that is statistically significant and that met other criteria—that is, those falling under either category A or B—could be found with daily prices but not with weekly average prices.

Table 3.5

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices

Parameter	WTI	Gasoline	Diesel	Heating oil	Jet kerosene	Residual fuel oil	Propane
Beginning–Mar. 2007	B	B	B	B	D	B[a]	B
Half-life (days)	87	101	18	21	n.a.	2	63
Beginning–Dec. 1999	D	B	B	B	D	B[a]	D
Half-life (days)	n.a.	44	25	24	n.a.	0.9	n.a.
Jan. 2000–Dec. 2003	B	B[a]	B	B	B	B[a]	B
Half-life (days)	3	2	12	11	19	3	7
Jan. 2004–Mar. 2007	A	B	B	B	B	B[a]	B
Half-life (days)	n.a.	15	10	12	16	2	5

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. The results using a GARCH(1,0) formulation giving a shorter half-life are given in annex 3.

Table 3.6

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices

Parameter	WTI	Gasoline	Diesel	Heating oil	Jet kerosene	Residual fuel oil	Propane
Beginning–Mar. 2007	B	B	B	B	B	B[a]	A[a]
Half-life (weeks)	12	10	3	6	8	6	n.a.
Beginning–Dec. 1999	B	B	C	B	B	B	B[a]
Half-life (weeks)	13	13	n.a.	7	9	0.6	1
Jan. 2000–Dec. 2003	D	C	B	B	B	B	B[a]
Half-life (weeks)	n.a.	n.a.	0.4	0.3	0.4	7	1
Jan. 2004–Mar. 2007	C	B	D	C	B	A[a]	B[a]
Half-life (weeks)	n.a.	1	n.a.	n.a.	5	n.a.	4

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. Results using a GARCH(1,0) formulation—where the half-life was found to be finite (for category A) or shorter (for category B)—are given in annex 3.

This difference is especially pronounced for the last subperiod, where no satisfactory equation could be found for weekly prices of WTI crude, diesel, and heating oil, but equations that appear satisfactory could be identified with daily prices. More detailed results (given in annex 3) show that there are several cases where GARCH(1,0) and GARCH(1,1) give seemingly valid results, but with the GARCH(1,0) formulation giving a stationary conditional variance and GARCH(1,1) giving a conditional variance that grows without bound.

The most extensive analysis was conducted on monthly prices; this was in part for comparison with the analysis of monthly oil and product prices in different regions of the world presented in chapter 4. Results from a total of six time periods are given in table 3.7. Two additional time periods are included:

- June 1995 to March 2007, a subperiod during which data are available for all the fuels. This subperiod was selected to see how much of the difference among fuels for the entire period is due to different durations of data availability.
- April 1999 to March 2007, which was selected based on findings by Lee and Zyren (2007), who, in testing weekly prices, found a dummy variable for the months after March 1999 to be statistically significant in the conditional variance equation. The authors attributed this to the new pricing policy introduced by OPEC in March 1999. Inclusion of a variable for OPEC spare capacity did not yield statistically significant results.

Most monthly price series fall under category D: no statistically significant and valid equations could be found, which may suggest that averaging prices removes much of the systematic dynamics. If so, it would be difficult to establish how variable price returns are and whether there is clustering—which in turn would make it difficult for governments to optimize policy responses. As with daily prices, repeating the GARCH analysis using data through October 2007 returned essentially the same results (see annex 3).

The results of runs tests are briefly summarized in table 3.8, with additional results given in annex 3. For comparison with cycle returns, logarithms are not taken in runs tests. The period from September 1995 to March 2007 was selected, because continuous price information is available for all fuels beginning in September 1995. Table 3.8 gives the percentage of months cumulative cycles are negative as well as the maximum sojourn, expressed in months, of cumulative cycles.

Cumulative cycles provide an indication of the balance in an oil account for smoothing petroleum

Table 3.7

GARCH of Returns of Logarithms of Nominal Monthly Prices

Parameter	WTI	Gasoline	Diesel	Heating oil	Jet kerosene	Residual fuel oil	Propane
Beginning–Mar. 2007	A	D	D	B	B	D	D
Half-life (months)	n.a.	n.a.	n.a.	0.4	4.8	n.a.	n.a.
June 1995–Mar. 2007	D	D	D	D	B	D	D
Half-life (months)	n.a.	n.a.	n.a.	n.a.	0.6	n.a.	n.a.
Beginning–Dec. 1999	A	D	D	B	B	D	B
Half-life (months)	n.a.	n.a.	n.a.	0.8	3.7	n.a.	0.9
Jan. 2000–Dec. 2003	D	D	D	D	D	D	A
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Jan. 2004–Mar. 2007	D	D	D	D	B	D	D
Half-life (months)	n.a.	n.a.	n.a.	n.a.	0.6	n.a.	n.a.
Apr. 1999–Mar. 2007	A	C	B	B	D	B	D
Half-life (months)	n.a.	n.a.	3.1	4.9	n.a.	4.4	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

Table 3.8

Runs on Cumulative Cycles of Nominal Prices, September 1995–March 2007

Averaging period	Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Daily	Percent negative[a]	66	79	52	58	65	53	55
	Maximum sojourn[b]	5.3	6.5	4.6	8.0	6.5	4.7	5.6
Weekly	Percent negative[a]	58	63	45	46	51	51	56
	Maximum sojourn[b]	24	23	28	27	26	21	25
Monthly	Percent negative[a]	34	36	32	32	39	39	42
	Maximum sojourn[b]	40	39	40	40	38	32	27

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

prices based on a long-term price trend. The oil account will receive the difference between the trend price and the actual price when the latter is lower, and, conversely, will pay for the difference if the actual price is higher. At any time when the cumulative cycle is negative, the balance in the oil account would be positive; when the cumulative cycle is positive, the oil account balance would be negative. This balance depends on when the oil account is put into operation (or the beginning of summation of cycles). The results show that cumulative cycles become increasingly positive with the increasing length over which prices are averaged: cumulative cycles are negative more than half the time for all fuels when daily prices are used, but less than half the time when monthly average prices are considered. Thus, a price-smoothing scheme based on the long-term trend of monthly prices—whereby prices are adjusted and transfers in or out of the oil account are made on a monthly basis—would have a negative account balance more than half the time. The maximum sojourn for a given fuel also increases with increasing averaging period. The maximum sojourns for monthly average prices are nearly all for positive cumulative cycles, which would correspond to months when the balance of this hypothetical oil account for smoothing prices is negative. More information on price smoothing can be found in chapter 7.

4 Application to Prices in Developing Countries

The tests run on U.S. Gulf prices presented in chapter 3 were applied to monthly prices in Chile, Ghana, India, the Philippines, and Thailand to capture the combined impact of foreign exchange and oil price fluctuations. For this purpose, international crude and oil product prices in U.S. dollars and local currency units in the U.S. Gulf Coast (for Chile), northwestern Europe (Ghana), the Persian Gulf (India), and Singapore (the Philippines and Thailand) were examined. For crude, prices for Nigerian Bonny Light were used for Ghana, those for Indonesian Minas for the Philippines and Thailand, and Dubai Fateh for India. Additional information on these price data are presented in annex 4.

Price information is available beginning in January 1987 for all fuels except those from the U.S. Gulf Coast, where the crude price series is available from January 1986 but the prices of oil products appear for the first time between June 1986 and as late as May 1995. In analyzing the prices in the five developing countries, three time periods were examined: the entire time period from the beginning to March 2007, a first subperiod from the beginning to June 1999, and a second subperiod from July 1999 to March 2007. The cut-off point of June 1999 was chosen because prices in local currency generally began to rise in the middle of 1999. The results from runs tests are reported only for the second subperiod and only for cumulative cycles in this chapter. Additional results can be found in annex 4.

For reporting price level and price volatility differences (presented in the first three tables for each country), three subperiods—from the beginning to June 1999, July 1999 to December 2003, and January 2004 to January 2008—as well as the entire period from the beginning to January 2008 were examined. In the case of real prices in Ghana, the price series had to be terminated in November 2007 because the consumer price index was not available after that month at the time of completing this report.

This chapter describes the price level and price volatility differences between the U.S. and local currencies, the results of ADF tests, GARCH analysis of nominal prices in local currency, and calculations of cumulative cycles during the second subperiod. Additional results are given in annex 4. As discussed in chapter 3, one interpretation of cumulative cycles is to consider a fund for smoothing oil prices (referred to here as the oil account) based on a long-term price trend constructed using an HP filter. When cumulative cycles are positive, the balance of the oil account is negative. In this chapter, the maximum sojourn (the number of continuous months when cumulative cycles have one sign) corresponds to the months when cumulative cycles are positive in every case. Thus, the maximum sojourns presented here tell how many months the oil account balance would have remained negative, imposing a fiscal burden on the government managing such an account. Note that the account balance is a function of when the fund is started. Computing cumulative cycles for the second subperiod is equivalent to setting up the oil account in July 1999.

Chile

Price increases in U.S. dollars and Chilean pesos were compared for the three subperiods (table 4.1). The increases in the mean local currency prices (averaged over each subperiod) were higher than those corresponding to prices in U.S. dollars in both nominal and real terms except when going from the

Table 4.1

Difference between Percentage Price Increase in U.S. Dollars to That in Chilean Pesos

Price	Subperiods compared	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Nominal	2 to 1	118	84	67	114	116	134
	3 to 2	–28	–28	–31	–30	–30	–28
	3 to 1	179	118	90	188	186	185
Real	2 to 1	18	28	48	17	17	20
	3 to 2	–24	–23	–26	–25	–25	–23
	3 to 1	3	19	53	2	2	1

Sources: U.S. EIA 2008a; author calculations.

Note: Subperiod 1 beginning in the month shown in table A4.1 to June 1999; subperiod 2 is July 1999–December 2003; subperiod 3 is January 2004–January 2008. The increase in the mean price from subperiod 1 to subperiod 2 (percentage increase in subperiod 2 over subperiod 1) computed in U.S. dollars is subtracted from the percentage increase in the mean price between the same two subperiods in Chilean pesos.

second to the third subperiod. In real terms, price increases from the first subperiod to the third for WTI crude, diesel, jet kerosene, and residual fuel oil were the same regardless of whether fuels were priced in U.S. dollars or Chilean pesos. See annex 4 for more information.

A comparison of standard deviations of returns of logarithms of nominal and real prices in U.S. dollars and Chilean pesos shows that nominal Chilean peso prices were less volatile during the first subperiod for gasoline, diesel, and jet kerosene and real Chilean peso prices were less volatile for all six fuels. For all other fuels and periods, volatility was the same or higher for Chilean peso prices. Exchange rate fluctuations were largest during the second subperiod, which also saw higher price volatility in local currency. During the third subperiod, the Chilean peso was appreciating against the U.S. dollar, but fluctuations served to amplify, rather than reduce, local currency price volatility.

ADF tests show some differences between U.S. and local currency prices. For the entire period, the results are the same and all prices are nonstationary except for residual fuel oil (in both nominal and real prices). In the first subperiod, prices for all fuels except gasoline are nonstationary in nominal and real prices when expressed in U.S. dollars. When the prices are converted to Chilean pesos, gasoline and kerosene prices are nonstationary in nominal terms and gasoline prices are nonstationary in real terms; other prices are stationary. During the second subperiod, all U.S. prices are nonstationary but local gasoline prices, nominal and real, are stationary.

The results of GARCH tests performed on local nominal prices are summarized in table 4.2. WTI crude, jet kerosene, and residual fuel oil have a conditional variance that is stationary for the entire period and during the first subperiod. Gasoline and gasoil have a nonstationary conditional variance even during the first subperiod. During the second subperiod, only residual fuel oil has a stationary conditional variance; meaningful equations could not be found for the other fuels.

Examination of cumulative cycles is given in table 4.3. The percentage of months when cumulative cycles is negative is lower for local prices, illustrating the impact of exchange rate fluctuations. This finding implies that the oil account balance would have been negative over a longer period than if prices were in U.S. dollars. The maximum sojourn during which the oil account balance remains negative continuously is 5.5 years for residual fuel oil.

Table 4.2

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Chilean Pesos

Parameter	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Beginning–Mar. 2007	B	D	D	B	A[a]	B
Half-life (months)	0.6	n.a.	n.a.	0.4	n.a.	0.6
Beginning–June 1999	B	A[a]	C	B	A[a]	B
Half-life (months)	1	n.a.	n.a.	0.5	n.a.	0.5
July 1999–Mar. 2007	D	D	D	D	D	B
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.	0.8

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. The results from not retaining the GARCH term, whereby a finite half-life was found, are presented in annex 4.

Table 4.3

Cumulative Cycles of Nominal Monthly Chilean Prices, July 1999–March 2007

Currency	Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
US$	Percent negative[a]	28	26	30	31	32	22
	Maximum sojourn[b]	49	50	47	46	48	59
	Average[c]	32	34	33	32	29	26
Ch$	Percent negative[a]	5	6	24	23	26	4
	Maximum sojourn[b]	56	62	50	50	50	66
	Average[c]	24,875	27,558	26,953	26,016	21,098	20,107

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

c. Average cumulative cycles over the period.

Ghana

Price increases were compared in U.S. dollars and Ghanaian cedis. As shown in table 4.4, the local currency price increases were higher in nominal terms for all subperiod comparisons. In real terms, however, local currency price increases in the third subperiod over the second subperiod were lower than U.S. dollar price increases, and the magnitude of the difference between the two sets of prices is the largest among the five countries examined here.

Comparison of standard deviations of returns of logarithms of nominal and real prices in U.S. dollars and Ghanaian cedis shows that volatility was higher for all periods in nominal and real terms. Exchange rate fluctuations amplified local currency price volatility.

ADF tests show that both U.S. and local prices, nominal and real, are nonstationary for the full period and the second subperiod. For the first subperiod, all prices are stationary except nominal local prices; these are nonstationary for every fuel, underscoring the magnitude of local inflation.

As shown in table 4.5, GARCH analysis of returns found meaningful equations for all fuels except gasoil during both the full period and the first subperiod. No satisfactory equations could be found for any fuel during the second subperiod,

Cumulative cycles during the second subperiod are negative less than a third of the time in U.S. dollars, but more frequently in local currency (table 4.6). This is the reverse of the Chilean case. Maximum sojourns are shorter in local currency than in U.S. dollars. The average cycle return is positive for every fuel. Thus, while managing the oil account might have been easier in the local currency than in U.S. dollars, it would still have posed a fiscal challenge, with the account balance being negative continuously for three years or longer.

Table 4.4

Difference between Percentage Price Increase in U.S. Dollars to That in Ghanaian Cedis

Price	Subperiods compared	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal	2 to 1	974	957	938	934	1,005
	3 to 2	75	72	75	75	65
	3 to 1	3,044	2,846	2,941	2,937	2,727
Real	2 to 1	94	92	90	90	99
	3 to 2	–44	–41	–44	–44	–37
	3 to 1	93	89	91	91	84

Sources: Energy Intelligence 2008; author calculations.

Note: For definitions and calculation procedures, see the notes to table 4.1. Real prices only through November 2007.

Table 4.5

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Ghanaian Cedis

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Beginning–Mar. 2007	B	B	A	D	A[a]
Half-life (months)	0.6	0.5	n.a.	n.a.	n.a.
Beginning–June 1999	B	A[a]	A	D	B
Half-life (months)	0.9	n.a.	n.a.	n.a.	0.7
July 1999–Mar. 2007	D	D	D	D	D
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. The results from not retaining the GARCH term, whereby a finite half-life was found, are presented in annex 4.

Table 4.6

Cumulative Cycles of Nominal Monthly Ghanaian Prices, July 1999–March 2007

Currency	Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$	Percent negative[a]	28	26	31	31	20
	Maximum sojourn[b]	52	50	46	46	60
	Average[c]	34	42	37	30	31
₵	Percent negative[a]	47	42	45	46	35
	Maximum sojourn[b]	37	35	35	35	47
	Average[c]	45,237	90,771	52,540	31,425	97,924

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

c. Average cumulative cycles over the period.

India

Price increases are compared for U.S. dollars and Indian rupees (table 4.7). The local currency price increases in the third subperiod over the second were lower in nominal and real terms; the difference between the two currencies is greater when prices are measured in real terms.

A comparison of standard deviations of returns of logarithms of nominal and real prices in U.S. dollars and Indian rupees shows that there is virtually no difference in volatility between the two currencies. Where they differ slightly, local currency prices have higher volatility.

ADF tests show that all prices are nonstationary when the entire period as well as the second subperiod are considered. In the first subperiod, all prices are stationary except nominal local gasoil prices.

As in other countries, GARCH analysis of returns in local currency found meaningful equations for the entire period as well as for the first subperiod, with the exception of gasoil (table 4.8). During the second subperiod, no meaningful equations could be found except for residual fuel oil, the conditional variance of which seems to grow without bound.

Cumulative cycles are negative slightly less frequently in local currency than in U.S. dollars (table 4.9). The maximum sojourns are longer in local currency and range from one month shy of four years to longer than five years.

Table 4.7

Difference between Percentage Price Increase in U.S. Dollars to That in Indian Rupees

Price	Subperiods compared	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal	2 to 1	112	99	96	97	127
	3 to 2	–14	–13	–15	–16	–13
	3 to 1	211	174	199	208	211
Real	2 to 1	29	25	24	24	33
	3 to 2	–24	–23	–26	–28	–22
	3 to 1	20	16	19	19	21

Sources: Energy Intelligence 2008; author calculations.

Note: For definitions and calculation procedures, see the notes to table 4.1.

Table 4.8

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Indian Rupees

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Beginning–Mar. 2007	A[a]	B	B	D	B
Half-life (months)	n.a.	2	2	n.a.	0.7
Beginning–June 1999	A	A	B	A[a]	B
Half-life (months)	n.a.	n.a.	1	n.a.	0.7
July 1999–Mar. 2007	D	D	D	D	A
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. The results from not retaining the GARCH term, whereby a finite half-life was found, are presented in annex 4.

Table 4.9

Cumulative Cycles of Nominal Monthly Indian Prices, July 1999–March 2007

Currency	Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$	Percent negative[a]	30	34	34	38	18
	Maximum sojourn[b]	53	49	48	46	61
	Average[c]	29	22	25	16	36
Rs	Percent negative[a]	27	30	33	37	15
	Maximum sojourn[b]	56	53	50	47	63
	Average[c]	1,598	1,388	1,429	1,019	1,852

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

c. Average cumulative cycles over the period.

The Philippines

The results of the price increase comparison are shown in table 4.10. As in Ghana, the local currency price increases are higher in nominal terms for all subperiod comparisons. In real terms, prices in Philippine pesos increased less in the third subperiod over the second subperiod.

A comparison of standard deviations of returns of logarithms of nominal and real prices in U.S. dollars and Philippine pesos shows that local prices were consistently more volatile than U.S. dollar prices for all the periods examined.

ADF tests for the entire period show that all prices are nonstationary. For the first subperiod, prices are stationary except nominal and real U.S. gasoline prices, nominal and real local crude oil prices, and real U.S. gasoline prices. During the second subperiod, as in Chile, all prices are nonstationary except nominal and real local gasoline prices.

The GARCH analysis results follow the trend observed in other countries, with no meaningful equations identified during the second subperiod (table 4.11). During the first subperiod, the conditional variance is bounded for crude oil, gasoline, and residual fuel oil.

The percentage of months when cumulative cycles are negative is 40 percent or less in all cases and comparable between the two currencies (table 4.12). The maximum sojourns are also comparable.

Table 4.10

Difference between Percentage Price Increase in U.S. Dollars to That in Philippine Pesos

Price	Subperiods compared	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal	2 to 1	128	110	109	110	142
	3 to 2	7	8	9	8	6
	3 to 1	300	266	277	278	293
Real	2 to 1	34	29	29	30	39
	3 to 2	−13	−12	−13	−13	−11
	3 to 1	48	42	44	45	47

Sources: Energy Intelligence 2008; author calculations.

Note: For definitions and calculation procedures, see the notes to table 4.1.

Table 4.11

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Philippine Pesos

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Beginning–Mar. 2007	D	B	A[a]	A	D
Half-life (months)	n.a.	0.7	n.a.	n.a.	n.a.
Beginning–June 1999	B	B	A	D	B
Half-life (months)	1.5	1.6	n.a.	n.a.	0.6
July 1999–Mar. 2007	D	D	D	D	D
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

a. The results from not retaining the GARCH term, whereby a finite half-life was found, are presented in annex 4.

Table 4.12

Cumulative Cycles of Nominal Monthly Philippine Prices, July 1999–March 2007

Currency	Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$	Percent negative[a]	28	32	34	40	17
	Maximum sojourn[b]	52	46	47	44	60
	Average[c]	35	26	27	21	39
₱	Percent negative[a]	29	33	33	37	18
	Maximum sojourn[b]	47	43	43	40	57
	Average[c]	1,323	868	967	731	1,625

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

c. Average cumulative cycles over the period.

Thailand

The results of the price increase comparison are shown in table 4.13. As in Chile and the Philippines, the local currency price increases in the third subperiod over the second were smaller in nominal and real terms.

A comparison of standard deviations of returns of logarithms of nominal and real prices in U.S. dollars and Thai baht shows that Thai baht prices were the same or more volatile than U.S. dollar prices for all the periods examined except for residual fuel oil in the first subperiod in nominal terms.

ADF tests show that all prices—nominal or real, in U.S. or local currency—are nonstationary for the entire period as well as during the second subperiod. For the first subperiod, all prices are stationary except nominal U.S gasoline prices and real U.S. and local gasoline prices.

It was difficult to identify meaningful equations through GARCH analysis except for gasoline in the first subperiod and residual fuel oil in both subperiods (table 4.14). For data from the full period, the conditional variance is bounded for gasoline and kerosene, and unbounded for gasoil and residual fuel oil.

There is no marked difference in the cumulative cycles between local and U.S. dollar prices during the second subperiod (table 4.15). Cumulative cycles are negative less than a third of the time, and as little as 12 percent for local residual fuel oil prices.

Table 4.13

Difference between Percentage Price Increase in U.S. Dollars to That in Thai Bahts

Price	Subperiods compared	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal	2 to 1	80	69	69	70	88
	3 to 2	–22	–22	–23	–24	–20
	3 to 1	125	111	117	117	121
Real	2 to 1	47	40	40	41	52
	3 to 2	–20	–19	–21	–21	–17
	3 to 1	59	52	55	55	58

Sources: Energy Intelligence 2008; author calculations.

Note: For definitions and calculation procedures, see the notes to table 4.1.

Table 4.14

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Thai Bahts

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Beginning–Mar. 2007	D	B	B	A	A
Half-life (months)	n.a.	0.5	6	n.a.	n.a.
Beginning–Dec. 1999	D	B	D	D	B
Half-life (months)	n.a.	2	n.a.	n.a.	0.8
Jan. 2000–Mar. 2007	D	D	D	D	A
Half-life (months)	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Results are classified into the four categories defined on p. 13.

Table 4.15

Cumulative Cycles of Nominal Monthly Thai Prices, July 1999–March 2007

Currency	Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$	Percent negative[a]	28	26	31	31	20
	Maximum sojourn[b]	54	49	48	45	63
	Average[c]	34	42	37	30	31
B	Percent negative[a]	24	27	27	31	12
	Maximum sojourn[b]	52	49	49	45	63
	Average[c]	1,715	1,366	1,505	1,247	1,874

Source: Author calculations.

a. Percentage of months when the cumulative returns are negative.

b. Maximum sojourn in months.

c. Average cumulative cycles over the period.

Observations

Nominal prices in some countries show large effects of exchange rate fluctuations, with marked differences from the behavior of prices in U.S. dollars. Because government interventions target local price movements, local prices are more useful in assessing policy options. In Chile, local prices have tended to be more stable, potentially making policy interventions easier than if the government were dealing with world oil prices in U.S. dollars. At the opposite end of spectrum is Ghana where, in the first subperiod, nominal local prices were nonstationary but real prices were stationary, suggesting high local inflation.

There was no marked difference in the variance of price returns between U.S. dollar and local currency prices. If anything, despite appreciating local exchange rates in most of the countries examined in this study, price returns have varied slightly more since 2004 in local currency units than in U.S. dollars. This finding would suggest that, from the point of view of tackling price volatility, the problem faced by the governments in these countries was not much different from those dealing in U.S. dollars. While some correlation between local inflation (relative to that in the United States) and exchange rate variation over time is expected, the correlation is not necessarily systematic; these two factors thus may have separate effects. As shown in annex 4, average nominal cumulative cycles in the first subperiod are positive even in local currency for all the fuels. This finding, combined with the results reported here, would suggest that price smoothing based on long-term trends would have imposed a considerable fiscal drain.

5 Hedging

Role of Hedging

In response to the variability and unpredictability of the prices of oil and other commodities, futures markets have become widespread. In these markets, a contract can be entered into at a known price to purchase or sell a given quantity of the commodity in a given number of months. In this sense, they perform a similar function for agents as the long-term contracts that were in common use before the first oil price shock of 1973–74. The futures price essentially removes the risk associated with unknown spot prices, but does not eliminate the possibility of regret—for a seller, if spot prices rise (box 5.1), and for a purchaser, if they fall.

For example, on the last trading day of January 2007, the price of a futures contract for WTI crude for delivery in April 2007 was US$58.85 a barrel, for delivery in July 2007 was US$60.67, and for delivery in January 2008 was US$62.92. At that point (January 2007), the monthly average spot price for the same oil was US$54.51 a barrel. A company or government agency wishing to purchase (or sell) oil in July 2007 might have been concerned that if it waited until that date to purchase (or sell), the spot price then might be considerably higher (or lower) than the futures price for that month. It would thus be less risky to purchase (or sell) the futures contract so as to lock in a certain price. In July, the purchaser (or seller) would receive (or deliver) the oil paid for in the futures contract. If the spot price had actually fallen below the futures price by July, there would have been an opportunity cost of making the purchase on the futures market.

To provide insurance against the possibility of regrets, options on futures contracts can be used. A *call option* gives the holder the right, but not the obligation, to purchase a specific futures contract for a prespecified price (the *exercise* or *strike* price). The holder of the option has to pay a premium (the *option* price) to the writer of the option. A *put option* gives the owner the right, but not the obligation, to sell the specific futures contract at a prespecified price. The holder of the put option also has to pay a premium to the writer of the option. Options, which are traded on the same exchanges as oil futures, can be used to hedge physical sales or purchases while avoiding the risk of not being able to benefit from rising spot prices (for a physical seller) or falling spot prices (for a physical purchaser). Options are distinct from futures contracts in that they involve upfront costs (for the

Box 5.1

Sasol's Hedging Experience

The South African synfuel producer Sasol has been hedging a portion of its production since 2004 to protect the firm from downside risks so that it could fund its capital spending program. In its most recent hedge, effective for a year from May 2007 and 45,000 barrels a day of oil, Sasol would receive an average floor price of US$62.40 a barrel and, in return, would forgo the upside if the price of Brent crude oil exceeded US$76.80 barrel. This hedging strategy is reported to have cost Sasol R 3 billion (US$375 million at the exchange rate prevailing in March 2008) since inception. The amount includes projected losses from hedging for the second half of fiscal 2008 (April to March). These losses were previously estimated at R 854 million (US$110 million), but, with oil prices surpassing US$100 a barrel, some analysts believe the second half hedging loss could double (Business Report 2008).

holders of the option), which are incurred regardless of whether the option is actually exercised.

In practice, futures markets are not normally used to buy or sell oil for delivery. Instead futures (paper) contracts are combined with a physical sale of the commodity to provide a hedge against the uncertainty of prices in the future. Hedging crude oil and oil products is a well-established practice. Every day on the New York Mercantile Exchange (NYMEX) and on the Intercontinental Exchange (ICE), oil futures and options contracts are traded at a volume many times that of world oil daily consumption. Although a substantial volume of this trading is by buyers and sellers that neither produce crude oil and oil products nor consume them in their institutional capacity, much is nevertheless traded by those directly concerned with the oil industry. The primary purpose of futures markets is to allow one party to transfer some risk associated with future price changes to another party more willing to bear the risk. Actual producers and consumers of oil may wish to use this instrument in order to lower their exposure to the risks inherent in oil price volatility over time.

Because the volatility of oil prices—even when prices are averaged over intervals as long as a month—is considerable, producers face a substantial degree of risk in assessing their future revenues. The actual price received six months from now may be very different from the price received for current sales. When a government derives a sizable fraction of its budget revenues from the oil sector, or when the seller of oil is the government (for example, through its ownership of the national oil company), oil price volatility can have large effects on budget revenue forecasts and expenditure planning. Under these circumstances, reducing the risk of revenue fluctuations through hedging may be an attractive policy. And even if a government is not involved in the direct sale of oil (which is usually the case), it may nevertheless treat its oil revenue flow as if it were receipts from direct sale of oil by the government.

Similarly, purchasers of oil face substantial uncertainty about the future costs of such purchases. In several oil-importing countries, governments subsidize the price of oil by instituting fixed or formula-based prices and financing the difference between these and world market prices. The unexpected fluctuations in oil prices make the costs of such a policy highly variable and lead to budget planning difficulties for the government. Oil-importing companies can face the same difficulty, but if they are free to pass on the full price increase to consumers, they bear relatively little of the risk attached to price volatility. In this case, consumers face the full oil price risk, but, with the exception of large industrial consumers (such as power stations), their consumption levels will be too small relative to the fixed costs of entering the futures market to consider hedging as a risk-reduction instrument. However, the government of an oil-importing country that subsidizes fuel prices may use the futures market to hedge the cost of the subsidy.

The attractiveness of the futures market in reducing the risks attached to oil price volatility depends on several factors:

- The extent of the risks currently being faced in the oil market, which depends primarily on the volatility of oil prices but also on the correlation between the price of the oil product actually exported or imported and the price of the instrument traded on the futures market
- The extent to which risks can be reduced through futures trading
- The costs of futures trading
- The benefits of risk reduction relative to the costs of futures trading

Many writers have described the mechanics of hedging (see, for example, Bailey 2005), and its possible use by governments in the oil market has been discussed in several studies, including Claessens and Varangis (1991, 1994), Satyanarayan and Somensatto (1997), Daniel (2001), the Alaska Department of Revenue (2002), Devlin and Titman (2004), and the United Nations Conference on Trade and Development (2005). Until recently, however, only a few governments have acknowledged hedging oil exports or imports. Some national oil companies possibly had hedged as part of their daily business without the direct involvement of the government. Chile hedged oil imports in 1991 during the First Gulf

War, while Ecuador and Mexico have hedged crude oil sales at various times.

In the last couple of years, the steep rise and high variability of crude oil and oil product prices have led several governments in oil-consuming countries to consider the possibility of hedging. A previous ESMAP report (Bacon and Kojima 2006) noted that Pakistan had recently considered whether to hedge oil imports; there have been reports in other countries as well that this option has been under discussion. For example, in response to continuing high oil prices and concerns about swelling fuel price subsidies in Sri Lanka, the Ceylon Petroleum Corporation in February 2007 announced that it was pursuing a hedging proposal made by several banks (*Financial Times* 2007) and concluded its first hedging deal for diesel in April 2007 (*Daily Mirror* 2007).

Recent oil price behavior and the evolving nature of oil futures markets make consideration of hedges particularly timely. As chapter 3 indicates, oil prices have exhibited considerable volatility over the last few years, and it is possible that the correlations between futures prices of standard traded crude oil and oil products with those of actual imports or exports have also changed. This possibility has been analyzed by Switzer and El-Khoury (2007). These changes could affect the amount of risk being carried by importers and exporters, as well as the reduction in risk that hedging might make possible. With regard to changes in futures markets, not only has the total volume of transactions increased, but the number of transactions that relate to future prices with longer horizons (durations) has increased markedly. These developments may now provide risk reduction that previously was not available for oil-producing and -consuming countries that are concerned with volatility over periods of many months, in part because of the link to the budget process.

This chapter begins with a description of a simple hedging strategy. The analysis opens with the case of a short hedger—that is, an entity committed to make a physical *sale* at a future date. It then reviews the case of a long hedger, an entity committed to make a physical *purchase* in the future.[1] This provides a background against which a discussion of the attractiveness of the strategy can be evaluated. The use of options strategies are briefly outlined; for other, more complex, instruments such as swaps, see such sources as Bailey (2005). An evaluation of the attractions of hedging in current market conditions follows, and an assessment of the difficulties in instituting such a policy is outlined.

For ease of exposition, much of the analysis focuses on oil producers that need to sell crude oil, but, as explained in the chapter at various points, the case of oil consumers that need to purchase crude oil or oil products is symmetric: in a situation where the former would make a gain through a hedging strategy the latter would make an equivalent loss, and vice versa.

Hedging with Futures Contracts

Consider a single sale six months ahead by a producer of oil that regularly sells a known amount each month. A possible hedging strategy would be to sell now a futures contract, covering the same volume as the planned physical sales, that matures in six months. At the end of the six months, the producer would buy a futures contract for immediate delivery and sell the actual crude oil then available. The purchase of the immediate delivery contract would cancel out in volume the contract for sale taken out earlier and would involve no net commitment to deliver or purchase any physical oil on the futures market. This strategy is designed to exploit two features of the prices:

- The sale price of the six-month futures contract is known at the time of purchase and provides certainty on this part of the transaction.
- The futures price for immediate delivery should be identical to the actual market (spot) price then in effect for the commodity defined in the futures contract.

The second feature ensures that, for example, if the spot price falls during the six months, the futures price for immediate delivery at that time will also have

[1] “Short” and “long” here do not refer to time duration. A short hedger is a seller of the physical commodity; a long hedger is a buyer of the physical commodity.

fallen, so that the price received for actual oil sales is balanced by the price paid for immediate delivery on the futures market. As a result, the producer receives net the amount of the futures contract taken out at the beginning of the six months and has avoided the risks of the unknown price at the time of sale.

This simple strategy, the so-called perfect hedge, would remove all risk from the sale of the crude but would commit the seller to the price currently set in the futures contract. If spot prices were to increase during the six months, the seller would not be able to benefit from that increase. If spot prices fell, however, the seller would not be adversely affected by that fall.

The case of a long hedger that intends to purchase oil at some future date is symmetric. Consider a hedger buying a futures contract now with a six-month duration. Just before the hedge expires, an equivalent amount is sold through a futures contract for immediate delivery. At the closing date, the hedger purchases physical oil on the spot market at a price that will ideally equal the price at which the futures sell contract is liquidated. The overall cost of the purchase is the initial futures buy contract price, thus removing risk from the transaction. Again, if spot prices rose, the hedger would not be exposed to these (the sell hedge cancels out this effect); but if spot prices fell, the hedger would not be able to benefit from them since the price on the sell hedge would also have fallen.

A perfect hedge can rarely be implemented in practice, and the spot price received or paid is different from the price of the buy or sell hedge taken to close the futures market position. This difference, termed the *basis*, is not constant and introduces a source of risk to the hedging strategy. The reasons for the existence of basis risk, and why these two prices can differ, are given below.

- The futures contract for immediate delivery may not coincide exactly with the timing of the physical spot sale. The last trading day for a contract on NYMEX is the third business day before the 25th on the month preceding the delivery month. Thus, to close out a sell hedge due to expire in July, a buy hedge to expire in July must be executed in June. Although the futures price converges toward the spot price as the closing date approaches, this restriction gives rise to a risk that the two will be different.
- The location in which the physical product is to be sold may not be the same as the one where the futures contract is exercised. NYMEX crude oil futures contracts are based on the underlying restriction that any delivery of a physical that takes place because contracts have not been closed out will be at Cushing, Oklahoma. Due to differences in transportation costs, the price set for this location would not necessarily be the same as the price for an identical product at the same time in a different location. This is another reason why the futures price and the spot price received by the seller could differ.
- The futures contract is specified for a particular type of crude oil (or oil product). The major crude traded on NYMEX is WTI, while Brent blend is traded on the ICE. If the physical sale is of a different quality, this introduces another risk that the prices will diverge. Crude oil can vary in quality across different types; the prices of the different crudes are highly, but not perfectly, correlated (see Bacon and Tordo 2005 for quantitative correlations). The greater the quality difference from the standard futures crude, the more room for the margin between the futures contract and the spot price to change over time and to introduce another source of risk. Moreover, the quality of oil can change over the lifetime of a field, leading to variations in the basis risk that may not be entirely foreseeable.

Therefore, the use of a hedge reduces the risks from the sale price of oil itself, but introduces another risk from the existence of the basis. Because of this risk, it is generally not optimal to execute the so-called naïve hedge in which all the oil for sale (or purchase) is hedged. Instead, only a fraction of this physical total should be hedged on the futures market.

Hedging theory provides a model that determines the risk-minimizing hedge ratio—the proportion of physical oil for sale that should be hedged to provide the minimum overall risk. In this chapter, *return* is used in the conventional sense to mean a change in the value of an investment or portfolio over a given period of time. As explained in annex 5, the risk-minimizing hedge ratio is given by the coefficient obtained when regressing historical data for the change in spot prices on the change in the futures contract price over the hedge duration. The efficiency (effectiveness) of the hedging strategy—the percentage reduction in the risk compared to not hedging—is given by the squared correlation from this regression. Although a risk-minimizing hedging strategy does not take into account the expected return from the portfolio of hedged and unhedged sales, the expected return can be estimated by examining the past price history and taking the mean of the actual change in the value of the portfolio over the same historic period for which the risk-minimizing hedge ratio is estimated. This estimate can be compared to the mean of the actual return from the change in spot prices over the same period, which gives the return on an unhedged strategy. Annex 5 provides more details.

Hedging theory also considers the case where the expected return on the hedged portfolio is taken into account, and an optimal combination of return and risk is calculated. The choice of risk versus return is influenced by the hedger's preferences, as expressed through a risk parameter. Large values of the risk parameter lead the hedger to choose a strategy that reduces risk slightly relative to the benefits of a higher return. In the extreme case where the risk parameter becomes very large, the optimum hedge is identical to the risk-minimizing hedge. The optimal hedging strategy generally leads to a different hedge ratio, hedging efficiency, and expected return on the hedged portfolio from the risk-minimizing hedge.

For both the risk-minimizing hedge and the optimal hedge, an important distinction must be made between an ex post hedge and an ex ante hedge. An ex post hedge is a hypothetical hedge set up after the fact and asks what decision would have been optimal based on what actually came to pass. An ex ante hedge is how hedges are made in practice, before complete information about prices becomes available. In an ex post hedge, the risk-minimizing hedge ratio and return on the hedge are calculated from the actual data covering the period for which the hedge is to be evaluated.

In analyzing the period January 2000 to December 2003, for example, the risk-minimizing hedge ratio and expected return can be estimated from the price behavior during that period. These values (which in practice would not be known by the hedger until the end of the period) yield the ex post hedging ratio. Using a value of the risk-minimizing hedge ratio and expected return derived from data generated prior to January 2000 would generate an ex ante hedging strategy. If the risk-minimizing hedge ratio and expected changes in spot and futures prices over a given duration remain fairly constant over long periods of time, the ex ante and ex post hedge ratios would be similar. However, changes in the oil market suggest that this may not be the case, and that it would not be possible to obtain as good a performance as suggested by the ex post hedge calculations. In particular, forming expectations of the changes in spot and futures prices over the duration of the hedge is difficult. It is reasonable to assume that the futures price of oil for a particular date is the best estimate that can be made of the spot price that will be in effect at that time.

Costs of Running a Hedging Program

Several costs will be incurred beyond any profits or losses that may be made directly from a hedging program. Some of these are proportional to the size of the program; others have a large upfront component relating to program establishment which may deter governments from starting such a program.

On both NYMEX and the ICE, a single futures contract is for 1,000 barrels of crude oil. A producer wishing to hedge 50 percent of a production of 100,000 barrels a day would thus have to sell 1,500 separate contracts each month. Although revenues will be proportional to the production volume—as will most costs—the operation of the futures contract can entail large short-term financing requirements, as explained below.

Exchange Fees and Brokerage Fees

Exchanges charge a number of small fees, including a trading fee, a clearing fee, and—within the United

States, for example—the National Futures Association fee. Brokers acting as agents to make purchases or sales on the futures markets also charge fees. These fees are small on a per barrel basis when compared to the risk and returns per barrel that can be achieved.

Margin Requirements

To cover the risks of default, an *initial margin* is deposited with a broker (when used) upon entering into a futures contract. This amount is determined by the rules of the exchange and is presently about US$3,300 per contract of 1,000 barrels. Each day the price of the futures contract for the month in question changes, and the hedger has to "tail the hedge." Specifically, if the price of a buy contract falls below the initial price, the hedger has incurred a temporary loss in terms of what the contract could be sold for. This notional loss is debited against the margin account. The hedger will then face a "margin call" and have to deposit a sufficient amount to bring the margin up to its original level. Alternatively, if the price rises, the margin account will be credited with the increment. This procedure continues each day until the contract is closed out. Over the life of the hedge, the change in the futures price will exactly equal the difference in the value of the margin account between the opening and closing amounts less any margin calls.

A simplified example derived from Bailey (2005) illustrates the process. Assume that one buy contract for seven days into the future is purchased on day 1 at US$1,000. The margin requirement to be held by the broker is US$250, so the initial margin account has this value. Each day, the futures price for delivery on day 7 is assessed and the margin account is credited or debited with the day's change in value of the hedge. If the margin account is reduced in value below the initial amount, the margin call restores its value.[2] Table 5.1 simulates the daily prices, daily gains or losses, the margin account, and the margin calls. On day 3, the fall in price by US$50 takes the margin account below the initial margin, so there is a call for US$30. On day 4, a further fall in price drops the margin account (after replenishment to bring it up to US$250) down to US$210, so there is a further margin call. By the end of day 7, when the contract expires, there is a profit of US$10 on the hedge itself (the difference between the final price and the initial price). This profit is equal to the value of the final margin account, which is returned to the hedger less the initial margin and the sum of the margin calls. In practice, the margin account is credited with the interest earned on the balance during the period, so there is no financial cost to the hedger in making these payments.

Although the operation of the margin account has no long-term financial implications, it could present a government with a substantial short-term financing requirement. A series of price falls during the period could result in a substantial maximum temporary outflow. Similarly, for a sell hedger, a series of price increases could result in a substantial short-term financing requirement considerably larger than the initial margin payment. Even if prices eventually revert to a historic mean level, oil prices are characterized by runs of successive increases, as shown in chapter 2.

Table 5.1

Margin Account for a Buy Hedge

Day	Price (US$)	Daily gain/loss	Margin account	Margin call
1	1,000	n.a.	250	0
2	1,020	+20	270	0
3	970	−50	220	30
4	930	−40	210	40
5	950	+20	270	0
6	980	+30	300	0
7	1,010	+30	330	0

Source: Author calculations.
Note: n.a. = not applicable.

[2] In practice, a separate maintenance margin, which is lower than the initial margin, is used, and only when the account drops below this value is it replenished.

External Management Costs

Governments or national oil companies considering whether to initiate a hedging program are unlikely to have the expertise to design and implement an effective hedging strategy over a sustained period. Actual hedging strategies are usually much more complicated than a series of straight futures transactions as described above. Either an all-service broker or specialist adviser can be entrusted with designing a strategy to obtain the best execution, but this will add to the costs of the program.

It is recommended that governments new to hedging follow the market for a substantial period through a set of simulated hedges. Such simulations help governments track potential costs and benefits and learn the mechanics of hedging and the various strategies available. Only when a government is fully aware of the potential costs and benefits of hedging should an actual program be initiated.

Internal Management Costs

In order to manage a hedging program and to instruct and cooperate with the adviser or brokerage firm, the government or national oil company will likely have to establish a specialist division responsible for checking transactions, authorizing payments on margin calls, and instigating changes of hedging strategy. This action involves both the fixed costs of establishing such a division, and possibly extra costs of hiring specialist staff to run the operation.

Estimation of Hedge Ratios, the Efficiency of Hedging, and Returns from Hedging

The risk-minimizing hedge ratio for the sale of WTI crude was estimated for a number of different hedging durations for the period January 1987 to March 2007 (using monthly data), and for the three subperiods—January 1987 to December 1999, January 2000 to December 2003, and January 2004 to March 2007—identified in chapter 3. Futures prices were used in two different forms. The first form used prices quoted on the last trading day of the month for a specified month ahead; the second used the average end-of-day price for all days in the month for the specified month ahead. The latter represents the average cost of purchase during the month but does not necessarily represent the price available on any particular day, whereas the former represents a well-defined opportunity in futures markets. Spot prices were taken as the average for the months in question.

Contract durations of 3, 6, 12, and 24 months were examined. Because the longer horizon contracts set in a particular month mature at later dates, the last date for taking the initial contract for which the closing contract price was available at the time of this analysis, was July 2005. To ensure exact comparability for the third subperiod estimations, the risk-minimizing hedge ratios were all estimated for contracts beginning on January 2004 through July 2005. Three- and six-month futures contracts were quoted for the entire period studied, but 12-month contracts became common after January 1989 and 24-month contracts after January 1996. Therefore, for the whole period and for the first subperiod, the number of data points varies by hedge duration. For the second and third subperiods, the same number of data points were used for all hedges.

The risk-minimizing hedge ratios used in the calculations over the period are based on data from each period, meaning the values given are for ex post hedges. Table 5.2 presents the risk-minimizing hedge ratios (h^* as discussed in annex 5), the hedging efficiency (R^2), and the mean return for the period considered (y^*) for the hedged portfolio for these various parameters. The mean unhedged return (Δp) is also given for comparison, although it is not taken into account in determining the risk-minimizing hedge ratio. Returns are measured in U.S. dollars per barrel hedged. The equations from which these parameters are derived are shown in annex 5.

The analysis of hedging strategies over the period from 1987 to 2007 yields the following findings:

- The regressions for the maximum data span for each hedging horizon show that the risk-minimizing hedge ratio tends to increase with the length of the horizon. The minimum risk strategy for a two-year contract requires 92 percent of the crude available to be hedged.

Table 5.2

Ex Post Risk-Minimizing Sell Hedging for WTI Crude for Various Periods Based on Monthly Prices, January 1987–March 2007

Subperiod	Parameter	3 months (month end)	6 months (month end)	12 months (month end)	24 months (month end)	3 months (month avg.)
Jan. 1987–Mar. 2007	Hedge ratio	0.76	0.83	0.80	0.92	0.99
	Hedging return	0.32	0.08	−0.28	−1.79	−0.02
	Unhedged return	0.59	1.18	2.54	9.13	0.59
	Hedging efficiency	0.50	0.66	0.70	0.85	0.61
Jan. 1987–Dec. 1999	Hedge ratio	1.04	0.97	0.90	1.16	1.15
	Hedging return	−0.06	−0.36	−0.60	−1.91	−0.20
	Unhedged return	0.20	0.38	0.97	3.38	0.20
	Hedging efficiency	0.71	0.79	0.72	0.89	0.65
Jan. 2000–Dec. 2003	Hedge ratio	0.78	0.89	0.90	0.97	0.96
	Hedging return	−0.47	−1.54	−2.83	−4.21	−0.59
	Unhedged return	0.46	1.16	3.05	10.80	0.40
	Hedging efficiency	0.53	0.68	0.73	0.89	0.58
Jan. 2004–July 2005	Hedge ratio	0.49	0.24	0.17	0.65	0.75
	Hedging return	2.92	6.47	12.47	5.29	1.81
	Unhedged return	4.58	8.17	15.19	19.51	4.60
	Hedging efficiency	0.28	0.08	0.06	0.69	0.40

Sources: Month-end futures prices from Bloomberg.com and average month futures prices from U.S. EIA 2008a; author calculations.

Note: The month-end futures price is the closing price on the last trading day of the month in which the hedge is taken out. The average month futures price is based on the average of closing prices for every trading day in the month in which the hedge is taken out.

- The hedging efficiency estimated over the whole data period also increases with the length of the hedging horizon. A 3-month hedge removes 50 percent of the risk, while a 24-month hedge removes 85 percent of the risk.
- Hedged and unhedged returns are closer for the short-duration hedges; at the longest duration, the unhedged return is much greater than the hedged return, which shows a loss on the hedged portfolio. This disparity is due to the rise in spot prices through the latter part of the period—any amount of hedging reduces the gains that could have been made by waiting and selling only spot on the delivery date.
- The first subperiod confirms the results for the whole period, but at each horizon the risk-minimizing hedge ratio and hedging efficiency were greater than for the entire period. The estimated risk-minimizing hedge ratio is greater than unity in some cases, indicating that a risk-minimizing strategy would have hedged the whole portfolio.[3] Hedging efficiency increases with contract duration, while the gap between the hedged and unhedged returns is substantial especially for the longest duration hedge.
- The results for the second subperiod indicate that both the risk-minimizing hedge ratio and hedging efficiency increase with contract duration. The

[3] A risk-minimizing hedge ratio of greater than unity indicates that a risk-minimizing strategy would have hedged more than the seller had crude available to sell. It is assumed that the oil producer would not wish to take such an action.

gap between the hedged and unhedged returns increases markedly with the duration of the hedge. The increase in spot prices during this period is particularly large for the two-year hedge.

- For the most recent subperiod, hedging efficiency is low for all but the longest hedge, and the risk-minimizing hedge ratio shows no pattern with respect to duration. The unhedged return is extremely large for long duration hedges, so sell hedgers would have experienced large opportunity losses.
- The three-month hedge calculated from average futures prices produces a higher risk-minimizing hedge ratio and a lower hedging return than the three-month hedge based on month-end prices. Hedging efficiency and unhedged return are similar to those for the end-month prices.
- Although the risk-minimizing hedging strategy does not take return on portfolio into account, it can be seen that ex post hedges in all cases have lower returns than an unhedged portfolio. Because futures prices rose during the length of the hedge, the strategy of selling and then buying back the hedge to close out the position reduces the return of the portfolio. In all cases, the difference between unhedged and hedged returns increases with the length of the hedge. During the second subperiod, when oil prices were beginning their steep climb, futures prices rose rapidly during the period of the hedge: for long hedgers, the failure to see the future's higher prices would have resulted in a large opportunity loss relative to an unhedged portfolio.
- For long hedgers, the negative of the returns of the hedged and unhedged positions shown in table 5.2 are interpreted as the direct costs of the hedge. For example, a buyer of crude during the period from January 2004 to July 2005 using a 24-month hedge would have experienced a cost per barrel of US$5.29 through hedging; an unhedged buy would have resulted in a cost of US$19.51. These costs, like the returns of a sell hedger, are measured relative to the current spot prices prevailing each month at the time of taking out the hedge. For every subperiod and duration, the cost of the risk-minimizing buy hedge is lower than the cost of remaining unhedged. This effect is particularly strong for the longest duration hedge in all periods.
- The returns from hedging at all contract lengths indicate that, over the duration of the hedge, the futures contract underestimated the rise in spot prices that actually took place. This effect is most noticeable during the most recent subperiod where all durations show a substantial gap between hedged and unhedged returns.

These results from a risk-minimizing hedging strategy indicate that taking expected returns into account might go far in making the case for hedging. The risk-minimizing hedge is in effect identical to an optimal hedge when the risk parameter is so great that a large trade-off in return would be accepted for a small reduction in risk. The impacts of different relative preferences for risk are explored through the use of an optimal hedge, calculated for different values of the risk parameter.

As an example, the three-month sell hedge based on end-of-month prices for WTI crude is estimated and simulated over the period January 2004 to July 2005. This again is an ex post hedge using the estimated values of the optimal hedge ratio and mean change in futures prices derived from the same subperiod. The results of this hedging strategy are shown in table 5.3 for a range of risk parameters. Values of the optimal hedge ratio, the variance of the portfolio, and the return for the optimal hedge are shown. Values for the risk-minimizing hedge (where the risk parameter is set equal to infinity) and the return from the unhedged position are also included.

The calculation shows that the impacts of varying the risk parameter—unless it is very low—on the choice of optimal hedge ratio, return, and risk as measured by variance are small. However, the ability to forecast the average spot price return over the period and build this into the hedging strategy does allow a considerable reduction in risk to be achieved if risk is seen as highly important relative to return.

Thus far, the hedges considered have all been calculated for a seller of WTI crude, allowing removal of the basis risk element due to quality differentials. For sellers of other crudes, whose spot

Table 5.3

Optimal Three-Month Ex Post Sell Hedge for WTI Crude, January 2004–July 2005

Risk parameter	Optimal hedge ratio	Optimal return	Optimal variance
0.4	0.36	3.38	23.07
0.5	0.39	3.29	22.44
1	0.44	3.10	21.05
3	0.48	2.98	20.03
5	0.48	2.96	19.81
10	0.49	2.94	19.65
20	0.49	2.93	19.56
40	0.49	2.93	19.52
60	0.49	2.93	19.51
∞	0.49	2.92	19.48
Unhedged	n.a.	4.58	27.07

Source: Author calculations.

Note: n.a. = not applicable.

prices may not move as closely to crude futures as does WTI crude spot, the greater basis risk can tarnish the attractiveness of a hedging strategy. Data were available for a number of monthly average spot crude prices starting in February 1988, and the risk-minimizing ex post hedge was estimated for these 16 crudes for the whole period and the subperiods. The risk-minimizing hedge ratio and hedging efficiency are shown in table 5.4. The results of additional calculations for hedged and unhedged returns are given in annex 5.

The hedging performance of various crudes based on a six-month ex post hedging ratio reveals some important characteristics:

- The efficiency of hedging for all crudes is lower than that for WTI crude; the basis risk increases for crudes for which no futures contracts exist. This effect is particularly pronounced in the most recent subperiod.
- Hedging efficiency does not vary greatly among crudes in the first subperiod, but there are certain crudes for which the differences are more marked in the second and third subperiods. For Kole and Mandji, the efficiency falls to about 30 percent in the second subperiod.
- The risk-minimizing hedge ratio is near unity in both the first and third subperiods, suggesting that virtually all physical sales should have been hedged to minimize risk. In the second subperiod, the risk-minimizing hedge ratio is substantially lower for most crudes. The variations in hedging efficiency and the risk-minimizing hedge ratio suggest that a dynamic hedging strategy and alteration of the risk-minimizing hedge ratio as markets changed over time would have been useful.
- The unhedged and hedged returns (shown in annex 5) are similar to those for WTI crude for a six-month duration hedge. In the second and, especially, the third subperiod, unhedged returns are greater than hedged for sellers of crude.

Buyers or sellers of oil products can hedge certain products on NYMEX, which could enable importing governments to reduce the risk of future purchase costs. Because only certain specifications of these products are quoted on the exchange, there will be a basis risk element relating to the difference between the quoted quality and the imported quality. For example, for motor gasoline, the NYMEX contract is for reformulated regular gasoline; for heating oil, it is the "number 2" heating oil used in domestic and medium-capacity industrial burners. Contracts for reformulated gasoline ended in mid-2006 and were replaced by those for the gasoline blendstock for blending with ethanol. The risk-minimizing three-month hedge for these two products was calculated for the whole period for which data were available and for the subperiods identified above. The results are shown in table 5.5.

The performance of hedging oil products on NYMEX would have been similar to that of hedging WTI crude. In the earlier subperiods, the risk-minimizing hedge ratio is near unity, suggesting that hedging virtually all products for sale or purchase would have minimized risk. Hedging efficiency falls in the most recent subperiod and is lowest for gasoline,

Table 5.4

Ex Post Risk-Minimizing Six-Month Sell Hedge Ratio and Hedging Efficiency for Various Crudes, February 1988–December 2006

Crude, country	Feb. '88–Dec. '06 Hedge ratio	Feb. '88–Dec. '06 Hedging efficiency	Feb. '88–Dec. '99 Hedge ratio	Feb. '88–Dec. '99 Hedging efficiency	Jan. '00–Dec. '03 Hedge ratio	Jan. '00–Dec. '03 Hedging efficiency	Jan. '04–Dec. '06 Hedge ratio	Jan. '04–Dec. '06 Hedging efficiency
Brega, Libya	0.96	0.61	1.04	0.73	0.82	0.64	0.98	0.56
Cabinda, Angola	0.90	0.58	1.00	0.71	0.75	0.55	0.91	0.52
Cossack, Australia	0.97	0.61	1.00	0.74	0.90	0.59	1.00	0.56
Dukhan, Qatar	0.91	0.59	0.96	0.72	0.75	0.65	0.94	0.53
Es Sider, Libya	0.95	0.60	1.04	0.72	0.80	0.62	0.96	0.55
Forcados, Nigeria	0.99	0.60	1.07	0.73	0.80	0.62	1.02	0.55
Iran Heavy, Iran, Islamic Rep. of	0.85	0.57	0.95	0.71	0.66	0.51	0.86	0.52
Iran Light, Iran, Islamic Rep. of	0.89	0.58	1.00	0.71	0.69	0.53	0.90	0.54
Kole, Cameroon	0.99	0.59	1.06	0.74	0.68	0.30	1.06	0.60
Mandji, Gabon	0.97	0.58	1.03	0.71	0.65	0.32	1.05	0.60
Marine, Qatar	0.87	0.57	0.96	0.72	0.72	0.62	0.88	0.50
Murban, Abu Dhabi, UAE	0.91	0.59	0.97	0.72	0.77	0.66	0.94	0.52
Oriente, Ecuador	0.89	0.54	1.00	0.72	0.80	0.52	0.88	0.47
Saharan, Algeria	0.97	0.60	1.07	0.72	0.83	0.64	0.98	0.54
Urals, Russian Federation	0.90	0.58	1.04	0.69	0.69	0.54	0.90	0.54
Widuri, Indonesia	0.94	0.62	1.00	0.75	0.88	0.66	0.96	0.56
WTI crude, U.S.	0.82	0.67	0.99	0.79	0.89	0.68	0.71	0.67

Sources: Spot prices from Energy Intelligence 2008; author calculations.
Note: UAE = United Arab Emirates.

at only 33 percent. A sell hedger would generally have found that the return from an unhedged position was greater than that for a hedged position, while a buy hedger would have found the reverse. One exception is crude oil in the third subperiod, which shows that the unhedged return was lower at 2.29 than the hedged return at 2.44.

Use of Options

The use of options on futures contracts has become better established in recent years, but, although there is regular activity on the markets, there is little evidence that governments wishing to hedge oil imports or exports have begun making much greater use of this financial instrument. Nevertheless, an instrument that avoids large regrets could become increasingly attractive.

On any day in the market, call and put options for future months can be obtained. Although these can extend six years ahead, few deals are concluded on any day for more than one year ahead. The options contract offers a potential option-holder a menu of choices. For a wide variety of strike prices (the prices at which the holder will have the right to purchase or sell at the time of contract expiry[4]) the premiums to be paid for this right will vary according to market beliefs about future prices. Table 5.6 shows call options prices

[4] A European option gives the right to exercise the option only at its expiration, while an American option gives the right to exercise the option at any time until the expiration date.

Table 5.5

Ex Post Risk-Minimizing Three-Month Sell Hedge Ratio and Hedging Efficiency for Gasoline and Heating Oil on NYMEX, January 1987–April 2007

Fuel and dates	Hedge ratio	Hedging efficiency	Hedged return	Unhedged return
Gasoline (US¢/U.S. gallon)				
Jan. 1995–Mar. 2007	0.98	0.60	0.95	1.92
Jan. 1995–Dec. 1999	1.05	0.54	–0.36	1.37
Jan. 2001–Dec. 2003	1.03	0.58	–2.71	1.34
Jan. 2004–Mar. 2007	0.84	0.33	5.80	12.09
Heating oil (US¢/U.S. gallon)				
Jan. 1986–Apr. 2007	0.98	0.60	0.95	1.92
Jan. 1986–Dec. 1999	1.16	0.59	0.65	0.92
Jan. 2000–Dec. 2003	1.14	0.54	–2.54	0.38
Jan. 2004–Apr. 2007	0.84	0.65	5.99	7.85
WTI crude (US$/barrel)				
Jan. 1987–Mar. 2007	0.76	0.50	0.32	0.59
Jan. 1987–Dec. 1999	1.04	0.71	–0.06	0.20
Jan. 2000–Dec. 2003	0.78	0.53	–0.47	0.46
Jan. 2004–Mar. 2007	0.61	0.44	2.44	2.29

Source: Author calculations.

quoted on the NYMEX on October 11, 2007, when the spot price for WTI crude was about US$84 a barrel. The table indicates that a call option giving the right to buy WTI crude in December at a price of US$69 a barrel would have required a premium of US$11.71 to be paid, while an option with the right to purchase at US$79 in December would have required a premium of US$3.45. The very high premium attached to a strike price of US$69 indicates that market sentiment felt that the spot price at the expiry date would be quite high, so the options writer (the agent selling the call option to the holder) would require a large premium to offset an option price much below the expected spot price. The higher the strike price, the less likely the future spot price would be above this level and allow the premium to be reduced.

The option contract can be combined with the physical purchase in much the same way as a simple futures contract. For example, an agent that knows it will purchase crude oil in March 2008 could have purchased a call option in October with a strike price of US$77 a barrel, paying US$5.34 as the option price. As the expiry date approaches, the decision will have to be made as to whether the option should be exercised. Affecting the decision are two potential situations, as follows:

- *The spot price in effect at the time the agent is considering whether to exercise the option is above the strike price.* Assume a spot price of US$83 a barrel and a strike price of US$77 a barrel. In this case, it will be profitable to exercise the option since that is the less expensive means of acquiring the physical commodity. As described above, to obtain the guaranteed overall price, the agent must close the position on the futures market by selling a contract to expire on the contract expiry date, thus offsetting the position in the futures market. Since this sell price should be close to the spot price that will govern the physical purchase, the net cost is that of the options contract—which will equal the strike price plus the option price

(US$77 + US$5.34). The sum of these two can be greater than the prevailing spot price. However, because the options price has already been incurred, only the strike price is relevant in deciding whether it is better to exercise the option. As with simple hedging described above, there is a basis risk on this transaction in that the futures sell price, entered into to close the futures position, may differ from the spot price at the time of physical purchase.

- *The spot price in effect at the exercise time is below the strike price.* In this case, it is better to let the option expire and purchase crude on the spot market at this lower price. The total costs will be the sum of the option price (paid regardless of whether the option is exercised) plus the spot price at the time of the physical purchase.

Similar considerations govern the use of put options that might be utilized by an oil producer wishing to lock in a floor price for a future sale, while not missing the opportunity to benefit from an unforeseen increase in spot prices. The producer entering into a put option pays the option price to the writer. The option price increases at higher strike prices because the probability that the holder will choose to exercise its right to sell will be greater at higher spot prices. If the spot price ruling at the time of exercise of the contract is lower than the strike price, then the holder of the put option will exercise it in order to maximize the gains. If the spot price is above the strike price, the holder of a put option would allow it to expire.

In sum, an options holder can obtain a more favorable distribution of outcomes by allowing the option to expire in high-regret circumstances (a low spot price for call options and a high spot price for put options), but there is an additional cost—that of the premium—to be paid whatever the outcome. To obtain a large margin of protection against regrets (a very low spot price for buyers of crude) will require a large upfront premium, which will reduce the attractiveness of the strategy.

Table 5.6

European Call Options for WTI Crude on NYMEX, October 11, 2007 (US$)

Strike price	Option price for Dec. 2007	Option price for Mar. 2008
69.00	11.71	10.97
71.00	9.84	9.40
73.00	8.05	7.92
75.00	6.35	6.56
77.00	4.81	5.34
79.00	3.45	4.27
81.00	2.39	3.39
85.00	1.02	2.01
87.00	0.63	1.54

Source: Author calculations.

Issues in Operating an Oil Hedging Program

The primary purpose of an oil hedging program is to reduce the risks from the volatility of crude oil or oil product prices. Oil-producing nations, facing uncertain future revenue streams, could hedge revenues from future production, while importing countries could hedge purchases of gasoline or diesel. State-owned enterprises also may be large enough to engage in a systematic hedging program. The United Nations Conference on Trade and Development (2005) describes the possibility of a state transportation company using a swap agreement to reduce risks on the purchase of fuel supplies. Other agencies such as power companies may similarly wish to reduce risk by means of these instruments. To date, however, there is no evidence that governments and their agencies have begun making use of this financial instrument much more than in the past, and it appears that there are several factors to be considered before a government would be willing to institute such a program. If the main objective of the government is to stabilize public expenditure or the balance of payments, it would be more appropriate to find a hedging instrument that is highly correlated with variations in public expenditure or the balance of payments. Only when variations in the oil price are the dominant factor in their volatility will oil price hedging provide a large degree of risk reduction.

Degree of Volatility of Crude Oil and Oil Product Prices

The statistical tests reported in chapter 3 show that the volatility of crude oil prices, whether measured daily, weekly or monthly, was lower in January 2004 to March 2007 than in January 1986 to December 1999 and January 2000 to December 2003. Gasoline, diesel, and jet kerosene prices were slightly more volatile in the most recent subperiod; heating oil, residual fuel oil, and propane were less volatile compared to January 2000 to December 2003, but not January 1986 to December 1999. In virtually every case, volatility was higher in the second subperiod than from the beginning of the sample period to December 1999. The changes in volatility and in correlation between spot and futures prices resulted in a decline in hedging efficiency in the most recent subperiod for both crude oil and gasoline. The actual hedging efficiency for crudes and for oil products is not particularly high in any period (except for a hedge of two-year duration which reaches close to 90 percent in two subperiods); it is low for WTI crude and gasoline in the most recent subperiod. The basis risk is an increasingly important factor in the oil futures market, so the attractiveness of hedging as an instrument to reduce risk (as measured on an ex post basis) does not appear to have increased in the recent period of higher oil prices.

The calculations undertaken for hedging returns show that, during the periods considered and especially the most recent subperiod, a sell hedger would have been better off not to have hedged at all but to have just sold on the spot market and thereby benefited from the steady climb in prices. Conversely, a buy hedger would have found it much more attractive to have hedged during this period, locking in the futures prices which generally turned out to be lower than the spot prices in effect at the time of hedge closing. To illustrate, figure 5.1 compares monthly average spot prices of WTI crude with 6-month, 12-month, and 24-month futures contract prices; table 5.7 summarizes statistics on the data shown in the figure. Since 1986, futures prices proved to be lower than spot prices 63 to 79 percent of the time when futures prices were available for the specific duration. The percentage increases, and correspondingly the correlation coefficient with the current spot price decreases, with increasing number of months in the futures contracts. When data from January 2004 are considered, the percentage rises to as much as 100 percent for 24-month futures contract prices. That is, a buyer of WTI crude oil would have consistently benefited from locking into 24-month futures prices.

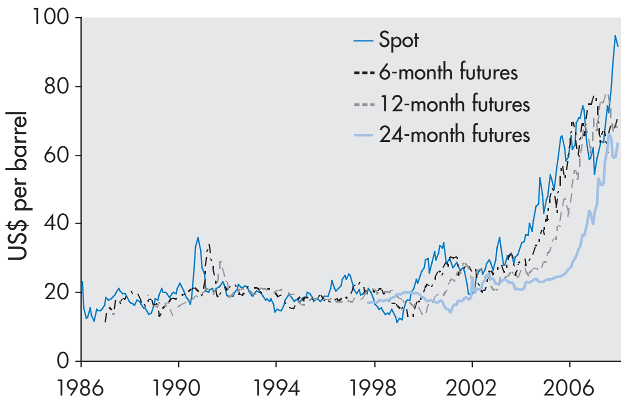
This ex post finding should not be taken as an endorsement of the use of futures markets to mitigate the adverse effects of large price increases. At the time of taking out the hedges, the futures prices may have been the best estimates possible of the spot price that would be in effect at the time of closing out the futures contract. Importing governments or their agents are unlikely to be able to make a systematically better estimate of the prices in the coming months than the market itself. Hedging is designed to remove risk and not to increase returns, and the ex post experience of a period of unhedged returns exceeding hedged returns is no gauge as to whether this will continue. For large oil-exporting countries with substantial experience in selling crude on the international market, it is more plausible that they on occasion may be able to make superior estimates of price movements in the coming months and hence be able to engage in a successful hedging program.

Duration of Available Hedges

The futures markets have seen a steady lengthening of the duration of futures contracts available. From the experience of the 1980s, when crude oil futures contracts stretched out only to six months, the maximum duration of a contract is presently around seven years, although not all months are traded at such long durations. The duration of contracts for gasoline and heating oil have also increased to around three years. This provides a much more flexible approach to hedging and the possibility of reducing risks over a longer period, as the superior performance of two-year futures contracts in reducing risk illustrates. However, during the periods analyzed, and especially the most recent subperiod, the unhedged return (for a seller) greatly exceeded the hedged return.

Figure 5.1

Spot and Futures Prices of WTI Crude



Statistic	6 mo.	12 mo.	24 mo.
% of months when futures prices were lower than current spot prices, entire period	63	67	79
% of months when futures prices were lower than current spot prices, since Jan. '04	78	74	100
Correlation with spot price, entire period	0.93	0.88	0.77
Correlation with spot price, since Jan. '04	0.81	0.80	0.69

Sources: U.S. EIA 2008a and Bloomberg.com; author calculations.

Note: Spot prices are monthly averages; futures prices are those quoted 6 months, 12 months, and 24 months earlier on NYMEX.

Basis Risk

For all crude oil and oil products, there is a basis risk which leaves a residual uncertainty about revenues to be received. Hedging efficiency calculations show that the basis risk is extremely large in the most recent subperiod, reflecting the fact that the futures price for immediate delivery (for the month ahead in which the contract was to be closed out) was not always close to the spot price in the delivery month.[5] The two-year hedge has the greatest hedging efficiency. The basis risk for crudes other than WTI (which forms the reference for NYMEX) is in most cases slightly higher than that for WTI, but this gap is particularly pronounced in the most recent subperiod. Gasoline and heating oil have a similar residual risk to that of crude. Hedging efficiency never exceeds 90 percent; for many durations and subperiods, it is below 70 percent, indicating the magnitude of residual risk even under relatively favorable circumstances.

Governments looking to hedge oil product imports should note that for certain products (kerosene and automotive diesel), there are no direct futures trades; consequently, a further basis risk would be involved if gasoline or heating oil futures were used to hedge these products. The correlation between, for example, spot kerosene and futures heating oil prices would clearly be weaker than that between spot heating oil and futures heating oil.

Actual Sale or Purchase of Physicals

The analysis of operations of a simple hedging contract described above implicitly assumes that the seller or purchaser of physicals will be making and financing the futures contracts through the broker. In practice, this is often not the case (see, for example, Gerner and Tordo 2007). For a producing country, the national oil company—if it is actually producing and marketing the crude—would be able to carry out both operations. In some countries, the national oil company or petroleum ministry will merely be receiving taxes and royalties on the sale of crude produced and marketed by international oil companies. Where production levels and plans are not directly controlled by the government, there are additional risks that inappropriate amounts might be hedged. For example, a shutdown or sudden decline in production not foreseen by the government could lead it to hedge more than was appropriate, with a possibility that its obligations through the closing-out buy hedge would leave it with a temporary financing burden. Moreover, since tax and royalty payments lag crude sales, revenue flow may be uneven to an extent that could not be removed by a simple hedging strategy.

Oil products may similarly lead to problems, even though governments rarely purchase these themselves. Private sector purchases of oil products in a country where government hedging is designed to smooth out the payment of subsidies through a price support scheme leads to the possibility that

[5] In practice, spot transactions are made on a particular day; thus, the monthly average price is not necessarily representative of a particular transaction.

changes in private sector purchase plans would result in inappropriate quantities being hedged by the government.

Financing Margin Calls

The operation of the futures market requires the hedger to be able to finance daily margin calls, depending on the day-to-day price movements of the contract. Some of these daily movements have been large in recent years, and runs of successive price increases are not uncommon. Chapter 3 indicated that lengthy runs of cumulative positive or cumulative negative deviations were common even when looking at the deviation of prices from a trend (the Hodrick-Prescott filter), and that in the extreme cases these lasted several years. If hedging decisions were made on the basis of the filtered prices, the cumulative margin calls could be large and persistent. Even though the margin is eventually returned and earns interest, the temporary financing requirement could prove unmanageable for the government. The resulting short-term and immediate financing requirement when a large volume of crude is being hedged would result in highly variable outflows and inflows to the government agency taking out the hedge. This lack of predictability could be difficult to handle in countries where there is only weak cooperation between the hedging agency and the central bank. In addition, extremely careful monitoring would be needed to ensure that appropriate amounts are transferred.

Oversight

Because an actual hedging program requires specialist knowledge, oversight for the government becomes both important and difficult. If the hedging program is carried out by government employees—whether in the treasury, a state company, or a dedicated agency—a layer of oversight will be needed with the authority to review all documents and trades. Agents given too much latitude in running the hedging program may be able to conceal for a long time trading mistakes that have been made. There are incentives to cover up losses by making even riskier trades in the hope of incurring an offsetting profit. Recent examples in the private sector of single individuals apparently responsible for large losses serve as a warning as to the difficulty of maintaining adequate oversight.

Legal Restrictions

In some countries, state oil companies or other government agencies are not permitted to use futures or options because of their association with purely speculative activities. Where such a ban exists, the government would have to consider whether it wished to change the law and how to do so in a way that would limit risk from speculative trading by its agents. Commodity hedging programs may require the passage of legislation authorizing the program and establishing boundary conditions for its implementation. Although active hedging may be more effective than rule-based hedging, it might require a higher degree of autonomy on the part of the executive branch. Because spending authority is normally established by an existing budget law, the type and efficiency of hedging strategies available to a government may be limited.

Political Accountability

Ultimately, as numerous writers have pointed out, the government is responsible for the success or failure of a hedging program. When prices rise, the use of a sell hedge can result in missing the opportunity to achieve higher sale prices by avoiding the futures market and selling on the spot. The government could come under pressure to explain why its revenues have not risen in line with world oil prices. The extra certainty in the revenue flow provided by the hedge may not satisfy those who do not have to manage budget expenditures. Similarly, a buy hedger, in a period when product prices actually fall, may pay more through the hedge than could have been achieved by waiting to purchase. If the government's critics were unaware of what could have been achieved through a hedge when product price had risen, there would not be a symmetric complaint concerning the government's lack of hedging to have captured such gains. Any asymmetry of such pressure would reduce the likelihood that a government would be willing to undertake a hedging program. It also suggests that if a government were to consider doing so, a widespread public education program should be conducted, as was done by the state government of Alaska when it was considering whether to hedge oil production. (In the end, Alaska chose not to hedge.)

Some of these concerns can be addressed by the use of options, which permit a seller to take account of prices higher than initially anticipated or, for a buyer, prices lower than anticipated. However, the size of premiums that may have to be paid to obtain a substantial degree of cover against these possibilities could seem expensive in retrospect and provoke further opposition.

Lack of Models

For some governments, the lack of well-known and successful examples in other countries that could be studied and copied is a considerable drawback. Learning from the actions of others can be particularly useful for such a complex operation, and one in which large sums of money are involved. The fact that governments do not now appear to be hedging sales or purchases on a broad scale indicates that hedging is not a simple solution for dealing with problems of oil price volatility.

Even very large and sophisticated companies have on occasion lost large sums of money through the use of derivates. Bailey (2005) describes the case of Metallgesellschaft Refining and Marketing whose business centered on buying oil products (diesel, heating fuel, and gasoline) at spot prices and selling to customers on long-term contracts. The company also traded in futures and swaps for which the underlying assets were oil products. In late 1993, its losses on this business were more than US$1 billion, of which a substantial fraction could be attributed to the injudicious use of derivates.

6 Security Stocks and Price Hikes

In the absence of buffer stocks, physical disruptions to supply can cause temporary sharp spikes in end-user prices. As a result, stocks of crude oil and oil products have been a common feature of the oil industry worldwide. Coordinated use of stocks to smooth price volatility is not unique to oil, and efforts have been made to do the same for other commodities (box 6.1).

Supply Disruptions

In countries that import or produce crude oil to supply domestic refineries, crude stocks provide a necessary buffer to allow the refinery to be supplied at a constant rate even if there are fluctuations in production or imports. Delays in shipments or unloading are fairly common but are not normally protracted; a modest amount of stock is thus sufficient insurance against this type of supply disruption.

Similar considerations explain why companies hold stocks of oil products. Demand may experience a sudden surge or supply a temporary dip (for example, from an unscheduled refinery shutdown). An adequate level of commercial stocks ensures that sharp price spikes, rationing, or both can be avoided. In markets with several sellers, companies have a strong incentive not to run out of supplies, since a temporary inability to supply the market may lead to a permanent loss of business to reliable-appearing rivals able to provide supply. Again, such disturbances tend to be small compared to sales, so stocks need not be very large. Carrying stocks incurs costs—both in terms of the capital required to construct additional storage facilities (tanks) and the interest costs forgone on the value of the crude oil or oil product held in stock. These costs need to balanced against possible benefits. Where the likelihood of a disruption is higher (for example, where alternative supplies cannot be brought in quickly, as in land-locked countries with no pipeline infrastructure), or where the costs of being short are seen by a company as being more damaging, the amount of precautionary stock held is likely to be higher.

On rare occasions, the oil market suffers large disruptions of either an internal or external nature. A lengthy shortage of crude oil or oil product can be highly damaging to an economy, as users of oil products face rationing or even the complete unavailability of a crucial input. Two significant users of crude oil and oil products are the power sector—when electricity is generated from fuel oil or

Box 6.1

Experiences with Other Commodities

As noted in chapter 1, price volatility is not confined to the oil sector. For example, there have been numerous attempts to smooth prices for agricultural and mineral commodities through various stock schemes. Some of these schemes have been designed to stabilize the world price through stock additions or withdrawals, while others have focused on internal price adjustment to consumers. Upon reviewing the literature, Dehn, Gilbert, and Varangis (2005) concluded that, for export commodities, the crucial problem was that there were overoptimistic price expectations, leading to eventual bankruptcy of many of the schemes. Although the current era of high oil prices is different from earlier episodes of falling export prices, the difficulty of predicting the general level of future prices is common to both oil and other commodities, and mistakes in such forecasts can be just as expensive now as they were earlier.

diesel—and the transport sector. Because power and transport typically play major roles in the production structure of an economy, a complete disruption of supply would have great adverse effects on the economy.

In the case of the power sector, there may be excess capacity of other forms of generation that can be run more extensively. Diesel may serve as a backup fuel to fuel oil; it is also used for the small generators used to supplement grid supply, which is subject to outages. If the country were to experience shortages of both fuel oil and diesel, the costs to the economy would indeed be large. In many countries, there are no alternative fuel sources available in the short run, and rationing would have to be imposed. The inability to obtain continuous power supply—especially if unanticipated—can impose very high costs on businesses that depend on power as a key input. The costs of unserved power are often estimated as vastly exceeding the costs of served power.[1]

In the transport sector, which covers goods transport (trucks and rail) and passenger transport (buses and cars), there are no short-run substitutes available when a disruption in oil product supply occurs. Rationing may be used to direct limited supplies to priority uses—such as away from private car use to public transport—but there will inevitably be a loss of production and welfare.

In practice, major disruptions have rarely resulted in complete unavailability of oil supplies, but rather in price spikes when reductions in supply have forced prices up. This was the case in Zanzibar when a cargo failed to arrive on time in 2005. In other cases, however, inadequate transport capacity for alternative sources of crude oil or oil products has led to both markedly higher prices and actual physical shortages, as experienced in 2005 by copper mines in Zambia. In that case, fuel oil shortages were caused by a shortage of rail tankers, and mines were forced to cut back copper production drastically or stop production altogether (Bacon and Kojima 2006).

On the global front, Leiby (2004) and Harks (2003) provide details of major oil market disruptions between 1950 and 2003; this is summarized in table 6.1.

IEA Response

Faced with the possibility of a large supply disruption and the associated spike in international oil prices, many governments have established strategic oil reserves. In this regard, the member countries of the International Energy Agency (IEA) created the International Energy Program, which includes rules for the amount of oil stocks to be held by member countries and rules for releasing such stocks onto the market. The arrangement requires that each member hold stocks equivalent to at least 90 days use of net

Table 6.1

Types of Oil Market Disruptions, 1950–2003

Type	Number	Duration (months)	Size (% of world supply affected)
Accident	5	5.2	1.1
Internal political struggle	9	6.5	2.3
International embargo/economic dispute	4–6	11.0 (6.1[a])	6.2
War	4–7		
Total number, average duration, and average size	24	8.1 (6.0[a])	3.7

Source: Leiby 2004.

Note: The duration and size of international embargoes and wars are combined here. Some of these events were difficult to classify, affecting the data in the number column.

a. Excluding 44 months of Iranian oilfield nationalization.

[1] Estimates for the costs of unserved power vary widely and depend on the mix of household and business users. The *East African* (2000) quotes figures for Kenya of between US$0.50 and US$0.80 per kilowatt-hour for unserved power, while the Energy and Resources Institute (TERI 2001) estimates the production loss in two Indian states between Rs 7.2 and 24.7 (US$ 0.15 to US$0.52 using the average exchange rate in 2001) per kilowatt-hour.

imports (see Hale & Twomey Limited 2005 for an operational discussion of this arrangement in New Zealand). Such stocks may be held by the government directly, or companies can be mandated to hold certain amounts of stocks beyond their normal commercial levels, as in Japan and the Republic of Korea.

Under the original Agreement on an International Energy Program, stocks could be released if one or more members sustained a reduction in the daily rate of their oil supplies at least equivalent to 7 percent of the average daily rate of their final consumption. The agreement was complemented in the 1990s by the Coordinated Emergency Response Measures, which provide a rapid and flexible system of response to actual or imminent oil supply disruptions, including supply reductions below 7 percent. The agreement was superseded in the 1990s by the Coordinated Emergency Response Measures, which is a consultation process among members of the IEA on whether it is appropriate to recommend a coordinated stock drawdown. As discussed by Emerson (2006, p. 3380), this provision has rarely been used, partly because "strategic oil reserves were to be saved in case they were more urgently needed later on."

At the same time, it has become clearer to policy makers that oil security is less a matter of volume than of price. Indeed, Taylor and Van Doren (2005) concluded that the costs of running the U.S. Strategic Petroleum Reserve had largely outweighed its benefits, and that this was likely to continue to be the case in the future.

The use of security stocks to provide temporary domestic supply in the presence of a global supply disruption will depend on how such a disruption is defined. The IEA approach is to work through its governing board to determine whether an actual or potentially severe oil supply disruption is occurring, and, if so, to recommend to member countries to take a number of actions including stock drawdown. Such an approach is quite distinct from a scheme that is responsive only to price changes. For example, the steady run-up in prices during the 2004–07 period, caused by market sentiment rather than a major and unanticipated reduction in global supply, did not trigger an IEA stock release.

The use of security stocks to smooth the effects of high international prices has attracted some attention. On two occasions, the United States has released stocks to mitigate high price levels in an action independent of formal IEA criteria. The European Union considered, but did not legislate, a directive that would have made price smoothing a direct target of stock use. If a large stockholder or a bloc of countries such as the IEA members were to release stocks onto the market, there could be two effects on prices. First, the extra supply could be sufficiently large relative to global supply so as to lower the market-clearing price. Second, the willingness to respond in this way could persuade those trading or hedging on the oil markets that higher prices will be met with stock drawdowns, thus reducing the chances that prices will rise further.

Implications of Security Stock Holding

As a result, the mere existence of the security stocks means that futures prices are less likely to be driven up when there is a perception that the market will become tighter. Such a large-scale stock drawdown creates important externalities for consumer countries that did not reduce stocks, since they benefit from the general lowering of oil prices. This is due to the global nature of the oil market whereby a shock to one part of the market is quickly reflected in prices throughout the market.

For a small country or one whose stocks are not large by global measures, stock releases could not be large enough to have a material effect on global oil prices. However, such stocks could be sold into the domestic market below the import price, thus protecting consumers in part from the impact of the international price rise. The government might wish to protect only certain groups (such as the commercial transport sector through its purchases of diesel), or it might wish to provide some price protection to all members of the society. To achieve the latter end, the government would have to mandate a price at which all supply, whether from imports or stocks, would have to be sold in order to avoid only select purchasers benefiting from the stock release.

To operate such a scheme, the government has to purchase stocks when prices are relatively low, store them until needed, and then release some onto the market at times of higher prices. This cycle has to be repeated if the scheme is to have a long-run effect. The timing and amount of purchases and releases are critical, as are the costs of holding the inventory.[2] Brathwaite and Bradley (1997) analyzed the operation of such a scheme for California, assuming that costs of refilling would be less than the depressing effect on prices of the subsequent stock release, and that release and refilling would occur each year. Their study targeted a decrease of US$0.12 a gallon (US$0.032 a liter) below market prices, and found that, if prices during restocking at annual intervals rose by more than US$0.02 a gallon (US$0.005 a liter, or US$0.84 a barrel), the scheme would not be worthwhile.

The issue of how to purchase oil to place into the security stock has been analyzed by Yun (2006), who evaluated various hedging strategies for purchases. The basic scenario assumed that when the oil price was higher than normal, stocks were released; and, simultaneously, the stockpiler was assumed to buy forward in times of low oil prices to protect against price increases during the refilling period. More complex hedging rules were also considered. However, the study did not consider the more realistic case of the stockpiler considering whether to replenish at a given moment depending on prevailing prices.

As chapters 3 and 4 show, crude oil and oil product prices appear to have become nonstationary in recent years and do not exhibit strong mean reversion. Consequently, the government often may have to wait a lengthy period before it can refill at prices that seem economic. Moreover, there is a distinct risk that the inventory might be filled at a price that turns out to be higher than subsequent market prices. This circumstance would mean either that stocks would have to be sold at a loss, or that a large inventory would have to be financed for a lengthy period. A formal analysis of the optimal operation of a commodity inventory when prices are stochastic but mean-reverting is provided by Secomandi (2007).

Any scheme with given rules for the purchase, storage, and release of oil in relation to price signals could be mirrored by a "virtual" stock in which the government, instead of purchasing oil, put an equivalent amount of money into a dedicated account. When the rules indicate that oil should be released onto the market at prices below the international price, money would be released from the fund to lower the prices charged relative to those paid for the import of crude oil or oil products. The basic features of the operations of a security stock scheme designed to smooth domestic prices are illustrated by a simple two-period example.

The Operation of a Two-Period Price-Smoothing Security Stock Scheme

Two different schemes are illustrated: scheme A uses physical stocks that are purchased, stored, and then released; scheme B involves "virtual" stock, in that cash is provided by the government to lower oil prices in the country when international prices are too high. In both cases, the consumption of oil products in the country is 40 units per period. Two scenarios for international prices are considered. In both, the international market price (paid to import oil) is US$40 per unit in the first period. In the second period, alternatives of US$60 per unit or US$35 per unit are considered. The cost to the government of storing one unit of oil for one period is 5 percent of the value of the stock held.

Scheme A, the physical stock scheme, is governed by the following.

- If the price is less than US$45 a unit in the first period (floor trigger price), the government will buy 20 units in the first period and store them.
- In the second period the government will release 20 units from stock, if available, when the price is above a trigger of US$55 a unit (ceiling trigger price).
- The price charged to consumers during a stock drawdown period will be the weighted average of the amount released from the stock valued at the ceiling trigger price and the balance purchased by companies valued at international market prices.

[2] DynMcDermott (2005) quotes US$3.00 a barrel per year for the Japanese oil reserves, US$1.60 for the European oil stockpile, and US$2.40 for U.S. industry stocks.

A market unit price of US$40 in the first period is below the floor trigger, and the government purchases 20 units at a cost of US$800. If the international price rises to US$60 in the second period (above the ceiling trigger), the government releases the 20 units from the stock at a price of US$55 per unit to the companies. The companies then sell 40 units priced at US$57.50 a unit, which is the weighted average of the international market price and the stock sale price: ([US$55 × 20] + [US$60 × 20]) ÷ 40. If the price instead falls to US$35, the government continues to hold the stocks.

In scheme B, the virtual stock scheme, whenever the unit price of oil rises above the ceiling trigger price of US$55, the government offers a cash transfer to the companies sufficient to allow the price to consumers to be set at the mean of the international market price and US$55. In the first period, the government takes no action and incurs no costs. In the second period, if the international price rises to US$60, the government provides US$2.50 for each of the 40 units sold, at a cost of US$100, allowing the market price to be US$57.50. If prices instead fall to US$35, the government takes no action.

In both cases, the consumers face the same prices and therefore are indifferent between the two schemes. When the government caps the price, the benefit to consumers is US$100 in total (US$2.50 per unit × 40 units). On the other hand, the government faces different costs in the two schemes, as shown in table 6.2.

Using physical stocks, the government can benefit from capital appreciation if prices rise and can pass these benefits on to consumers. The net position of the government depends on the magnitude of the price change and the costs of storage. If prices fall, the government suffers a capital loss and also has to pay for longer storage. If the government instead uses a virtual stock scheme, the cost will only be the amount of subsidy provided when the price is high.

The foregoing example shows that a virtual security stock scheme can protect consumers but will be more expensive to the government in times of rising oil prices, which is when such a scheme is needed. The capital gain on physical stocks is not available to help finance the lowering of prices when they are deemed undesirably high. Viewed in the long run, however, the situation may be different. If prices are equally likely to fall as to rise at any moment, then a security stock scheme would suffer capital gains and losses equally, and incur the costs of storage and interest forgone. However, security stocks can be used in the rare event of an unavoidable shortage that cannot immediately be met by paying higher prices and are clearly superior to the use of a virtual stock, which would be available to

Table 6.2

Costs of Security Stock Operations in Two-Period Case

Scheme	Period	Action	US$60 per unit in period 2	US$35 per unit in period 2
A	1	Purchase/sale costs	−800	−800
		Storage costs	−40	−40
	2	Purchase/sale costs	1,100	0
		Storage costs	0	−40
		Current value of remaining stock	0	700
	Both		260	−180
B	1	Purchase/sale costs	0	0
		Storage costs	0	0
	2	Purchase/sale costs	−100	0
		Storage costs	0	0
	Both		−100	0

Source: Author calculations.

transfer money to consumers but would be unable to meet any absolute physical shortage caused by some disruption in the supply chain.

The design of a security stock scheme to be used to combat higher prices requires several determinants.

- *The nature of the price event to be ameliorated.* Security stocks can protect against two scenarios. One is a temporary disruption in the market in which prices suffer a very large but short-lived spike. Such an occurrence is rare. The other scenario is a period of a more prolonged large price rise. In this case, it is important not to dispose of the whole stockholding in one period, because of the risks that high prices will continue for some time.
- *The maximum size of the stock*. The stock held should be in proportion to the normal rate of consumption of oil products. The IEA's recommendation to hold the equivalent of 90 days net imports as security stocks reflects this consideration. The larger the stock, the greater the impact it can have on reducing a period of high prices—but the greater the risk of a large capital loss if prices fall. Also, the carrying costs of storage will increase with the size of the stock.
- *The floor trigger price below which purchases would be made if the stock is not full.* The government has to decide on a price that is lower than the expected future shock price in order to be able to purchase and resell at a profit. If this floor price is too low, the stock may never be filled; if it is too high, gains from selling may be small and will not offset the costs of running the scheme.
- *A ceiling trigger price above which sales would be made.* The ceiling trigger price is a price that is thought to be harmful and at which amelioration will provide substantial benefit. When it is set high, the stocks would rarely be used; thus, the government would be able to benefit from buying low and selling high less often. The choice of ceiling price should be closely related to the overall strategy. If the rare but extreme event is the target, the ceiling price would be correspondingly higher.
- *The sales volume per time period to be made when the ceiling trigger price is exceeded*. The maximum volume to be released each period has to be sufficient to make a meaningful reduction in consumer prices possible. However, a large release relative to the size of the stock could make a large downward adjustment to prices possible only for a very short period and reduce the opportunity to have further stock on hand against the possibility that prices would temporarily rise even further.

Simulation of a Security Stock Scheme between 1986 and 2007

A simulation of a physical security stock scheme illustrates some of these issues and shows how choices of the key parameters affect the scheme's overall performance. The history of oil prices between 1986 and 2007 provides the opportunity to simulate the operation of a security stock in two rather different contexts. Between January 1986 and December 1999, the average monthly price of WTI crude was US$19 a barrel and was scarcely higher at the end of the period than at the beginning. However, from September through November 1990 oil prices spiked, reaching a peak of more than US$36 a barrel. A very different pattern was in evidence between January 2000 and March 2007, during which time oil prices climbed steadily and ultimately more than doubled. A simulation of month-by-month government purchases or sales, depending on international market prices and the amount already in stock, is described below.

Security Stocks and a Price Spike (January 1986–December 1999)

A simulation for the first period was carried out with the assumption that the stocks would be used only in the case of a truly exceptional market price increase. Based on the experience of prices over this period, an exceptional event was defined as one that could be expected, on average, once in 100 months (once every eight years). This exceptional price corresponded approximately to US$29 a barrel.[3]

[3] The mean of log prices was 2.930 during the period, with a standard deviation of 0.188. The distribution of log prices was approximately normal, and the value of a one-sided normal distribution with a probability of 1 percent is 2.33. Hence, the critical log price is (2.93 + 0.188 × 2.33).

Operation of the security stock is governed by the following:

- The monthly rate of consumption is 1 million barrels of oil.
- The maximum monthly purchase into stock is 1 million barrels.
- The maximum stock is three months' worth of consumption at 3 million barrels.
- If a decision is taken to release oil from the stock, the monthly release is 750,000 barrels.
- The maximum floor trigger price for purchase is US$17 a barrel.
- The sale price for stock release is US$29 a barrel.
- During stock release, consumers pay the weighted average of released stocks (at US$29) and the then-prevailing international market price, the weights being three to one in this illustration (see below).
- The monthly interest rate is 0.8 percent (10 percent a year compounded).
- The costs of storage are US$0.20 per barrel per month.

The baseline operation of the security stock scheme is simulated using monthly prices of WTI crude. The initial value of the stock is zero. The simulation runs from January 1986 until the end of December 1999. The stock would have been filled completely between February and April 1986, when prices were low. No further movement would have taken place until September to November 1990, when a stock release takes place, leaving just 750,000 barrels in store. The stock would then not have been refilled until the months of November 1993 to January 1994, when it would have been completely refilled. It would then have remained full until the end of the period. This scheme, with three consecutive large monthly drawdowns (three-quarters of monthly consumption, and hence the relative weights of three to one) was designed to have a large moderating effect on prices when the international market price spike was exceptional. During the 14-year period, there were just three months when the price rose sufficiently to stimulate a stock drawdown. However, had world prices skyrocketed between November 1990 and November 1993, this country would have been without much protection.

The cumulative monthly expenditure on the scheme—including purchases, interest, and storage costs and subtracting the values of sales—is tabulated to identify the maximum resources the government would have had to devote to the scheme, before allowing for unsold stock valued at the current market price at the end of the period. During the period, the cumulative financial outlays by the government change depending on purchases and sales. If there are positive stocks at any time, these would provide a total or partial offset to these financial outlays. The net cost to the government at the end of the period is the cumulative financial outflow—that is, purchases less sales, plus costs, less the closing value of unsold stocks. The financial performance of the scheme is shown in table 6.3.

The security stock performed as planned, seeing releases in just three months. During those months, the price charged to consumers on average would have been US$3.70 below the international market price. In October 1990, when international prices peaked at US$36 a barrel, the sales price to consumers would have been US$30.70. The terminal net cost to the government of running the scheme would have been US$31.1 million, while the total benefit to consumers would have been relatively

Table 6.3

Costs and Benefits of a Security Stock Scheme Operated January 1986–December 1999

Monthly release (barrels)	Max. buying price (US$/barrel)	Selling price (US$/barrel)	Final net cost to gov't (US$ mil.)	Benefit to consumers (US$ mil.)	Max. financial exposure (US$ mil.)	End-of-period stock (mil. barrels)
750,000	17	29	31.1	11.2	109.4	3.0

Source: Author calculations.

small at US$11 million. The government's financial outlays would have reached the maximum value of US$109.4 million at the end of the period, but could have been partially offset by selling the stocks at the then-current price.

Security Stocks and a Sustained Price Rise (January 2000–March 2007)

The second detailed simulation covers a period in which prices rose and stayed high for a sustained period. It is assumed in this case that the objective is to offer some relief to consumers but to keep sufficient reserve in stock to maintain this for several periods if necessary. Several different sets of operating conditions are considered. First, the floor trigger price is set at US$35 a barrel and the ceiling trigger price at US$65, to give the government the opportunity to buy at low prices and to sell at higher—but not necessarily extreme—prices, as experienced during the period. For this price range, three different sales policies of increasing monthly amounts are considered, ranging between 150,000 and 500,000 barrels per month. Two additional trigger price scenarios are considered, one with a narrower band between buying (US$40 a barrel) and selling (US$55 a barrel) and the other with a wider band (US$30 a barrel for purchase and US$70 a barrel for release). The other factors are kept the same as in the price spike simulation. The price to consumers is the weighted average of the trigger release price and the international market price, with the weights being determined by the size of the stock release relative to the monthly demand. Had the same criterion for setting the ceiling trigger price as that in the first period been used, the ceiling trigger price would have been US$89 a barrel.

In the base case (US$35 and US$65), with a sale amount of 150,000 barrels, the stock would have been filled during the first three months of 2000 with no change until September 2005, when the first drawdown would have occurred. There would have been further releases in January 2006, and then every month from April until August 2006.

The financial performance of the scheme under different assumptions is shown in table 6.4. In the base case (the first three rows in the table), the scheme with the largest monthly stock release would have brought the largest benefits to consumers and to the government through its ability to sell large amounts at peak prices. Had the scheme been extended beyond March 2007, the third scheme in the table would have had no further stock to combat even higher prices. Because world oil prices have not fallen to the maximum selling price of US$35 a barrel since, this scheme would have ceased to operate short of changing operating rules.

At a release level of 250,000 barrels, a narrow price band would have given larger benefits to consumers, while a wider price band would have given the least protection to consumers. For all three price bands at this stock release level, the government would have experienced a small net cost or even returned a net gain.

Table 6.4

Costs and Benefits of a Security Stock Scheme Operated January 2000–March 2007

Monthly release (barrels)	Max. buying price (US$/barrel)	Selling price (US$/barrel)	Final net cost to gov't (US$ mil.)	Benefit to consumers (US$ mil.)	Max. financial exposure (US$ mil.)	Months of stock release	End-of-period stock (mil. barrels)
150,000	35	65	1.9	5.2	172.4	7	1.95
250,000	35	65	–7.2	8.7	172.4	7	1.25
500,000[a]	35	65	–24.8	13.4	172.4	6	0.00
250,000[a]	40	55	0.9	24.0	168.5	12	0.00
250,000	30	70	–1.0	2.31	182.7	4	2.00

Source: Author calculations.

a. Stocks were exhausted by the end of the simulation period.

The second scenario indicates that a security stock operation designed to ameliorate the impact of higher prices on consumers can be successful during a period of rising prices. The degree of success depends on the ability to fill the stock at a time of relatively low prices, thus profiting from later opportunities to sell at higher prices. However, the largest consumer and government benefits were achieved by using the largest monthly stock release amount. Since there were several months that triggered a potential stock release (a price of more than US$65 a barrel), stocks were empty by March 2007. The subsequent history of oil prices, with the October 2007 monthly WTI crude average reaching US$85.40 a barrel, illustrates the dangers of too early a release at a period when oil prices are very volatile and on the rise.

Assessment of the Two Periods

Whatever the intended purpose of the scheme, the temporal behavior of oil prices will be the crucial determinant of its likely success or failure. The scheme is needed to ameliorate the impact of unusually high prices, so the probability of such prices occurring within a given period of time is important. If oil prices had a fixed probability distribution (with a constant known mean and standard deviation) and were independent from period to period, then an accurate assessment of the probability of a certain price occurring could be calculated and would continue to be valid into the future. This situation was illustrated with the simulation for the period 1986 to 1999, where the mean did not vary greatly during the period, and where the probability of extreme events could be reasonably calculated.

Although the design of a security stock scheme to cope with extreme prices could be successful in achieving price moderation, when prices fluctuate around a fairly constant mean value, the period during which stocks have to be stored will be lengthy; if refilling takes place, the government will be holding stock throughout the period, except for a very few months when prices are abnormally high. Furthermore, in order to have sufficient stock on hand to make a significant difference in the price at such times, the inventory carried will have to be large. The government will want the ceiling trigger price to be fairly high in order to obtain sufficient capital gain to cover some or all of the costs of running the scheme. Only if the international price were substantially higher would the welfare benefits of lowering domestic oil prices toward the ceiling trigger price be worthwhile. The variation in prices is also an important determinant of the usefulness and cost-effectiveness of using stocks in this way. When variability is high, the chances of an extreme event are increased, so stocks may be more useful. When variability is low, stocks would be used only rarely. If prices fluctuate around a constant mean, the operation of security stocks will almost inevitably be extremely costly.

If prices were nonstationary instead of being mean-reverting, they could drift lower as well as higher, so a scheme to hold stocks until a very high price was experienced might need to run for a long time before stock releases took place. The risks of the government facing an increasingly large financing cost would be higher than in the case where prices reverted to a mean.

The second example illustrates the case where prices follow a generally rising path for much of the period. If the government were able to anticipate the price rise and buy stocks at a "low" price, it could use the capital gains from low-price purchases to support the reduction in prices to consumers when prices are higher. Such a scheme could be entirely self-financing over the period in which the general price movement is upward. The problem for the operation of this approach is to determine beforehand when prices are likely to follow a rising pattern. One conventional tool for assessing market views of likely price trends is the futures prices for crude oil and oil products, as discussed in chapter 5. Often, a commodities market is in backwardation—futures prices are below current prices—but at times, markets go into contango—futures prices are higher than current prices. If there is a deep contango, or the futures prices increase steeply with the length of the contract, this serves to indicate the market sentiment that actual prices will turn out to be higher in the future.

An alternative to basing views on the futures market is to track historical prices with a filter, as discussed in chapter 3. This technique can be used to constantly update the estimate of the trend price as new data are added. Forecasting still requires assumptions to be made about the course of prices. The use of a filter (or any moving average price-smoothing technique) would respond to situations such as that experienced from 2004 onward, when oil prices began a steady climb.

The simulation results suggest that using a fixed set of rules for purchases and sales is too limiting. The rules that were adequate during the period 1986 to 1999 would have been completely inadequate after 1999, because they would never have permitted any purchase of stock, and the stock left over from before the beginning of 2000 would have been exhausted by early 2001 before the large price increase took place. The trigger prices would need to be updated as the mean price forecast is increased in order to provide some relief against exceptional and above-trend variations.

International Experience with Strategic Petroleum Reserves

The 26 industrialized countries that are members of the IEA held public and commercial stocks of crude oil and oil products of 4.1 billion barrels in June 2007; this was equivalent to nearly 150 days of net imports (IEA 2007). Of this total, some 1.5 billion barrels were public stocks held exclusively for emergency purposes, while the rest were industry stocks held to meet government stockholding obligations and for commercial purposes.

Since its formation, the IEA has acted on two occasions to bring additional oil to the market through coordinated actions: in response to the 1991 Gulf War and to the hurricanes in the Gulf of Mexico in 2005. At the time of Hurricane Katrina (September 2005), the IEA members agreed to make available to the market some 60 million barrels of oil equivalent, primarily through a stock release. (In fact, 29 million barrels were drawn from public stocks and a further 23 million barrels were made available by lowering stockholding obligations on industry.) Other supply disruptions—such as those in early 2003, when there were strikes in Venezuela and Nigeria and the outbreak of war in Iraq—did not elicit any response from the IEA.

Countries outside the IEA are constructing strategic petroleum reserves as well. China has begun storage construction in a three-phase program (*Oil and Gas Journal* 2007a and 2007b). In the first phase, to be constructed between 2004 and 2008, stocks are planned to cover about 13 days of oil consumption (100 million barrels); in the second phase, another 200 millions barrels will by added by 2010; and, in the third phase, another 200 million barrels are to be added. Emerson (2006) and the *Oil and Gas Journal* indicate that the Chinese may consider using the strategic petroleum reserves to control price swings, as well as to provide a reserve against unexpected supply shocks.

United States

At the end of October 2007, the United States held 1,708 million barrels of crude oil and oil products in public and private stocks, which was equivalent to 130 days of net imports. Of these, nearly 700 million barrels were in the government-financed Strategic Petroleum Reserve. This level of coverage gives the country the flexibility to release stocks even when the IEA has not decreed that an emergency situation exists; such was the case in 1996. The United States has low-cost storage capacity available in the form of salt domes located near the Gulf coast, allowing for cheap storage and efficient drawdown. The operation of the U.S. Strategic Petroleum Reserve is governed by the Energy Policy and Conservation Act.[4] Under this act, the president can determine whether a supply shortage or high prices could affect national security and, if so, authorize a drawdown.

Nontest releases from the reserve have occurred on three occasions (test releases are small releases designed to test the operation of the system):

- 21 million barrels were released in 1990–91 because of Desert Shield/Storm

[4] For a description, see the U.S. Department of Energy Office of Fossil Energy Web site at www.fe.doe.gov.

- 28 million barrels were released in 1996–97 for nonemergency reasons
- 11 million barrels were released in 2005 because of Hurricane Katrina.

The 1996–97 sales were designed to help reduce the budget deficit at a time when crude oil prices were high. In addition, loans and swaps with commercial companies have been made 10 times, including a 30 million–barrel exchange of crude oil for heating oil to be stored in the Northeast United States at a time when heating oil stocks were particularly low in that region. By lowering heating oil prices, however, extra imports from Europe were not attracted, thus negating the desired effect of improving regional supply.

Japan

Japan holds stocks equivalent to about 170 days of domestic consumption, of which 320 million barrels of crude are in the state stockpile, while the private sector holds 130 million barrels of crude and another 130 million barrels of oil products. Companies are required to hold stocks equivalent to 70 days of domestic consumption, which is identical to the country's net imports. Japan therefore also has the flexibility to release stock even when there is no IEA mandate, while keeping to its obligations to maintain 90 days of import coverage. Furthermore, under the country's Petroleum Stockpiling Law, the private sector holds the equivalent of 60 days imports of liquefied petroleum gas. Japan, according to its IEA obligations, released part of its private sector stockpile during the first Gulf War and Hurricane Katrina. It did so by reducing the mandatory amount to be held by the private sector.

The public stockpile is partly stored in underground and floating storage, which is substantially more expensive than above-ground storage but gives an insurance against natural disasters such as earthquakes and typhoons. Even though private sector stockholding is partly subsidized by the government, it constitutes an extra cost for oil companies and acts as a barrier to market entry. Japan uses its stocks strictly following the IEA model, with reductions in stockholding permitted only when the IEA has indicated that an emergency situation exists.

Republic of Korea

The Republic of Korea also holds stocks in excess of the IEA-recommended level. As of July 2006, the public sector stocks were equivalent to 57 days of imports, while private sector stocks accounted for another 69 days of imports. Private sector companies must hold at least 40 days of cover for domestic sales. The operation of the Republic of Korea's stocks follows IEA guidelines. In addition, the public stockpile, which is managed by the Korean National Oil Corporation, uses time swaps with the private sector in order to reduce costs and keep reserves in circulation. Companies are invited to bid a user charge (premium) for a quantity of stockpiled oil, which they must return within a stipulated period.

Assessment

To date, government-owned or -mandated private sector security stocks have been held as an insurance against sudden supply shortages. The one exception to this practice appears to have been the use by the United States of government stocks to reduce prices in the 1996–97 period. However, it is possible that countries now building security stocks will consider their use for domestic price stabilization at times of unusually high prices, even when these are not linked to any sudden supply disruption.

The experience of the IEA scheme, which depends on the IEA's Governing Board identifying an episode of actual or potential substantial supply disruption, suggests that stocks held for this purpose will rarely be used. For high-income countries, the costs of filling and running the security stocks that are rarely used will be affordable. For lower income countries, on the other hand, the costs may be too high, and the number of days covered may need to be somewhat lower than the 90 days of imports mandated by the IEA.

Simulations of the use of stocks to smooth out extreme price events indicate that this strategy is most likely to be successful and operated at least cost in a period of rising prices. Conversely, the scheme would be very expensive in a period of falling prices. Since the behavior of oil prices has been extremely difficult to predict, any government considering using stocks for this purpose may be dissuaded by the high degree of uncertainty about the likely costs and benefits of such a scheme.

7 Price-Smoothing Schemes

Many governments have operated schemes designed to smooth the path of domestic oil prices to consumers. Two different approaches to price control are widely used. One approach is to cap prices when they get too high, either by reducing product tax rates or by providing direct subsidies. This scheme "slices the top" off high international prices, at the cost of loss of government revenue or increased fiscal burden. It effectively has the dual outcome of lowering the average price paid over a period of time and reducing volatility. The second approach is to control prices in such a way that the scheme is self-financing over a period of time. In this latter approach, the government acts to reduce domestic prices when international oil prices are higher than some ceiling threshold; conversely, it maintains domestic prices at the floor when international prices are below a predetermined floor threshold. The costs of support in high international price periods are balanced against extra receipts in times of lower international prices. A price-smoothing scheme operates in a manner similar to a virtual security stock, but instead of coping only with spikes in prices, it aims to continually reduce the magnitude of any price swings. The nearer the ceiling and floor prices are to each other, the more stable the actual domestic price will be.

The key to both a price-capping scheme and a price-smoothing scheme is the target price. For price capping, this target is the level of prices that is the highest the government considers acceptable to the public at that moment; for a price-smoothing scheme, it is the price around which market prices are to be smoothed. In both cases, this price can evolve over time according to market conditions—in fact, a price-smoothing scheme must follow market conditions so that it does not run a persistent deficit at a time of steadily increasing international market conditions.

There are several methods of determining price-smoothing scheme ceiling and floor prices or the price band that will be used to reduce the volatility of domestic prices around the target price. These methods are described in detail by Federico, Daniel, and Bingham (2001); LeClair (2006) analyzes a proposed scheme using variations in tax rates for the United States.

A price-smoothing scheme can be judged in terms of three outcomes:

- The reduction in the volatility of domestic prices
- The reduction, if any, in the overall level of domestic prices
- The fiscal cost or forgone revenue

The magnitudes of these outcomes have to be evaluated using a counterfactual of what the domestic prices would have been in the absence of the scheme. To carry out such a calculation from actual data would require detailed information on the whole product-pricing structure, so that international prices can be linked to domestic prices set and to the exact point in the product price chain at which the price control is imposed (ex-refinery prices, wholesale prices, or retail prices).

Setting a Target Price

Faced with steadily increasing international oil prices, a number of developing countries are subsidizing prices on some or all oil products (Bacon and Kojima 2006, IMF 2007). In the face of the general rise in oil prices since 2004, some countries that had not been using price caps, or had limited caps on certain fuels, have introduced or widened the existing scheme. The continued rise in international prices has led to mounting fiscal costs in these cases. As a result, some countries have more recently reversed this decision and abandoned price subsidies as being too expensive. A particular problem with some of these schemes is that the price caps set have been ad hoc, bearing no systematic relation to the international price. With such an approach, there can be a tendency for the capped price to increase less rapidly than the international price, with the increasing per unit subsidy worsening the total fiscal costs of the scheme against the backdrop of continuing international price increases.

Governments that have set the regulated price through an explicit or implicit formula have usually done so in a way that tracks movements in international prices, even if there is not a full pass-through of these prices to consumers. This approach tends to limit the magnitude of the total subsidy, while giving a signal to consumers that the cost of oil is rising and that they should adjust their consumption accordingly. The formula used for tracking the movements of international crude oil or oil product prices, while limiting volatility of domestic prices, requires a built-in smoothing mechanism. Whether smoothing prices is progressive or regressive depends on the range of products considered and on the share of expenditures on these products in total household expenditure at different income levels. For example, smoothing only gasoline prices will tend to benefit the richer members of society in developing countries, because the poorer members generally do not own cars or use gasoline.

Two approaches dominate the setting of regulated prices:

- The first (semi-automatic) approach is to set a "reasonable" price based on current market experiences and then review the target price periodically. When international prices have risen by a sufficient margin and for a long enough period of time, a new price is set. This approach produces a series of step changes at irregular intervals, but, provided the government is sufficiently responsive to new higher prices, the fiscal burden should not increase unexpectedly.
- The second approach is to use a fully automatic pricing scheme whereby international prices are continuously reviewed and new domestic prices are regularly determined on this basis. The review period could be daily, weekly, monthly, or even less frequently. Once the review period and formula are determined, the domestic price is set accordingly.

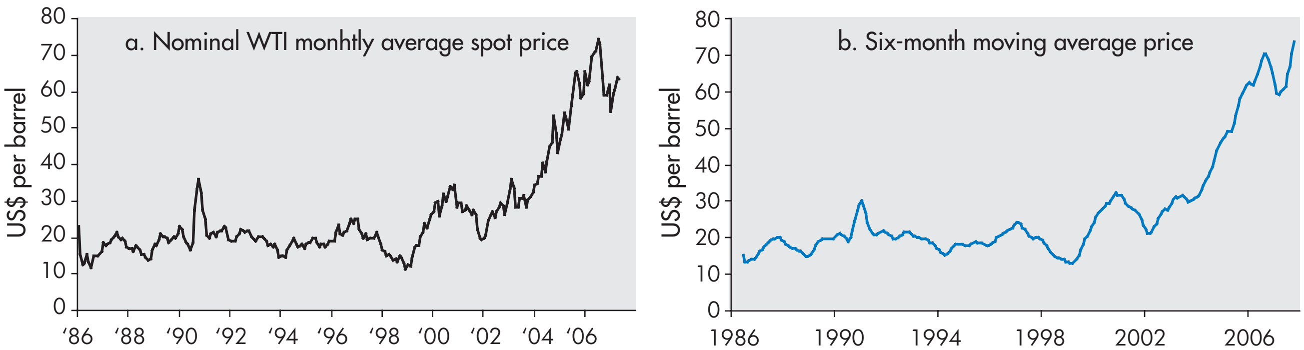
A successful formula designed to track the general level of international prices while being less volatile than these prices will usually be based on some moving average of past actual prices and, where suitable, futures prices. The simplest scheme is to use a moving average of previous prices. For example, in setting prices each month, the target price might be an average of the prices during the previous three months. This ensures that the target price is changed each month in response to recent price movements. Moreover, by taking an average over three months, the resulting series is smoother than daily, weekly, or monthly prices. A longer average, based on more months, will be less variable. However, in a time of steadily rising (or falling) international prices, the longer the averaging period, the greater the difference between the current international price and the moving average (figure 7.1)

An extension of this approach is to use futures market data as a better proxy for where prices might be at the time the regulated price comes into operation. An average of futures contracts at the current date for several durations can be constructed (see annex 6 for price-smoothing formulae) as such an index. The absence of futures product markets apart from in the United States and the United Kingdom—and these only for a small range of products—limits the applicability of this approach.

Table 7.1 provides summary statistics that describe the volatility of the various price-smoothing formulae based on the logarithmic returns of different series. As well as three- and six-month moving averages based on past data, a series based on the average of the three different futures contracts for the next three months and another based on an average of the three-month

Figure 7.1

WTI Crude Monthly and Six-Month Moving Average Prices



Sources: U.S. EIA 2008a; author calculations.

Note: Six-month moving average prices are averages of the current spot price and the prices during the previous five consecutive months.

moving average and the three months average of futures contract prices are constructed. The standard deviation of the returns (which, when multiplied by 100, approximate percentage changes) measures the average volatility of the series, and the maximum and minimum measure the extremes of volatility. Taking moving averages over increasingly long lags decreases the volatility of the series substantially. Compared to the standard deviation of spot prices, which is equivalent to an average monthly change of 8 percent, the standard deviation of the three-month moving average is 5 percent; for the six-month moving average, it is 3.5 percent. The maximum monthly price swings are also substantially reduced by averaging. Spot prices have a maximum monthly increase of nearly 40 percent, while the six-month average has a maximum month-to-month increase of 13 percent. The returns on futures prices as averaged over three different contract durations (one, two, and three months) are just as volatile as current spot prices, while the average of the previous three months' spot prices and the three contract months of futures prices has comparable volatility to that of the three-month moving average of spot prices.

The choice of the smoothing formula affects the difference between the formula price and the actual international price ruling in the same month, which in turn affects the cost of operating the smoothing scheme. For a country that is importing WTI crude, the regulated price for a particular month has to be determined before the onset of that period. For example, using a three-month moving average

Table 7.1

Summary Volatility Statistics for Returns of Current Prices, Moving Average WTI Crude Prices, and Futures Prices, July 1986–October 2007

Statistic	Current monthly avg. spot price	3-month avg. of spot prices	6-month avg. of spot prices	Avg. of 1, 2, and 3 months of futures contracts	Avg. of 3-month spot prices and 3 months of futures contracts
Mean	0.0072	0.0068	0.0061	0.0051	0.0070
Standard deviation	0.078	0.050	0.035	0.073	0.052
Maximum	0.392	0.238	0.125	0.285	0.227
Minimum	–0.209	–0.150	–0.082	–0.329	–0.168

Sources: U.S. EIA 2008a and Bloomberg.com; author calculations.

Note: Returns are based on differences in the logarithms of prices in US$ per barrel.

approach, the regulated price for December would have to be based on actual prices in September, October, and November. This inevitable lag introduces a form of basis risk, in that the most recent actual information is not incorporated. Cumulating the difference over the period between the international spot price and the regulated price derived from the lagged three-month moving average produces the cumulated cost to the government of setting regulated prices in this way.

Figure 7.2a and b illustrate the cumulated cost for one barrel of crude based on this pricing scheme for three- and six-month lagged moving averages, respectively. Between 1986 and 1999, the scheme works well, with the cumulated cost fluctuating around zero. From 2002 onward, the steady rise in international prices means that the regulated price based on a moving average is constantly behind the international price, leading to an ever larger cumulative cost to the government—despite large increases in the regulated price itself. By October 2007, the cumulated cost per barrel using a three-month moving average reaches US$132, while that using a six-month moving average reaches US$220 as a result of the longer moving average falling further behind in a time of steadily rising prices. A regulated price, based on the average of the lagged three-month moving average and the average of futures prices through one to three months, would have produced a cumulated cost to the government by the end of the period of US$128 a barrel.

Comparing the two moving average schemes based on past spot prices indicates that, over the period of analysis, the longer the moving average the lower the volatility, but the higher the cost to the government for basing its regulated price on that moving average. The use of an average based on three past monthly spot prices and three monthly futures contract prices has almost identical volatility and fiscal cost as a scheme based only on the past three monthly spot prices. The failure of the addition of futures prices to improve the performance of the moving average indicates the weak link between futures contract prices and the actual spot prices that have emerged at the time of delivery.

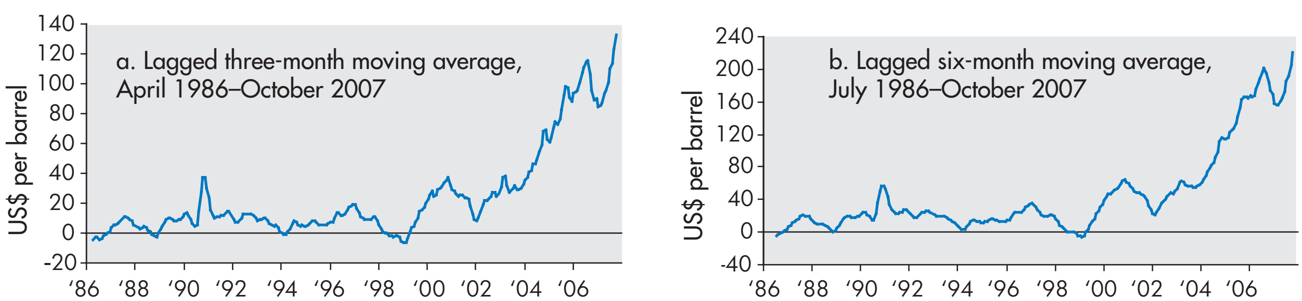
A smoothing filter used to describe past data movements, such as the Hodrick-Prescott filter discussed in chapters 2–4, is another method of smoothing prices. Using this lagged smoothed series as a proxy for the current target price would have resulted in a cumulative deficit of US$110 a barrel over the period.

Even though crude prices did not begin their major run-up until 2004, the use of a moving average price-setting scheme resulted in very long sojourns in deficit for the financing of the regulated prices. With a three-month moving average, the scheme would have been continually in deficit between December 1988 and October 2007 (figure 7.2a). With a six-month moving average, the scheme would have been in deficit since April 1994 (figure 7.2b).

As LeClair (2006) points out, if consumers understand the price-setting mechanism, they might adjust their consumption behavior, which could affect the level of domestic prices in the market by changing demand. Also, where the short-run price elasticity

Figure 7.2

Cumulative Cost of Regulating the Price of Crude Oil with Lagged Three- and Six-Month Moving Averages



Sources: U.S. EIA 2008a; author calculations.

of demand is above zero, the moderation of prices through a formula will result in a higher demand than would have occurred in the absence of regulation, and this would have a second-round impact on the government tax take.

Federico, Daniel, and Bingham (2001) analyze an extension of the moving average rule to allow for ceiling and floor barriers to regulated prices. A target price is defined through some form of moving average scheme, and a ceiling and floor around this target are then determined. The regulated prices are set equal to international prices as long as the latter are between the ceiling and floor. If the international prices are outside the band, the regulated price is set equal to the ceiling (or floor), and the difference between the international price and the regulated price is financed by a tax reduction (increase) or subsidy increase (reduction). A version of this scheme uses moving average price as the target and sets a band around this within ±X percent. This ensures that the ceiling and floor prices change with the target price. If the value of X were set to zero, this would correspond to the simple moving average regulated price scheme described above.

In the next illustration, the target price is set as the three-month moving average of WTI crude prices as determined in the previous period, while the moving ceiling and floor prices are set 10 and 15 percent, respectively, above and below this level. The government intervenes whenever the current WTI crude price is above (below) the target price ceiling (floor) by reducing (increasing) tax rates. The cumulated fiscal cost of the scheme simulated from April 1986 to October 2007 is calculated for one barrel of oil consumed every month. The results are shown in table 7.2.

The results demonstrate how a scheme based on a moving average price, but with a ceiling and floor to contain extreme price movements, would have reduced the cost of intervention. The wider the bands, the lower the costs of the intervention to the government would have been. However, the wider the price band, the more volatile would be the regulated price: regulated prices would be equal to actual international prices for a larger part of the time, and the ceiling and floor would be in operation for a smaller part of the time.

Table 7.2

Fiscal Costs of Regulating WTI Prices through Three-Month Averaging for Different Price Bands, April 1986–October 2007

Parameter	0% band	±10% band	±15% band
Cumulative cost per barrel (US$)	132	37	26
Standard deviation of returns	0.050	0.062	0.070

Source: Author calculations.

Note: Returns are based on differences in the logarithms of prices in US$ per barrel.

Most governments wishing to smooth prices are concerned with the prices of oil products to end users. The mechanics of a price-smoothing scheme will depend in part on whether products are subject to taxes in the local market, or whether they are implicitly or explicitly subsidized. In many countries, oil products are an important source of fiscal revenue, subject to sales taxes (or value added tax) and an additional excise tax. The tax structure can be varied so as to reduce the final price, providing the tax rates are larger than the desired subsidy. Since sales taxes tend to be universal across commodities, excise taxes are most likely to be varied.

Imports of oil products will normally be priced in U.S. dollars, but the smoothing scheme would need to base the moving average on prices in local currency. This would have the effect of also smoothing out fluctuations in exchange rates. The cases of Kenya and Ghana, described below, illustrate the impacts of smoothing the prices of imported products in local currency.

During the period 1986 to 2007, the Kenyan shilling fluctuated continuously against the U.S. dollar, without sudden movements due to a devaluation. In January 1986, the exchange rate was K Sh 16.3 to US$1; by August 2007, the rate was K Sh 66.9 to the dollar. This simulation assumes that oil products are imported from the Persian Gulf; hence, the prices are based on Gulf prices as quoted by Energy Intelligence (2008). For comparison, the price of Dubai crude is also analyzed. Table 7.3 presents the volatility measures for imported products, based on different moving averages, in both U.S. dollars and local currency.

As is the case for WTI crude, the longer the moving average, the lower the volatility of all fuel types. Volatility is slightly higher when measured in local currency for all products and for all price averages. The small size of this effect is explained by the fact that the volatility of the exchange rate (based on monthly returns) at 0.033 is much smaller than those of oil prices measured in U.S. dollars. Thus, the impact of this extra component on the volatility in local currency is minor.

In the case of Ghana, the movement in the exchange rate during the period was larger. In January 1986, the rate was ₵80 to the U.S. dollar; by August 2007, this had reached ₵9,300 to the dollar. The relevant market for products and crude oil for Ghana is assumed to be northwest Europe, and hence product prices from Rotterdam are used. The relevant crude is taken to be Brent. Table 7.4 presents the volatility measure for Ghana.

The pattern of volatility in Ghana is very similar to that shown in table 7.3 for Kenya. The local currency volatility is higher than that in U.S. dollars, but the difference is small. Again, the longer period moving averages in all cases reduce the volatility substantially.

Table 7.3

Standard Deviation of Returns for Oil Products Imported to Kenya Based on Various Moving Average Prices, July 1986–September 2007

	US$			K Sh		
Fuel type	Current monthly spot	6-month average	3-month average	Current monthly spot	3-month average	6-month average
Crude	0.083	0.056	0.037	0.089	0.060	0.040
Gasoline	0.081	0.050	0.033	0.087	0.054	0.036
Gasoil	0.094	0.059	0.041	0.100	0.063	0.045
Kerosene	0.112	0.066	0.046	0.116	0.069	0.049
Fuel oil	0.129	0.076	0.051	0.132	0.078	0.052

Source: Author calculations.

Note: Returns are based on differences in the logarithms of prices in US$ or K Sh per barrel.

Table 7.4

Standard Deviation of Returns for Oil Products Imported to Ghana Based on Various Moving Average Prices, July 1986–September 2007

	US$			₵		
Fuel type	Current monthly spot	6-month average	3-month average	Current monthly spot	3-month average	6-month average
Crude	0.088	0.056	0.038	0.090	0.060	0.043
Gasoline	0.094	0.059	0.040	0.101	0.066	0.047
Gasoil	0.086	0.055	0.039	0.091	0.062	0.046
Kerosene	0.087	0.057	0.040	0.092	0.063	0.047
Fuel oil	0.113	0.067	0.047	0.116	0.073	0.053

Source: Author calculations.

Note: Returns are based on differences in the logarithms of prices in US$ or ₵ per barrel.

Case Studies in Price Smoothing

To illustrate different approaches to smoothing the retail prices of oil products, the cases of Chile and Thailand are described. Chile currently operates with an explicit formula for a target price and sets a ceiling and a floor price around this target price to contain large fluctuations in prices. The target price is set according to a moving average of international prices. Thailand, by contrast, has not used an explicit formula but has varied tax rates and subsidies to cap retail prices.

The Chilean government first established the Petroleum Prices Stabilization Fund in 1991 (ENAP 2007) in order to smooth domestic prices of gasoline, diesel, kerosene, liquefied petroleum gas, and fuel oil. The operation of the scheme is described by Valdés (2006) and Libertad y Desarollo (2006). There have been three versions of the fund:

- From 1991 to 2000, prices were set according to an average of the historic price and the long-term expected price, and taxes were kept at a fixed rate, while adjustments were made on an ad hoc basis. The fund was endowed with resources to enable it to support the domestic price when necessary. When oil prices remained relatively constant, the scheme worked well and withdrawals from the fund were balanced by inflows. However, the rise in international prices in 2000 necessitated a revision in the fund's operation.
- In the second version of the fund, regulated prices were set weekly, taking into account expert views on future oil prices, and subsidies were to be limited to an amount that the fund could sustain for 12 weeks at current prices. The target price was calculated to reflect medium- and long-term international oil market prices based on 2 years prior and up to 10 years future expected prices. The price band for the floor and ceiling was set at 12.5 percent of the target price. The persistent rise in oil prices from 2004 meant that the fund was practically exhausted by the time of Hurricane Katrina and the associated sharp increase in oil prices in August and September 2005.
- The Fuel Price Stabilization Fund was established in October 2005, with an initial endowment of US$10 million taken from Chile's copper fund. New mechanisms for determining the target price and the floor and ceiling prices were put in place. The new target price was based on actual prices over a period of up to 52 weeks before the current date, and on futures contract prices for delivery up to six months ahead. The length of the moving average could be varied, but a particular choice had to remain in force for at least four weeks. The price band for intervention was narrowed from 12.5 percent to 5 percent of the target price. The operation of the fund has twice been extended. During the period July to November 2006, the fund disbursed credits because international prices were above the ceiling prices. Then, between September and November 2006, the Fund collected revenues by imposing a tax when the international price was below the floor price. With respect to gasoline prices during this 22-week period, the fund disbursed for 8 weeks and collected taxes for 11 weeks; for three weeks, it did neither since the international price was between the ceiling and floor values. In early 2008, the government injected US$200 million into the fund to help lower prices.

The evolution of the rules governing the pricing of oil products in Chile, through the use of the Petroleum Prices Stabilization Fund and Fuel Price Stabilization Fund, illustrates some of the main issues associated with a price-smoothing scheme. The use of a long-period moving average to determine the target price was successful while international oil prices were fairly stable. Once the fluctuations became larger, however, the Petroleum Prices Stabilization Fund could not support such a scheme. The move to shorter moving averages reduced the chance that there would be a series of substantial withdrawals from the fund. At the same time, the use of a wider band to regulate volatility meant that, for much of the time, the prices were not regulated and instead fluctuated with market price. The tighter price band introduced in the Fuel Price Stabilization Fund will have reduced volatility, but, during periods of steeply rising prices in 2007, the moving average determination of the target price could have resulted in a long period of disbursements from the fund. From the calculations reported earlier in this chapter, it appears that the use of an average based partly on futures contract prices was not likely to have safeguarded against underestimation of the level of actual international prices during this period.

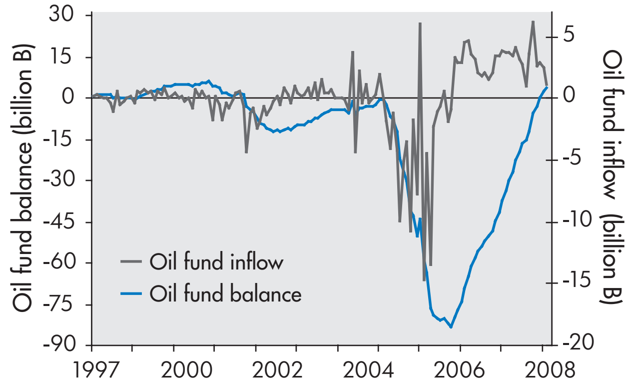
Thailand's experience with capping and smoothing oil product prices is described by Bacon and Kojima (2006). Prior to February 2003, the only oil product subsidy was for liquefied petroleum gas. This was financed through the State Oil Fund, which received levies from other oil products. At that time, the fund had a deficit of US$96 million. Faced with an anticipated price spike in oil and oil products prices caused by the invasion of Iraq, the government reintroduced subsidies on other products, but these were phased out in April 2003. In January 2004, faced with a moderate increase in crude oil prices, the government reintroduced a price cap for an initial period of two months, with the expectation that the price rise would be short lived and that the maximum cost to the government would be B 5 billion (US$128 million at the time). The subsidy on gasoline was removed in October 2004, but the much larger subsidy on diesel continued until July 2005; indeed, diesel prices were actually frozen between January 2004 and February 2005. By the time the subsidy scheme was abandoned, the total cost of the scheme was B 92 billion (US$2.2 billion at the time). Since then, the accumulated deficit on the oil fund has been steadily reduced through the levies on oil products (excluding liquefied petroleum gas) so that, by September 2007, the fund was almost back in balance (figure 7.3). These levies could have been used to support other development objectives, rather than repaying the past subsidies to consumers of oil products.

The course of actual retail diesel prices between 2002 and 2007, and the hypothetical prices that would have emerged with the same tax structure and marketing margins, but in the absence of contributions from the oil fund, is shown in figure 7.4.

Figure 7.4 illustrates the danger of excessive smoothing of prices around a fixed level. During the period of rapidly increasing international prices, the fixed domestic prices resulted in a rapidly escalating fiscal cost. Even though the regulated price was increased on a few occasions, it failed to keep pace with international prices. The regulated price also exhibited a few very sharp increases. In March 2005, the price of diesel was increased by B 3 a liter (a 20 percent increase), which was much greater than any weekly change that would have occurred had prices been unregulated. A moving average target price would also have lagged behind international prices, but the accumulated costs need not have risen so rapidly. The danger of fixing prices was that it was difficult to change them. Only in

Figure 7.3

Thai Oil Fund Financial Status

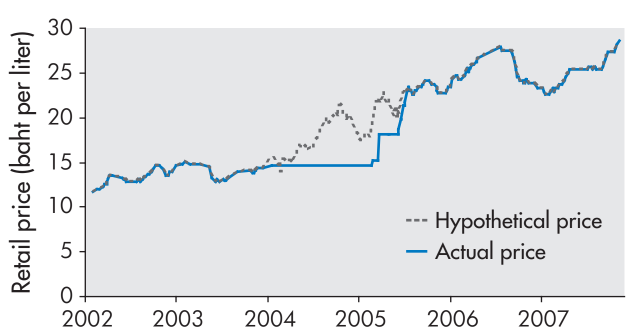


Source: EPPO 2008.

Note: During the 1997–2007 period, the Thai baht fluctuated between a low of 31.36 to the U.S. dollar in 1997 to a high of 44.43 in 2001.

Figure 7.4

Actual and Hypothetical Diesel Prices in Thailand, January 2002–September 2007



Sources: EPPO 2008; author calculations.

the face of unsustainable financing pressure did the government feel able to pass some of the cost increase on to consumers.

Assessment

Faced with large oil price increases, some governments have sought to shield consumers from the effects of the increased costs of oil and their increased volatility. Price-smoothing schemes based on moving averages of previous spot and futures prices can be highly successful in reducing the volatility of consumer prices. When there is no strong trend in the underlying international prices, such schemes can operate without incurring an excessive fiscal burden for the government in the long run. However, even in this case, the pattern of oil price changes can result in the scheme running a deficit for a lengthy period, which may be politically difficult to support.

The choice of moving average is important in this context. The longer the moving average, the more vulnerable the scheme will be to periods of sustained price increases, but the lower will be the volatility of the regulated price. The incorporation of several futures prices into the moving average appears to make little difference to the scheme's ability to track the general level of spot prices while simultaneously reducing volatility.

Schemes that introduce a ceiling and floor price band around the moving average can offer a good trade-off between reducing the cost of support to the government while reducing volatility relative to international prices. The wider the price band, the less the cost of support but the greater the volatility of domestic prices.

Schemes that set a price cap on an ad hoc basis run the danger of rapidly accumulating a substantial deficit in times of increasing international prices, because the government is not forced by the use of an explicit formula to constantly revise the regulated price. A regulated price that is infrequently changed does reduce volatility—at least in the short run—but is likely to result in a few but very large price changes as the government is periodically forced to reset the regulated price. Financing the deficit of such a scheme, which is not designed to capture any upside when regulated prices are above international prices, effectively faces a one-sided risk—if prices steadily increase, there will be a permanent deficit that will have to be financed out of other taxes.

As with other schemes designed to reduce the impact of the volatility of oil prices, the emergence of a period of steadily increasing oil prices, which are largely unforeseen, is likely to result in the scheme's eventual failure and a substantial financial burden for the government—and, ultimately, for the population.

8 Tackling Oil Intensity and Diversification

The measures discussed in the preceding chapters are designed to reduce price volatility or uncertainties about future price volatility. This chapter considers managing oil price volatility by reducing oil consumption, and thus reducing the relative importance of oil consumption. The greater the amount of oil a country consumes relative to its current gross domestic product (GDP), the greater the consequences throughout the economy; the higher the level of oil dependence, the greater the adverse effects of oil price volatility felt by consumers and businesses at any given percentage change in prices. The relative importance of oil consumption as a share of GDP can be reduced by lowering demand for oil. This can be achieved by

- improving the efficiency of oil-consuming activities (for example, by increasing vehicle fuel economy or improving the efficiency of power plants fired by diesel or fuel oil),
- restricting activities consuming oil (such as by restricting car use and raising thermostat settings for air conditioning in the summer),
- diversifying away from oil.

Such demand-restraining measures can be implemented through exhortation, incentives, fiat, or pricing mechanisms (making it more expensive to drive, for example). More detailed examples, as well as a review of international experience to mid-2006, are given by Bacon and Kojima (2006). This chapter complements that work by reviewing global trends in oil's share of GDP, oil intensity, and energy diversification. Throughout this chapter, oil refers to a basket of three marker crudes: Brent, Dubai, and WTI.

Oil Share of GDP and Intensity

The oil share of GDP is defined in this study as the percentage of GDP in current U.S. dollars spent on oil consumption, where oil is valued—also in current U.S. dollars—at the average annual market price of Brent, Dubai, and WTI. For ease of calculation, freight charges for importing countries are not included, and thus the calculations here may underestimate actual expenditures on oil. For those oil-producing countries that provide oil on the domestic market below world prices, the market price of oil would represent forgone economic opportunity costs rather than actual expenditures.

There are 163 countries for which oil consumption data are available for 2006 from the U.S. Energy Information Administration (EIA). Although 2005 and 2006 consumption figures are given as estimates and may be revised in the future, they provide an indication of where countries stand. The distribution of the oil share of GDP in 2006 is shown in table 8.1. Half of the countries spent more than 6 percent of GDP on oil consumption. Ten percent spent more than 15 percent of GDP, and 4 percent more than 20 percent of GDP.

Figure 8.1 plots the historical oil share of GDP since 1980 for select countries. In China, Japan, and Kenya, oil share of GDP was at its highest in 1980 when oil prices in real terms were higher than in any other year during the period examined. As will be shown below, more than one-third of the countries for which data are available experienced their highest oil share of GDP in 1980. Almost as many countries, including Jordan and Guinea Bissau, experienced their highest oil share in 2006.

Table 8.2 takes 135 countries that existed in 1980 and for which data are available to compute the oil

Table 8.1

Distribution of Oil Share of GDP in 2006

	Percentage share less than:						
Parameter	**1**	**2.5**	**5**	**7.5**	**10**	**15**	**20**
Number of countries	2	19	72	103	124	147	157
Percentage of countries[a]	1	12	44	63	76	90	96

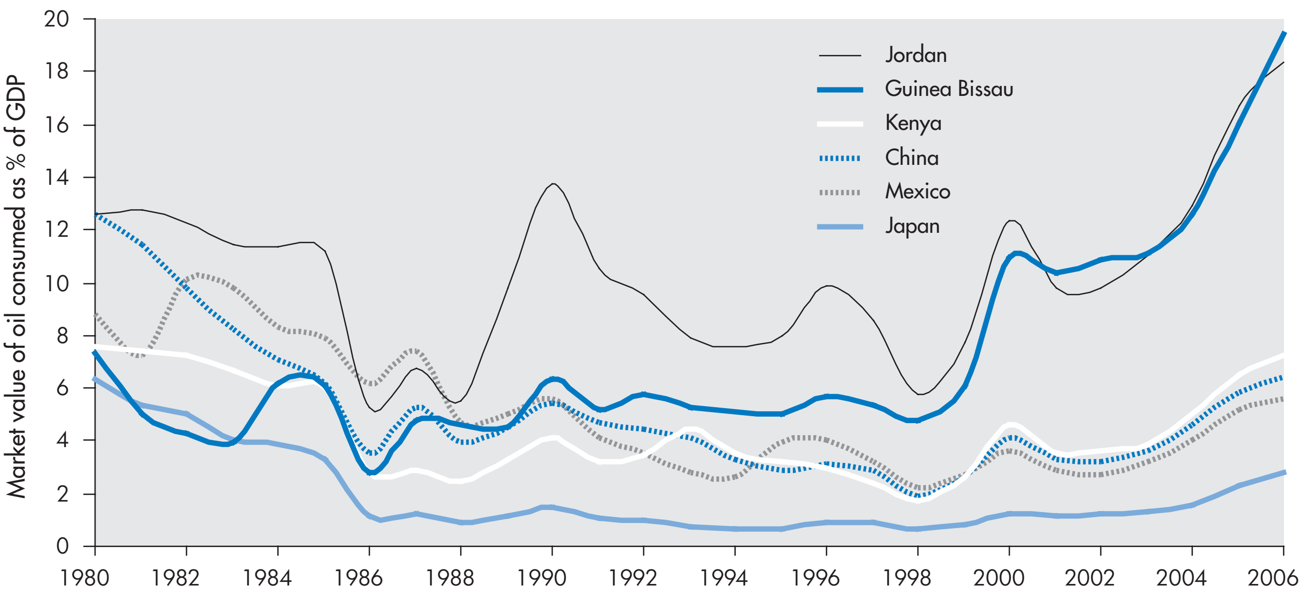
Sources: U.S. EIA 2008b; author calculations.

Note: Oil share of GDP defined as the percentage share of current GDP in US$ spent on oil consumption, where oil is valued at the average annual price of Brent, Dubai, and WTI.

a. Out of a total 163 countries.

Figure 8.1

Historical Oil Share of GDP for Select Countries



Sources: U.S. EIA 2008b; author calculations.

Table 8.2

Maximum and Minimum Oil Shares of GDP, Selected Years, 1980–2006

Parameter	**1980**	**1981**	**1986**	**1988**	**1998**	**2005**	**2006**
No. of countries with maximum oil share of GDP	50	15	0	0	0	10	43
% of countries	37	11	0	0	0	7	32
No. of countries with minimum oil share of GDP	2	0	16	16	80	0	0
% of countries	1	0	12	12	59	0	0

Sources: U.S. EIA 2008b; author calculations.

Note: Data shown are for 135 countries that existed in 1980 and for which data are available from 1980 or 1981 to 2004 or later. Only those years in which there were at least 10 countries with a minimum or maximum share are shown.

share of GDP beginning in 1980 or 1981 to 2004 or later. The table gives summary statistics on when the maximum and minimum shares occurred. For about half the countries, the oil share of GDP was at its highest in 1980 or 1981. For nearly 40 percent of the countries, however, the maximum oil share of GDP was observed in 2005 and 2006. Not surprisingly, for 80 countries, the oil share of GDP was at its lowest in 1998, when world oil prices reached their lowest level in real terms.

The oil share of GDP is affected by two factors: the amount of oil consumed relative to GDP and the price of oil. The former effect, termed oil intensity, was here calculated by taking barrels of oil consumed and dividing by constant GDP expressed in 2000 U.S. dollars. Because the resulting numbers were small, they were multiplied by 1,000; this is the equivalent of expressing barrels of oil per US$1,000 of GDP in 2000 U.S. dollars. Table 8.3 shows the distribution of oil intensity in 2006.

For the 132 countries for which data were available to compute oil intensity between 1980 or 1981 and 2004 or later, historical oil intensity was computed for each year. Figure 8.2 shows the historical evolution for select countries. For many countries, oil intensity has generally been declining. However, for some, it has increased in recent years.

Table 8.4 summarizes the statistics as to when oil intensity reached its highest and lowest levels. For

Table 8.3

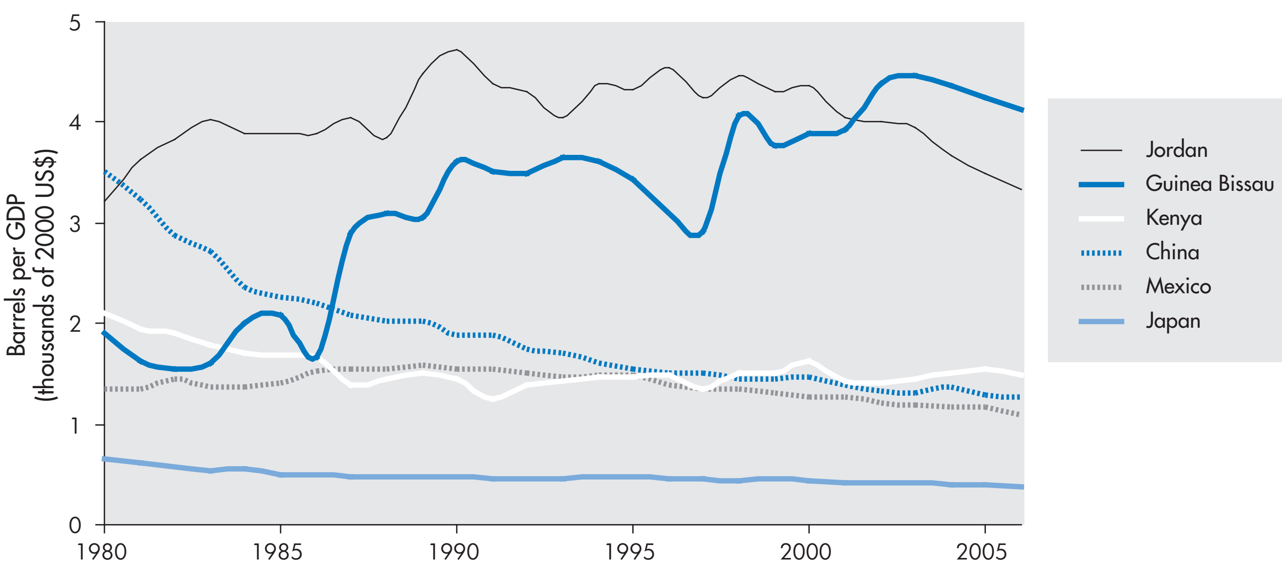
Distribution of Oil Intensity in 2006 Barrels per US$1,000 of GDP (2000 US$)

	Oil intensity less than:						
Parameter	**0.1**	**0.25**	**0.5**	**0.75**	**1.0**	**1.5**	**2.0**
Number of countries	1	3	15	32	66	103	120
Percentage of countries[a]	1	2	9	20	41	64	75

Sources: U.S. EIA 2008b; author calculations.
a. Out of a total 160 countries.

Figure 8.2

Historical Oil Intensity for Select Countries



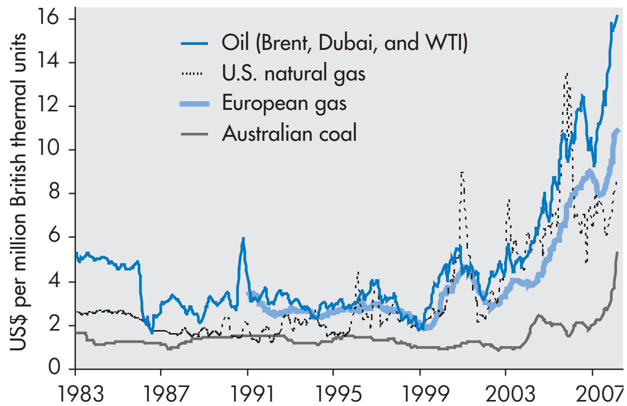
Sources: U.S. EIA 2008b; author calculations.

nearly half the countries, oil intensity was its highest in 1980 to 1984. For nearly a quarter, however, the lowest oil intensity was observed during the same period. Consistent with a general decline over time, oil intensity was at its lowest in 2006 for 41 countries. For 47 percent of the countries (63), oil intensity in 2005, 2006, or both was more than 90 percent of the maximum oil intensity during this period. In 25 countries, oil intensity has peaked during this decade.

The high oil share of GDP in 1980 and 1981 can therefore be explained by a combination of high oil prices and high oil intensity. Many countries, however, experienced a high oil share of GDP in 2005 and 2006 despite declining oil intensity, demonstrating the exacerbating effect of high oil prices.

Figure 8.3

Historical Oil, Gas, and Coal Prices



Source: World Bank Development Economics Prospects Group.

Relative Price Levels and Price Volatility

Price correlations between different fuels are useful in considering whether, and how much, to diversify energy sources. In the extreme, if the prices of different energy sources are perfectly correlated, then price volatility will also be similar between the two energy sources. Figure 8.3 shows monthly prices of Australian coal (spot price), crude oil, natural gas in Europe (average of contract prices for imported gas indexed to oil product prices with a lag), and natural gas in the United States (spot price at Henry Hub in Louisiana) since January 1983. The prices are expressed in nominal U.S. dollars per unit of energy, in this case million British thermal units. It should be noted that the spot market for coal accounts for about 10 percent of global coal trade; the remainder is covered by long-term contracts and generally has lower, more stable prices.

Coal prices are by far the lowest, and the price gap between coal on the one hand and oil and gas on the other has been widening in recent years. That said, coal prices have been rising rapidly in recent months. Table 8.5 shows price correlations for different fuels between January 1983 and December 2007, divided into subperiods.

Taking the entire period between 1983 and 2007, the most tightly correlated prices are, not surprisingly considering price indexation, those for crude oil and European gas. The pair is followed by oil and U.S. gas, European gas and U.S. gas, oil and Australian coal, and European gas and coal. The least correlated pair is U.S. gas and Australian coal. Since 2000, the most

Table 8.4

Maximum and Minimum Oil Intensity, Selected Years, 1980–2006

Parameter	1980	1981	1982	1984	1987	1988	1999	2000	2001	2006
No. of countries with maximum	42	6	9	4	2	2	6	3	6	5
% of countries	32	5	7	3	2	2	5	2	5	4
No. of countries with minimum	10	6	5	8	7	6	3	6	2	41
% of countries	8	5	4	6	5	5	2	5	2	31

Sources: U.S. EIA 2008b; author calculations.

Note: Data shown are for 132 countries that existed in 1980 or 1981 and for which data are available to at least 2004. Only those years in which there were at least six countries with a minimum or maximum intensity are shown.

Table 8.5

Fuel Price Correlation

Period and fuel	Australian coal	Oil	Gas, Europe	Gas, U.S.
1983–2007				
Australian coal	1.00			
Oil	0.79	1.00		
Gas, Europe	0.74	0.96	1.00	
Gas, U.S.	0.51	0.81	0.80	1.00
1983–99				
Australian coal	1.00			
Oil	0.39	1.00		
Gas, Europe	0.70	0.47	1.00	
Gas, U.S.	–0.22	0.21	–0.11	1.00
2000–07				
Australian coal	1.00			
Oil	0.85	1.00		
Gas, Europe	0.75	0.95	1.00	
Gas, U.S.	0.48	0.63	0.62	1.00
2000–03				
Australian coal	1.00			
Oil	–0.19	1.00		
Gas, Europe	0.41	0.37	1.00	
Gas, U.S.	0.08	0.55	0.64	1.00
2004–07				
Australian coal	1.00			
Oil	0.54	1.00		
Gas, Europe	0.27	0.89	1.00	
Gas, U.S.	–0.30	0.21	0.22	1.00

Source: Author calculations.

Note: All prices are monthly prices shown in figure 8.3. The European gas price series starts in January 1991.

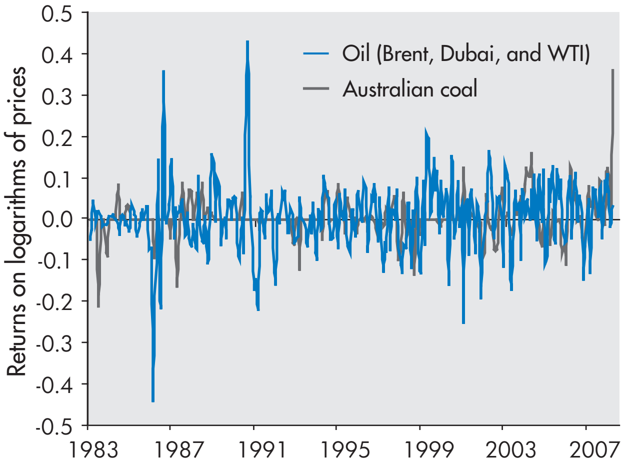
tightly correlated pair remains oil and European gas, followed by oil and coal, coal and European gas, and oil and U.S. gas. Between 1983 and the end of 1999, price correlations were fairly weak except between coal and European gas. In the most recent subperiod beginning in January 2004, the price correlation was strong between oil and European gas, but not for others; price trends have been the opposite for coal and U.S. gas.

Figures 8.4 and 8.5 plot the historical volatility of the monthly prices of the above four fuels, where volatility is expressed as returns on logarithms of prices. As before, returns multiplied by 100 approximate percentage changes in prices from one month to the next. The largest positive return is for U.S. natural gas at 48 percent, and the largest negative return is for oil at –44 percent.

Table 8.6 summarizes standard deviations of the returns shown in figures 8.4 and 8.5 for different subperiods. For every subperiod examined, U.S. natural gas is the most volatile price. Oil is the second most volatile, although coal price volatility has been catching up since the beginning of 2004. Coal and European gas prices had comparable volatility until the end of 2003, after which coal volatility began to increase while European gas volatility began to

Figure 8.4

Volatility of Historical Oil and Coal Prices



Source: Author calculations.

Table 8.6

Standard Deviation of Fuel Price Volatility

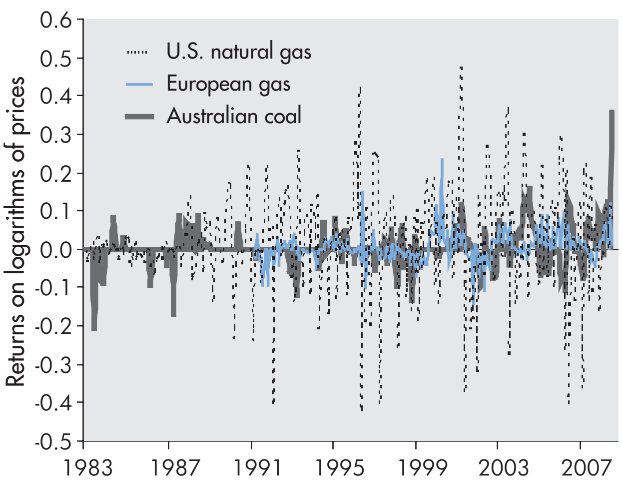
Period	Coal	Oil	Gas, Europe	Gas, U.S.
1983–2007	0.04	0.08	0.04	0.12
1983–99	0.03	0.09	0.03	0.11
2000–07	0.05	0.08	0.04	0.15
2000–03	0.04	0.09	0.05	0.16
2004–07	0.06	0.07	0.03	0.14

Sources: Price data from World Bank Development Economics Prospects Group; author calculations.

Note: Standard deviations are calculated on returns on logarithms of monthly prices expressed in nominal US$ per unit of energy. Coal is Australian coal. Oil is the average of Dubai Fateh, Brent, and WTI crudes. The European gas price series starts in January 1991.

Figure 8.5

Volatility of Historical Gas and Coal Prices



Source: Author calculations.

decline. One observation is that oil and European gas prices have been tracking each other closely with a growing offset since about 2004 (figure 8.3), but the price volatility of European gas has been much lower than that of oil. Therefore, diversifying away from oil to gas in Europe would offer protection against oil price volatility, if not higher oil prices.

Table 8.7 shows correlations between the four fuels for returns of logarithms of monthly prices. The correlations are much weaker than those for price levels, with the highest correlation being 0.39—that is, at most, 15 percent (square of 0.39) of the returns can be said to be explained by volatility correlation between two fuels (coal and U.S. gas in 2000–03, and coal and oil in 2004–07). The low correlation squares suggest that fuel diversification could help mitigate the price volatility of higher volatility fuels.

One approach in price risk management is to diversity the fuel portfolio to take into account risks associated with both price-level increases and price volatility. In this approach, the lowest cost fuel is not assigned 100 percent of the fuel portfolio. A simple illustration is given in table 8.8, where only two fuels are considered: oil and coal. These two fuels are considered in varying proportions, ranging from 100 percent oil to 100 percent coal. According to figure 8.3 and table 8.6, coal has consistently lower price levels and lower price volatility. For each combination examined, the standard deviations of fuel price volatility are lower when coal is included in the fuel mix than if only oil is used. What may be counterintuitive is the finding that using a mix of 10 percent coal and 90 percent oil lowers the price volatility of the fuel mix relative to using coal alone, although coal is consistently the less volatile of the two fuels. During 2004–07, a mix of 25 percent oil and 75 percent coal would also have lowered price return fluctuations.

Table 8.7

Fuel Price Volatility Correlation

Period and fuel	Australian coal	Oil	Gas, Europe	Gas, U.S.
1983–2007				
Australian coal	1.00			
Oil	0.19	1.00		
Gas, Europe	0.01	0.05	1.00	
Gas, U.S.	0.12	0.19	0.08	1.00
1983–99				
Australian coal	1.00			
Oil	0.09	1.00		
Gas, Europe	–0.01	0.02	1.00	
Gas, U.S.	0.15	0.22	0.08	1.00
2000–07				
Australian coal	1.00			
Oil	0.22	1.00		
Gas, Europe	–0.05	0.04	1.00	
Gas, U.S.	0.10	0.15	0.06	1.00
2000–03				
Australian coal	1.00			
Oil	0.04	1.00		
Gas, Europe	–0.02	–0.04	1.00	
Gas, U.S.	0.39	0.13	0.10	1.00
2004–07				
Australian coal	1.00			
Oil	0.39	1.00		
Gas, Europe	–0.12	0.17	1.00	
Gas, U.S.	–0.11	0.21	0.03	1.00

Source: Author calculations.

Note: All prices are monthly prices shown in figure 8.3. The European gas price series starts in January 1991.

Table 8.8

Standard Deviation of Fuel Mix Price Volatility

Period	Oil	75% oil/25% coal	50% oil/50% coal	25% oil/75% coal	10% oil/90% coal	Coal
1983–2007	0.084	0.075	0.063	0.048	0.039	0.043
1983–99	0.086	0.075	0.061	0.043	0.033	0.035
2000–07	0.079	0.074	0.067	0.056	0.049	0.054
2000–03	0.087	0.081	0.071	0.055	0.042	0.044
2004–07	0.070	0.066	0.062	0.056	0.055	0.062

Source: Author calculations.

Energy Diversification Index and Oil Share of Primary Energy

The previous section suggests that fuel prices and price volatility of different energy sources are not necessarily well correlated even over a number of years, and a diversified portfolio of energy sources could thus mitigate the price volatility of a particular energy source. The literature on the theoretical measurement of diversity is extensive, with substantial contributions coming from the field of ecology with its measures of biodiversity. Jost (2006) gives an extensive analysis of such indicators. With respect to energy, the most popular indicators are based on the Herfindahl-Hirschman index and the Shannon-Wiener index. This chapter uses the Herfindahl-Hirschman index, calculating it from six sources of energy: oil, natural gas, coal, hydropower, nuclear power, and other forms of renewable energy (geothermal, solar, wind, and wood and waste electricity generation). AA significant omission is biomass outside of the power sector. Small-scale biomass use is widespread in developing countries, especially among the rural poor and small commercial establishments. However, data limitations do not permit the inclusion of biomass in the present analysis. Its inclusion would lower all the numbers presented in this section.

To compute the Herfindahl-Hirschman diversification index (HHDI), the fractional share of each source (standardized in energy units), p_i, is squared and summed to yield

$$\text{HHDI} = \Sigma_i \, p_i^2, \qquad (8.1)$$

where i runs from 1 to 6. The higher the HHDI, the less diverse is the energy sector. The lowest possible value of HHDI, representing maximum diversification, is 0.17 for six energy sources. For a given HHDI, its inverse is the number of energy sources with equal shares that would have the same diversification index.

For computing energy diversification, the last year for which data are available was 2005. Table 8.9 presents the distribution of HHDI for the 181 countries for which data are available. There are only five countries with an HHDI smaller than 0.25, equivalent to using four energy sources with equal shares. More than half the countries have an HHDI higher than 0.5, or equivalent to being dependent on two or fewer energy sources with equal shares. Twenty-two countries have an HHDI index of unity, being dependent only on oil. Most, but not all, of these countries are small island nations; this group also includes small non-island African countries.

The historical evolution of HHDI for select countries is shown in figure 8.6. The most diversified economy in the world is Finland, with an HHDI of 0.21 in 2004, equivalent to using five energy sources equally. Some countries, such as China and Sri Lanka, have been showing an upward trend in HHDI, or falling energy diversification, in recent years.

Summary statistics on the evolution of HHDI for the 158 countries that have continuous data between 1980 and 2005 are given in table 8.10. Nearly two-thirds of the countries have minimum diversification in the early 1980s. A quarter of the countries, however, have maximum diversification during the same period. Close to another quarter have maximum diversification in 2004–05. The table also shows the difference between the maximum and minimum values of HHDI experienced by the countries between 1980 and 2005. Some experienced no difference, and all of them are countries with an HHDI of 1.0 throughout the period.

The HHDI measures diversity of all fuels, but does not explicitly indicate how much oil is contributing to the overall index. Although the HHDI may suggest

Table 8.9

Distribution of HHDI, 2005

Parameter	HHDI < ¼	HHDI < ⅓	HHDI < ½	HHDI < ¾	HHDI > ¾	HHDI = 1	Total
Number of countries	5	27	77	133	48	22	181
Percentage of countries	3	15	43	73	27	12	100

Sources: U.S. EIA 2008b; author calculations.

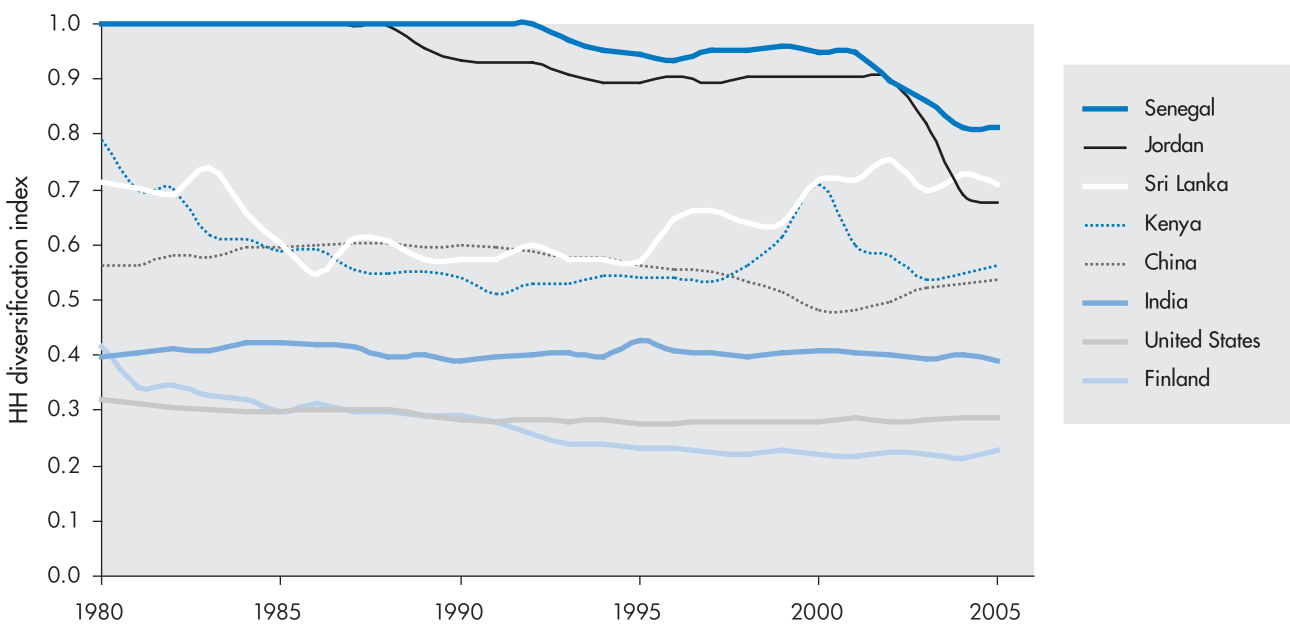
reasonable diversification, the oil share of primary energy may nevertheless be high; the reverse could also occur. To supplement the HHDI, a simpler measure—the oil share of total primary energy—was computed. This simply reports p_i in equation 8.1. The distribution of the oil share of primary energy in 2005 is shown in table 8.11.

For about a quarter of the countries, oil accounts for less than a third of total energy. Fifty-five percent of the countries, however, are dependent on oil for more than half of their primary energy, and about a third of the countries rely on oil for more than three-quarters of their primary energy. Those countries with an oil share of energy equal to unity are the same countries that had an HHDI of unity.

The historical evolution of the oil share of energy for select countries is shown in figure 8.7. They are the same countries as those in figure 8.6, except that Finland has been replaced by Trinidad and Tobago, which is the country with the lowest dependence on

Figure 8.6

Historical HHDI for Select Countries



Sources: U.S. EIA 2008b; author calculations.

Table 8.10

Maximum and Minimum HHDI, 1980–2005

	Year of minimum diversification			Year of maximum diversification			
Parameter	**1980**	**1980–83**	**2004–05**	**1980**	**1980–83**	**2004**	**2005**
Number of countries	74	102	9	27	40	15	21
Percentage of countries	47	64	6	17	25	9	13
	Difference in HHDI between maximum and minimum						
Difference	> 0.5	> 0.4	> 0.3	> 0.2	> 0.1	> 0.05	0
Number	1	9	22	53	102	123	20
Percentage of total	1	6	14	33	64	77	13

Sources: U.S. EIA 2008b; author calculations.

Table 8.11

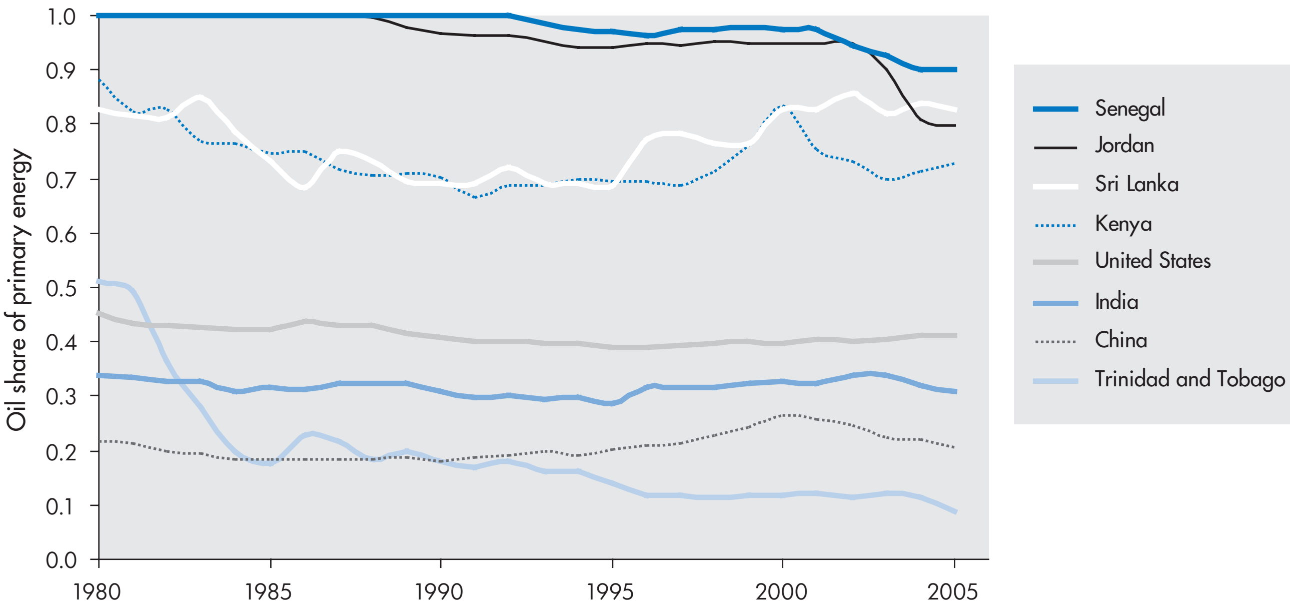
Distribution of Oil Share of Primary Energy, 2005

Parameter	Share < ¼	Share < ⅓	Share < ½	Share < ¾	Share > ¾	Share = 1	Total
Number of countries	29	44	82	121	60	22	181
Percentage of countries	16	24	45	67	33	12	100

Sources: U.S. EIA 2008b; author calculations.

Figure 8.7

Historical Oil Share of Primary Energy for Select Countries



Sources: U.S. EIA 2008b; author calculations.

oil. (Equatorial Guinea and the Democratic Republic of Korea have lower shares, but they are excluded for seeming data problems and an unusual political situation, respectively.) There are notable differences between figures 8.6 and 8.7. The United States, despite its high energy diversification, shows a relatively high level of dependence on oil, reflecting its heavy consumption of gasoline as an automotive fuel. China, in contrast, despite having an HHDI close to 0.5, shows low reliance on oil.

Summary statistics on the historical evolution of the oil share of energy between 1980 and 2005 are given in table 8.12. Half of the countries have the greatest reliance on oil in 1980. Nearly a third of the countries have the least dependence on oil in 2003–05. On the whole, countries are diversifying away from oil.

Although the HHDI and the oil share of energy are not comparable, it is worth noting that, in 2005, there are 50 countries in which the oil share of energy is lower than its HHDI. Among them, there are 20 countries in which the HHDI is larger than 0.5 but the oil share of energy is lower than one-third. There are no countries in which the HHDI is smaller than 0.5 and the oil share is greater than 0.75, but there are 19 countries in which the HHDI is smaller than 0.5 and the oil share is greater than 0.5.

Policies for Reducing Dependence on Oil

Dependence on oil can be lowered by reducing oil consumption per unit activity (such as fuel consumed

Table 8.12

Maximum and Minimum Oil Share of Primary Energy, Selected Years, 1980–2005

Parameter	1980	1981	1982	2001	2003	2004	2005
Number of countries with maximum	79	11	9	2	4	5	5
Percentage of countries	50	7	6	1	3	3	3
Number of countries with minimum	25	3	6	9	9	12	25
Percentage of countries	16	2	4	6	6	8	16

Sources: U.S. EIA 2008b; author calculations.

Note: Data shown are for 158 countries that existed in 1980 and for which data are available to 2005. Only those years in which there were at least nine countries with a minimum or maximum oil share are shown.

by driving a certain distance), reducing the level of activity consuming oil (driving fewer kilometers), and fuel switching. Fuel switching is easier in power generation and much more difficult in transport, where suitable substitutes for gasoline and diesel are not readily available. Car and appliance ownership as a function of household income is S-shaped, with low uptake at very low income and ownership rising steeply above a threshold income level before reaching saturation at high income. This trend means that low-income developing countries are particularly susceptible to steeply rising oil consumption in the medium term.

Over the long run, pricing oil products high through taxation is one of the most effective ways of promoting efficient consumption of oil and discouraging nonessential use. The first step for countries that are still subsidizing fuel prices is to start phasing down the subsidies. High prices force consumers to conserve and look for alternative lower cost energy sources. For example, high taxation on transport fuels will encourage the use of more fuel-efficient vehicles, reduce trip numbers and trip lengths, and favor public over private transport modes. A report by the U.S. Congressional Budget Office on instruments for improved fuel economy is informative in this regard. The report examines three different approaches to decreasing fuel consumption by 10 percent, and finds that the cheapest and most effective path would be a substantial increase in the fuel tax. Simply raising the federally mandated fuel economy standard would be the most costly approach for consumers. Raising gasoline taxes would not only cost less than the other two approaches considered (both of which involved raising vehicle fuel economy standards) but would start reducing consumption immediately, and the market effect would gradually drive the transition to more fuel-efficient vehicles (Automotive Environment Analyst 2004). High transportation fuel prices in Europe have led to widespread adoption of fuel-efficient cars and an increasing switch to compression ignition (diesel) engines, which are inherently more efficient than spark ignition (gasoline) engines. A recent review of vehicle fuel economy from around the world indicates large differences in the fuel consumption of new cars per unit distance traveled, with Japan and Europe leading in fuel efficiency and the United States—where retail fuel prices are among the lowest of high-income countries—lagging considerably behind (ICCT 2007).

Needless to say, high prices hurt consumers. Of particular concern in developing countries is the impact on the cost of living of higher prices of diesel, which is used in both freight and passenger transport. Increasing the price of diesel will increase input prices for major production sectors. Indirect effects of higher diesel prices on the poor can be considerable. Earlier studies in Pakistan and Yemen found that, as a percentage of household income, the adverse effect of increasing diesel prices was regressive and had the greatest impact on the poor (ESMAP 2001, ESMAP 2005). Additional tax revenue flowing to the treasury from higher fuel taxation could be used to target assistance to the poor.

Policies that are not necessarily based on fuel pricing and that reduce consumption of oil are covered in detail by Bacon and Kojima (2006). The report discusses a number of measures that limit petroleum fuel consumption in transportation, including

- traffic management in urban centers;
- limiting the speed limit, for example, to below 80 kilometers an hour;
- setting fuel economy standards;
- parking policies that make parking expensive, difficult (by limiting the availability of parking), or both;
- promoting public transport as well as car- and van-pooling;
- physical restraints on vehicle use, the best known scheme of which is an odd-even day restriction, whereby vehicles are banned from use on certain days depending on the terminal digit (odd or even) of their registration number;
- road pricing;
- limiting workdays;
- promoting better driving practices that conserve fuel.

Measures limiting petroleum oil consumption in the power sector, where oil is used as a fuel in power generation, include the following:

- Reducing the use of air conditioning, central heating, and elevators
- Encouraging more energy-efficient practices by setting efficiency standards, providing financial incentives through tax differentiation based on efficiency, and raising public awareness
- Imposing earlier closing hours on retailing and offices and introducing daylight savings time
- Reducing the length of the working week
- Imposing power rationing (the most radical approach)

Global experience indicates that increasing energy efficiency is important. Bacon and Bhattacharya (2007) show that, to the extent that rising fossil fuel consumption with rising GDP is offset, the offsets have been largely due to falling energy intensity (energy consumed per unit of GDP). Subsequent analysis shows that this has been achieved mainly through lowering energy intensity in each sector, and not by structural changes in the economy—for example, shifting out of manufacturing to the service sector (Lamech, Kojima, and Bacon 2007).

Fuel switching is another way of reducing dependence on oil. In the transport sector, three alternative energy sources are natural gas, electricity (mostly hybrid vehicles), and biofuels. Compressed natural gas is particularly suitable in countries with domestic gas production and where urban centers already have a network of pipelines. Conditions that make use of natural gas economic are reviewed by Gwilliam, Kojima, and Johnson (2004). Hybrid gasoline-electric or diesel-electric vehicles are only now beginning to be deployed on a commercial scale. Biofuels are being increasingly mandated in countries around the world, but the need for significant subsidies remains a barrier. Additionally, there are concerns about increasing correlations between oil and biofuel feedstock prices, and the upward pressure that will have on food prices (Kojima, Mitchell, and Ward 2007).

In the power sector, non-oil options are natural gas, coal, hydropower, nuclear power, and renewable energy such as geothermal, solar, and wind. These are not quick solutions but normally form part of a longer term power development plan: building a large-scale hydroelectric power plant, for example, takes years. The feasibility of switching to renewable electricity also depends on natural resource endowments (for example, availability of geothermal power).

Many countries are considering switching from oil and natural gas to coal for power generation. Some are even examining small-scale coal applications in remote areas and small island economies, where diesel is currently used. Given the large and possibly widening price gap between coal and hydrocarbons, as shown in figure 8.3, this may make sense in financial terms. When environmental externalities, which are poorly priced at the moment, are taken into account, switching to coal brings with it new problems. How to strike a balance between affordability and energy security on the one hand and environmental sustainability on the other is a challenge that merits careful consideration.

9 Conclusions

During the last 20 years, international oil prices have experienced dramatic changes. From a period of relative stability between the mid-1980s and the end of the 1990s, prices remained near US$20 a barrel, with the exception of a short-lived price spike during the first Persian Gulf War. From the end of the 1990s until the beginning of 2004, prices fluctuated but not to the extent of indicating the subsequent development in which their levels rose in real terms to above their historic maximum.

The path of price changes has not followed a smooth evolution over time; even during the last three years, there have been periods where prices declined by a large margin, only to rise further subsequently. These variations in prices add to the difficulties of planning ahead for governments, businesses, and consumers.

Statistical Analysis of Price Volatility

A statistical analysis of prices over the period 1986–2007 was able to establish certain important features. Both for the period as a whole and for three subperiods within this range, crude oil and oil product prices in nominal and real U.S. dollars were, in almost all cases, nonstationary with the exception of the first subperiod. There was no measurable tendency for prices to return to a mean value. Cochrane test statistics appear to suggest that shocks to the prices have both permanent and temporary components. This finding was also confirmed for five developing countries, when measuring prices in local currency. The one exception to this general tendency was in the first subperiod (1986–99) when some product and crude oil prices were stationary and therefore showed a tendency to revert to a mean value. The nonstationarity of prices has far-reaching implications for policy makers. Because current prices are presently giving only weak clues as to prices in the coming months, governments must consider a wide range of possible outcomes and plan accordingly. They also need to acknowledge that their policies may come into operation at a time when prices differ substantially from those projected.

The magnitude of this uncertainty about price behavior is measured in this report by the volatility of prices. This volatility is calculated as the standard deviation of returns (defined as the change in the logarithms of successive prices) and is used to compare prices in different subperiods and in various countries. Volatility is lowest measured on a daily basis, and highest measured on a monthly basis, which is relevant for governments making planning decisions based on average prices taken over longer time intervals.

For oil products, the volatility in daily prices was lowest in the earliest subperiod. This finding should be interpreted in terms of the measurement of volatility: for small values, the average return is approximately the average percentage change in prices from subperiod to subperiod observed during the period in question. Since prices were, on average, substantially higher in the third subperiod, the volatility in that subperiod corresponds to a larger average absolute change in prices than in the second subperiod.

The volatility of oil product prices was generally higher than that of crude prices, with gasoline exhibiting the greatest volatility. During the second and third subperiods, the volatility of the monthly average prices of most products approached a value of 0.1, indicating average month-to-month price changes of about 10 percent. This level of volatility, coupled with the lack of mean reversion in the level of prices, indicates why a successful policy to cope with volatility would be a valuable policy tool.

Studies in other markets have indicated that period-to-period measures of volatility show clustering—a large price swing in one period tends to be followed by a large price swing in the next. Recent history would then be a likely guide to the amount of volatility to be expected in the near future. Tests for clustering of volatility for U.S. price data using a GARCH model indicated that, for data based on daily prices—and, to a lesser extent data based on weekly average prices—volatility exhibited mean reversion. That is, there was clustering, but the effect died down over time, and the volatility tended to return to a mean value. It was difficult to establish any temporal pattern for volatility for monthly average price data, and a tendency to clustering could not be clearly identified. This pattern for monthly price data was also found in a sample of five developing countries, most markedly for the period from 2000 to 2007. More complex statistical analysis might reveal whether there is any underlying pattern in the sequential volatility of oil prices. At this point, however, it appears that there is little to guide policy makers as to the magnitude of volatility in subsequent periods, beyond the levels most recently experienced. This result has significance for those designing strategies that require a quantification of volatility in future periods, such as hedging.

A further aspect of the temporal pattern of oil prices is that of the sequential patterns of deviations from the underlying trend. Fitting a Hodrick-Prescott filter to oil prices produces a series that follows all the main fluctuations but with a smoother path from period to period. This series can be taken as a representation of how price expectations might be continuously revised as new data become available, and governments could take these trend values as those around which to build policies.

The deviations from this trend measure the temporary costs of basing policies on trend values rather than on international market prices. Tests using daily and weekly data for the presence of runs in these deviations indicate that the number of runs (sequences of the same sign for the deviations between actual and trend) was significantly below expectation, especially for residual fuel oil and propane. However, based on monthly average data, the number of runs was as would be expected if successive deviations from trend were independent. The monthly data for the five developing countries again indicated that, generally, the number of runs was not significantly different from that expected in the independent case.

Although the number of runs based on monthly average prices was generally consistent with successive deviations from trend being independent, the cumulated value of the deviations exhibited some lengthy sojourns (the period of time for which the cumulative sum remained the same sign). Based on monthly data, the longest sojourns for crude and for oil products were in virtually all cases longer than three years, and often between four and five years. And again in virtually all cases, the longest sojourns corresponded to a period when the cumulative cycles were positive. This finding has a very important implication for schemes in which the government tries to smooth prices through some form of target trend and plans to temporarily finance the differences from international prices. Such attempts could well remain in deficit for long periods, which could be politically difficult to handle. The maximum sojourns were much shorter and cumulative cycles were on average negative if daily prices are traced. However, operating an oil account for price smoothing based on daily prices would mean revising prices and transferring money in and out of the oil account on a daily basis, thereby increasing both end-user price fluctuations and administration costs.

There can be large differences in the behavior of price levels between prices denominated in U.S. dollars and those in other currency units due to exchange rate fluctuations. Price increases in the past four years have not been as large in the countries where the local currency has strengthened against the U.S. dollar in the face of the dollar's recent general depreciation. However, when price volatility is examined, exchange rate appreciation appears to have done little to moderate price volatility in the five developing countries examined. In several cases, exchange rate fluctuations seem to have increased, rather than reduced, the volatility of crude oil and oil product prices.

A number of policies have been used or considered for possible use in reducing the adverse effects of price volatility on economic agents. These policies fall into two classes. A first group of policies attempts to transfer the volatility of oil prices from the ultimate purchasers of the oil or products to another party. In the case of hedging, the counter-party is the futures market itself; while for security stocks and price-smoothing schemes, the counter-parties are effectively taxpayers in the country who are temporarily financing the costs of running the schemes. A second group of policies looks to manage volatility by reducing the level of oil consumption place the burden on individual users by providing disincentives or restrictions on its use.

Hedging

Hedging is widely used by the private sector to reduce the risks arising from volatility, and thus it might appear to be a prime candidate for governments to use as well. The statistical analysis of simple hedging strategies over the period studied in this report revealed important drawbacks to this approach. The efficiency of hedging crude on the futures market increased with the length of the duration of the hedge—contracts 24 months ahead provided the greatest risk reduction—but, at the same time, the value of the unhedged return was much greater than that of the hedged return for sellers of crude or of products. By the same token, the value of the hedged return was greater than the unhedged return for buyers of crude. For gasoline and heating oil, which were evaluated over a three-month contract duration, the hedged return was again greater than the unhedged return for buyers of product.

For sellers of crude oil or oil products, the gains of consistently selling on the spot market would have been larger than those from consistently selling on the futures market at durations ranging from 3 to 24 months. This difference was found for each of the three subperiods, including the first in which prices did not show a strong upward trend. However, the largest differences in returns between the two strategies were found in the most recent period.

For buyers of crude oil or oil products, hedging appears to have been a very attractive strategy, when purchasing forward could have both reduced risks and secured a lower price than the spot market for the commodity itself. Crucially, this strategy would have required agents to be able to anticipate the general rise in prices that occurred during the period. Since the futures prices so consistently underestimated the actual spot prices that emerged, it is difficult to believe that governments could have made better estimates of the prices that would actually emerge. The possibility of incurring large losses in the futures market, as must have happened to any seller using it consistently, is a clear indication of the dangers of relying on hedging for a commodity whose prices are so volatile and whose medium-term movements are so unpredictable. The possibility of consistently underestimating future prices in an upswing period, as has recently been experienced, is well illustrated by the length of sojourns of cumulative cycles. For countries that sell other crudes, or that need to purchase products other than gasoline or heating oil, the basis risk created by differentials between these prices and those quoted on the futures markets further reduces the attractiveness of hedging strategies.

Options contracts are designed to reduce the possibilities of regret by allowing contracts to expire when they appear to turn out to be unfavorable. However, at a time of widely varying prices and uncertainty about the general movement of prices in the market, the upfront costs of using options may well be a strong disincentive to governments for using options as a long-term strategy. The lack of widespread government endorsement of hedging strategies in the oil market is an important indication that such strategies appear to have substantial drawbacks. Overall, futures or options are an important risk-reducing strategy when there is strong evidence that prices will fluctuate around a mean value, or when the agent is certain about the overall direction of prices. The history of oil prices during the period, which did not exhibit mean-reversion, and when spot prices failed to be predicted by earlier futures prices, indicates why this strategy has not been more widely used as a long-run policy instrument.

Strategic Stocks

Many countries mandate the private sector to hold stocks above the levels required for commercial operations; in a few cases, the government finances its own security stocks. These stocks have been intended primarily as a buffer against rare but large disruptions of the physical supply of crude oil or oil products. There has been some discussion of the use of these stocks to smooth out extreme price increases—themselves caused perhaps by sharp changes in the actual or expected global supply of oil. Simulations of the benefits and costs of using security stocks to place a cap on these exceptional price increases suggest that this policy is likely to be most effective in a period of broadly rising prices, when the government has been able to buy low and sell high (but below international prices), thus obtaining a contribution to the costs of running the scheme. The history of oil price behavior indicates that it is difficult to identify such an episode before it happens. During a period of price mean reversion, when there may be a short-lived but exceptional event, the security stock can be effective in reducing the level and volatility of domestic prices. But the carrying costs of a scheme, where there is little opportunity to make a capital gain on holding the stocks, will be substantial.

Price-Smoothing Schemes

The most commonly used policy for reducing oil price volatility is price smoothing. The government lowers domestic prices at times of higher than "normal" international prices by lowering taxes or by increasing subsidies; it balances these costs by raising domestic prices at times of low international prices by increasing taxes or decreasing subsidies. Governments have generally not attempted to smooth prices around a constant level, effectively recognizing that price behavior is not mean-reverting. Instead, they have adjusted the target price, around which domestic prices are to be smoothed to follow the general trend of international prices.

The simulations carried out in the study indicate that price-smoothing schemes in which the target price is determined by a moving average of past spot (or futures) prices can be effective in reducing the volatility of domestic prices to consumers. The largest reductions were achieved with the longer moving averages. During periods of increasing international prices, the moving averages lagged behind, and there would have been an increasing financing burden for the government. This effect was larger when longer moving averages were used.

The use of a modified scheme with intervention only when international prices are outside a ceiling and floor price band (as is used in Chile) provides a method of obtaining a trade-off between the costs during a period of increasing prices and the reduction in volatility. The narrower the price band, the more the reduction in volatility, but the greater the financing costs to the government while prices are tending to increase. The evidence from sojourns data is particularly relevant to this approach. The cycles—which are the difference between the international actual price and the filter price, which is effectively a smoothed moving average of past prices—exhibited very lengthy periods in which their cumulative value corresponds to a continuous government financing deficit. Sojourns of five years or even longer were exhibited by many of the crude oil and products values in U.S. dollars and in local currency. Persistent deficits of this nature in an oil account may well be politically unsustainable. Governments that rely on ad hoc increases in the target price, made at irregular intervals when the possibility of increasing domestic prices seems politically acceptable, run the risk of very rapidly accumulating extremely large deficits, as was the case in Thailand.

Reducing the Importance of Oil Consumption

A different policy response to oil price volatility is to attempt to reduce its impact by reducing the relative importance of oil consumption. In this case, the volatility could remain the same for each unit consumed, but with the reduction in the number of units consumed, the aggregate significance of the volatility would be reduced. Schemes to reduce the impact of high oil prices by reducing demand therefore also reduce the aggregate effects of its volatility.

In 2006, nearly one-quarter of the 163 countries analyzed spent a sum greater than 10 percent of their current GDP on oil; for a quarter of the sample, 2006 was the year when this ratio was greatest during the period 1980–2006. Many countries have not been improving the ratio of physical oil use to real GDP during the period—only one-quarter of the sample experienced the lowest value of this ratio in 2006. These two sets of statistics indicate the need for strong policies to reduce the use of oil relative to GDP in a climate of very high prices and high price volatility.

A statistical analysis of the prices of competing fossil fuels revealed that the volatility of oil prices has been greater than that of gas prices in Europe (but lower than that of gas prices in the United States) and of spot coal prices. Further, correlations between the price volatility of different fuels are weak. At the same time, the gap between oil and gas prices on the one hand and coal prices on the other has been widening. These findings point to the possibility that countries may plan to diversify away from oil (and possibly even from gas) by increasing the share of coal in those uses where the fuels can be substituted, in order to lower both costs and cost volatility. An analysis of the overall diversity of six energy sources used in 2005 revealed that more than half the 181 countries in the sample had a Herfindahl-Hirschman diversification index of greater than 0.5, which is the equivalent of being equally dependent on just two fuels with equal market shares. Twenty-two countries were entirely dependent on oil, and 60 countries had a share of oil in total energy use of greater than 75 percent.

Some policies to reduce oil dependence revolve around pricing and taxation, but the higher domestic prices which may lead to lower consumption inevitably place burdens on consumers. Other policies to limit the consumption of oil products in the transportation sector—or the use of electricity where this is substantially fueled by oil products—are widely discussed but do not yet appear to have been implemented on a sufficiently broad scale to make an appreciable difference in oil consumption. Other studies have indicated that the most promising route to lowering oil consumption is to improve energy efficiency, and that policies focusing on end uses that involve the use of oil products along the supply chain should be pursued.

Annex 1

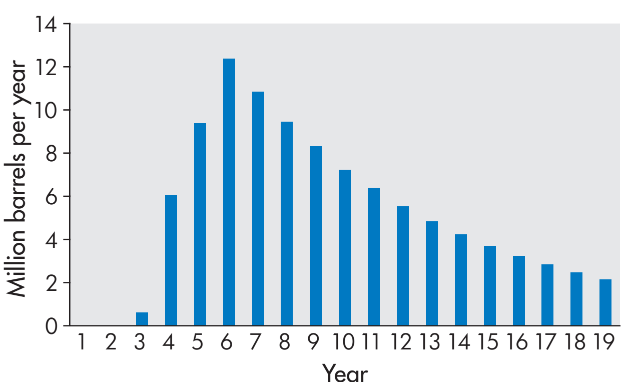
Impact of Fiscal Parameters on Government Oil Revenue

This annex takes an oil-producing country and gives a simplified illustration of the impact of varying fiscal parameters on government oil revenue. The annex examines the trade-off between revenue volatility and government income. It considers two fiscal regimes, one regressive (whereby the government take in percentage declines with increasing oil price) and the other progressive. The annex takes a hypothetical field that, over 19 years, produces 100 million barrels of oil. It then overlays them so that a field with the same production profile and cost structure is coming on stream every two years until a steady production level is reached. The simulation also assumes a constant cost structure in real terms. The combined effect of overlapping producing fields and assuming a constant cost structure is to remove volume and production cost volatility and leave oil price volatility as the main cause of revenue volatility.

The production profile and associated costs are taken from Johnston (2003). The production profile of each field and the sum of annual oil production from all producing fields are shown in figures A1.1 and A1.2, respectively. Calculation of government revenue starts in year 1 in figure A1.2, when 14 fields are producing oil. By then, the first field to have come on stream is in the 16th year of operation.

Figure A1.1

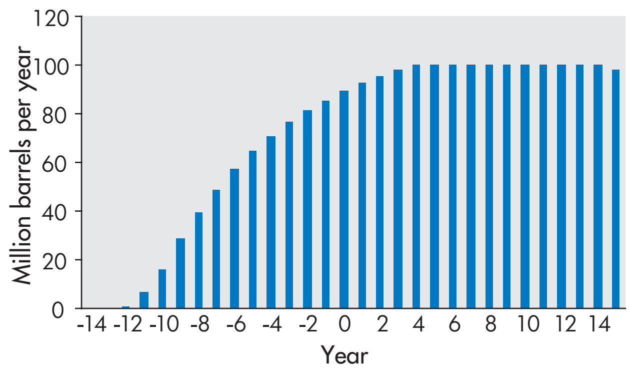
Production Profile of Each Field



Source: Johnston 2003.

Figure A1.2

Aggregate Production Profile of All Fields



Source: Author calculations.

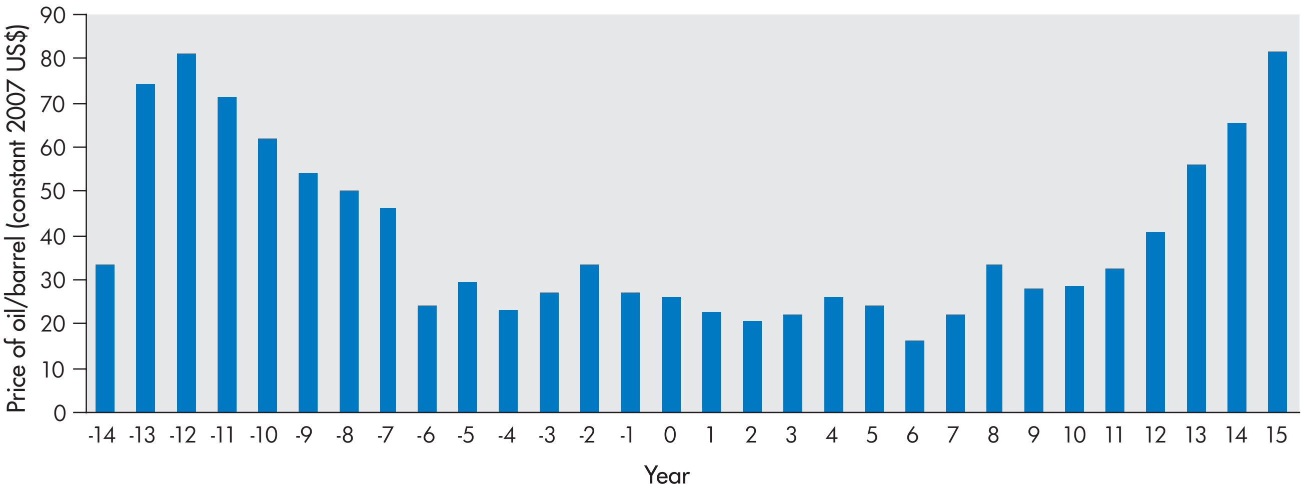
Historical spot prices of a basket of three marker crudes—Brent, Dubai, and WTI—expressed in constant 2007 U.S. dollars are used for calculating government revenue. They are taken from the annual average prices between 1978 and 2007; for 2007 (year 15), the monthly average price in October 2007 is used so as to amplify volatility. The prices are shown in figure A1.3.

This annex considers two production-sharing agreements (PSAs). PSAs normally provide for the sharing of production rather than profits. The state, which owns all petroleum, transfers title to a portion of the extracted oil and gas to the contractor at an agreed delivery point. The contractor is responsible for all financing and technology required for petroleum operations and bears the risks. Typical revenue streams in a PSA are shown in figure A1.4. Oil produced is split into cost oil, profit oil, and royalty. The payment streams in figure A1.4 are explained below.

- *Royalties* are based on the volume or value of oil extracted. They are paid as soon as commercial production begins, thereby providing early revenue to the government. They also ensure that contractors make a minimal payment. Simple royalties—for example, 10 percent of the value of the oil extracted—

Figure A1.3

Oil Prices Used in the Calculations



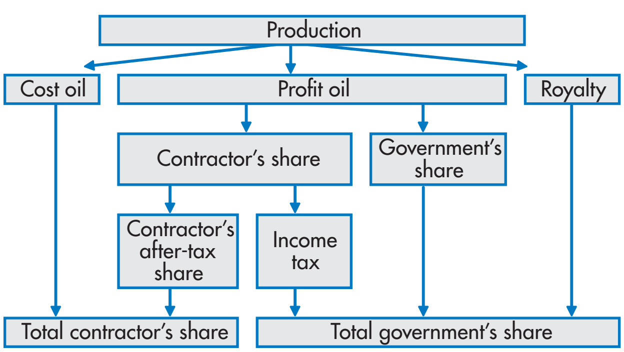
Source: Authors.

are easy to administer, but do not take into account the profitability of the project and hence are regressive. As such, royalties deter investment. One way of redressing this is to make the royalty rate depend on the level of production or the price of oil, increasing it with increasing production or oil. The rationale is that larger production levels lead to greater profitability because of economies of scale (this is not always the case, because many factors other than the scale of production affect a project's profitability), and similarly higher oil prices lead to greater profitability. In those cases, royalties are said to be on a sliding scale.

- *Cost oil* refers to the oil retained by the contractor to recover the costs of exploration, development, and production. Most PSAs limit the amount of cost oil that can be retained in a given accounting period. Costs that are not recovered are carried forward and recovered later; most PSAs allow virtually unlimited carry-forward. It is another avenue available to the government to ensure early revenue.
- *Profit oil* is the share of production remaining after the royalty is paid and cost oil has been retained by the contractor. In its simplest formulation, the agreement may stipulate that the profit oil be split, for example, 30/70—the contractor's share being 30 percent and the government's share 70 percent—irrespective of world oil price or production level. Production sharing can also be on a sliding scale: the government's percentage share can increase with increasing production level, cumulative production, or rate of return.
- *Income tax* is paid after production is shared in this figure; it is also possible to write a PSA in which income tax is paid before production sharing. In the figure, the contractor is subject to income tax based on taxable income.
- *Bonuses* are the most regressive fiscal parameters and give early revenue to the government. Signature bonuses are paid when the contract becomes effective and can be considerable in highly prospective areas.

Figure A1.4

Production-Sharing Revenue Flow



Source: Authors.

The fiscal parameters used in this annex are given in table A1.1. The first case considered is regressive: royalty, tax, and production-sharing rates do not increase with increasing net-of-cost income. There is a signature bonus of US$20 million, the royalty rate is fixed at 10 percent, and cost recovery for production sharing is restricted to 60

Table A1.1

Description of Two Fiscal Regimes

Parameter	Case 1	Case 2
Capital depreciation	Five-year straight line	Five-year straight line
Royalty	10%	Sliding scale as a function of oil price
Signature bonus	US$20 million	None
Taxable income	Gross revenue − (royalty + bonus + production share + eligible expenses)	Gross revenue − (royalty+ bonus + eligible expenses)
Income tax	30%	30%
Production share	70%	Sliding scale as a function of IRR
Cost oil ceiling	60%	None

Source: Authors.

percent in any given accounting period. All these provisions are designed to ensure early revenue. The government receives 70 percent of profit oil. After these payments, the contractor pays an income tax of 30 percent on profits derived from the remaining income. The second case does not have a signature bonus and has sliding scale royalty and production-sharing schedules (table A1.2). The royalty rate does not reach 10 percent (the rate set in the first case) until the extracted oil fetches at least US$25 a barrel. As the oil price increases, however, the royalty rate rises with it and reaches a maximum of 40 percent above US$60 a barrel. The government's share of profit oil increases with increasing internal rate of return (IRR) of the project, reaching 70 percent (the rate in case 1) when the IRR is between 30 and 35 percent, and as high as 90 percent when the IRR exceeds 50 percent.

Government revenues from the first field to come on stream in the two fiscal cases are shown in figure A1.5. Year 1 in the figure corresponds to year –14 in figure A1.3. Case 1 indeed gives higher early revenue to the government, but, starting in year 6, when the project has recovered capital expenditures and become profitable, the government revenue surpasses that in case 1 and remains higher for the rest of the life of the field. The cumulative revenue to the government is US$2.85 billion in case 1 and US$3.21 billion in case 2.

On the other hand, the sixth field to come on stream faces many years of low oil prices. In instances where project profitability is low, the regressive fiscal regime ensures early revenue to the government, as shown in figure A1.6, and a slightly higher cumulative income to the government.

Annual government revenues in the two fiscal cases from all fields, beginning in year 1 in figure A1.2, are shown in figure A1.7. The difference is evident in the last few years when oil prices are high.

The revenue flows given in figure A1.7 are analyzed using four different discount rates (table A1.3). At a discount rate of zero—equivalent to valuing income to future generations the same as income today—revenue volatility is greater in the more progressive of the two cases. As the discount rate is increased—which may be justified if there are urgent basic infrastructure needs such as provision of electricity and water for which the government needs funding now rather than in the future—the difference in revenue volatility diminishes, and, at a discount rate of 15 percent, the two cases give essentially the same results.

Table A1.2

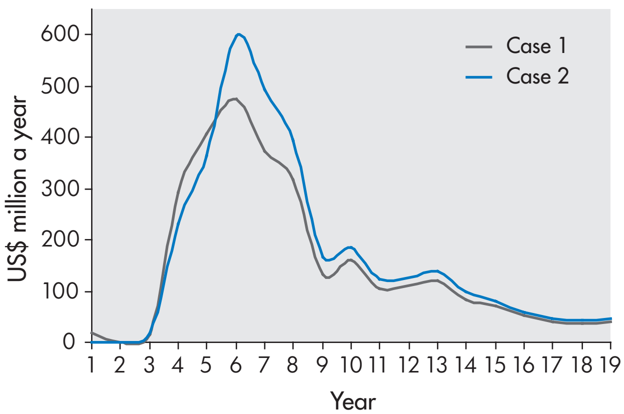
Sliding Scale Royalty and Production Sharing in Case 2

Oil price (US$/barrel)	**< 20**	**20–25**	**25–30**	**30–35**	**35–40**	**40–45**	**45–50**	**50–60**	**> 60**
Royalty, %	5	7.5	10	15	20	25	30	35	40
IRR threshold, %	**< 20**	**20**	**30**	**35**	**40**	**> 50**			
Gov't share of profit oil, %	0	40	70	75	80	90			

Source: Authors.

Figure A1.5

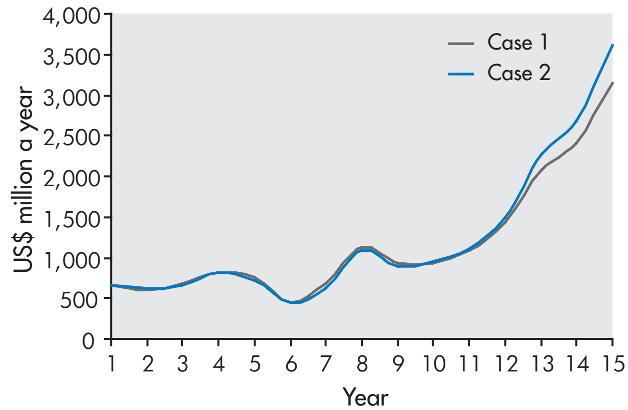
Government Revenue from First Field to Come on Stream



Source: Author calculations.

Figure A1.7

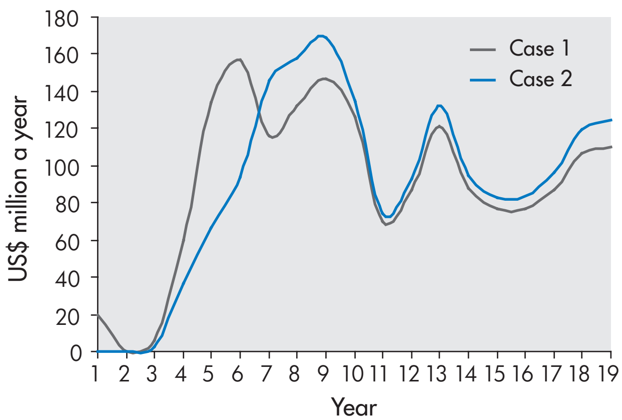
Government Revenue from All Fields



Source: Author calculations.

Figure A1.6

Government Revenue from Sixth Field to Come on Stream



Source: Author calculations.

This simple illustration shows that the ability of fiscal parameters to reduce revenue volatility in the face of widely fluctuating oil prices is limited. This annex considered two hypothetical cases that differed widely in their progressivity. But even these two extremes did not narrow volatility markedly. For example, the ratio of maximum annual revenue to minimum annual revenue is 7 under case 1 and 8 under case 2. The price the government adopting case 1 pays for reducing volatility somewhat is to forfeit about US$850 million (undiscounted) in income during the 15-year period.

In practice, the political pressure to maximize government revenue in times of high oil prices is likely to lead to opposition to a fiscal regime that may reduce revenue volatility somewhat, but will also discourage the government from enjoying windfall income when oil prices are high. The degree of this political pressure has been evident in recent months, when government after government in oil-producing countries and provinces have proposed revisions to the fiscal regime—all designed to allow the government to participate more in the gains from record oil prices.

For this reason, rather than attempting to reduce revenue volatility, it is generally recommended that governments focus on smoothing budget expenditures through long-term, well-planned, disciplined budget planning and execution. A few oil producers have used an oil fund successfully for this purpose. Expenditure smoothing faces enormous challenges of its own, but that is a topic for another study.

Table A1.3

Cumulative Government Revenue at Different Discount Rates (US$ million)

	0% disc. rate		5% disc. rate		10% disc. rate		15% disc. rate	
Parameter	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Min. annual rev.	445	449	341	343	264	266	207	208
Max. annual rev.	3,145	3,602	1,550	1,775	790	904	620	607
Max. difference	2,700	3,153	1,210	1,432	526	639	413	399
Median annual rev.	929	900	648	635	521	514	364	384
Avg. annual rev.	1,187	1,243	755	782	514	526	372	377
Standard deviation	771	910	318	388	137	166	117	117
Coefficient of variation	0.65	0.73	0.42	0.50	0.27	0.32	0.31	0.31
Cumulative rev.	17,802	18,649	11,330	11,726	7,714	7,894	5,584	5,658

Source: Author calculations.

Annex 2

Statistical Methods

This annex defines statistical terms and describes the statistical methods used in the study. Consider a series that is a function of time. $X(t)$ is used to designate the value of the series at a given period t. $X(t-1)$ represents the value of X at one period before t, and more generally $X(t-k)$ the value of X at k periods removed from t in the past.

Unit Roots

A series $X(t)$ has a unit root if it is generated by a process:

$$X(t) = \beta\, X(t-1) + \varepsilon(t), \qquad \text{(A2.1)}$$

where β is equal to unity and $\varepsilon(t)$ is a stationary random disturbance term. When β is less than unity, the process is stationary.

Augmented Dickey-Fuller Test

A test for a unit root in a series $X(t)$ performs the least squares regression of the first difference in X on the lagged value of X and, if desired, a constant, a linear trend, and lagged values of the difference in X. Standard tables exist for testing the null hypothesis that the process has a unit root (the coefficient of the lagged price level is zero). In this study, the equation included a constant and a trend, and the number of autoregressive terms (terms from previous time periods) was selected automatically by the program to minimize the Schwartz information criterion, which is a statistical criterion for equation specification selection.

Cochrane's Variance Ratio Test

A number of authors, including Pindyck (1999) and Reinhart and Wickham (1994), have noted that if the price level is generated by a stationary process—one whose mean and variance remain constant over time—for which the coefficient on the lagged price is near unity, standard ADF tests have very little power. That is, if there is no unit root, chances of maintaining that there is a unit root will be high, and only with very lengthy time series of data is it possible to distinguish between a process with a unit root and one that "almost" has a unit root. This point is important because the long-run behavior of these two models is different: the former has no tendency to revert to a long-run mean and all shocks are permanent, while the latter does revert to some value eventually and shocks are temporary.

To provide more evidence on the extent to which shocks (changes in levels from one period to the next) are temporary, variance ratio tests introduced by Cochrane (1988) are used. These relate to the variance of the difference in prices that are k periods apart. The test forms the statistics

$$R_k = (1 \div k)\ \mathrm{Var}\,[X(t+k) - X(t)] \div \mathrm{Var}\,[X(t+1) - X(t)], \qquad \text{(A2.2)}$$

where R_k is the Cochrane's variance ratio and Var is variance. If X is not stationary, R_k will tend to unity as k increases; if X is stationary, the ratio will converge to zero. If the process is more general, combining both permanent (nonstationary) and temporary (stationary) components, the ratio will tend to a finite value less than unity but greater than zero.

The Hodrick-Prescott Filter

The HP filter is a smoothing method that is widely used to obtain a smooth estimate of the long-term trend component of a series. Given a time series $X(t)$, the procedure constructs a filtered series $S(t)$ that minimizes the following criterion:

$$\sum_{t=1}^{T} [X(t) - S(t)]^2 + \sum_{t=2}^{T-1} \lambda \{[S(t+1) - S(t)] - [S(t) - S(t-1)]\}^2, \qquad \text{(A2.3)}$$

where T is the end of the estimation sample and λ is a smoothing constant that depends on the length of the time aggregate used. Suggested values are 14,400 for monthly data and 62,500 for weekly data. The difference between the actual value and the filtered value is termed the cycle value $C(t)$, which is given by $C(t) = X(t) - S(t)$.

Returns

With the exceptions of figures 3.4 and 3.5 and where runs tests are performed, the return of a price series X in this study is calculated by

$$R_{\log}(t) = \log X(t) - \log X(t-1) = \log [X(t) \div X(t-1)], \quad \text{(A2.4a)}$$

where logarithms are used, thereby making returns dimensionless. The Taylor series expansion of $\log(1 + \varepsilon)$, where ε is small, suggests that, if $X(t) \div X(t-1)$ is close to unity, the return multiplied by 100 is proportional to the percentage increase in X from period to period. Otherwise, returns are calculated by

$$R(t) = X(t) - X(t-1) \quad \text{(A2.4b)}$$

Cycle returns, $CR(t)$, are always calculated by

$$CR(t) = C(t) - C(t-1) \quad \text{(A2.5)}$$

because cycles can be negative, and hence it is not possible to take logarithms of cycles.

Variance Equality Test

This test splits the total sample into two subgroups and calculates the sample variance of each. The test statistic for variance equality based on Fisher's F-distribution is

$$F(T_1 - 1, T_2 - 1) = \mathrm{Var}_1 \div \mathrm{Var}_2, \quad \text{(A2.6)}$$

where Var_i is the variance of subsample i, T_i is the number of observations in subsample i, and $T_1 - 1$ and $T_2 - 1$ are their corresponding degrees of freedom.

GARCH Models for Autocorrelation of Returns Variance

The GARCH approach allows for autocorrelation (correlation between the elements in a series at different points in time, also known as serial correlation) in the variances of the series in question over time. It specifies two equations. The first (mean) equation relates the variable of interest (the returns) to possible explanatory variables plus an error term. The variables might include a constant, a trend, lagged values of the returns, and any economic variables that might be thought relevant. The residuals are hypothesized to have a variance that is time dependent and can be modeled as a mixed autoregressive/moving average process. The mean equation might be represented by

$$R(t) = \alpha + \beta \text{ Trend} + \gamma R(t-1) + \varepsilon(t), \quad \text{(A2.7)}$$

where α, β, and γ are parameters to be estimated, Trend is a linear trend, and the variance of $\sigma(t)$ at time t is $\sigma^2(t)$.

The second (variance) equation in a GARCH(1,1) model would be represented by

$$\sigma^2(t) = \omega + \psi\, \varepsilon^2(t-1) + \chi\, \sigma^2(t-1), \quad \text{(A2.8)}$$

where ω, ψ, and χ are parameters to be estimated, and $\sigma^2(t)$ is the variance of the error term in equation A2.7. Such an equation is interpreted as indicating that this period's variance consists of a weighted average of a constant value, the new information about volatility experienced in the previous period (the ARCH term), and the estimated variance in the previous period (the so-called GARCH term). The GARCH term is in fact a weighted average of all past information of volatility to that date. The (1,1) refers to the presence of a first-order, moving-average ARCH term (the first term in the parentheses) and a first-order, autoregressive GARCH term (the second term in the parentheses). If the GARCH model reveals that there is autocorrelation in the error variances—that is, if $\omega + \chi$ is not equal to zero—then equation A2.8 can be used to construct estimates of the systematic and predictable component of the variance period by period (parallel to the single variance in the homoskedastic model). Because $\sigma^2(t)$ is based on past information on $\varepsilon^2(t-1)$ or on both $\varepsilon^2(t-1)$ and $\sigma^2(t-1)$, it is known as the conditional variance.

If $(\omega + \chi)$ is equal to zero, there is no autocorrelation in the variance term and it is homoskedastic. A series is homoskedastic if all its elements have the same finite variance. If $(\omega + \chi)$ is equal to unity, the long-run variance tends to infinity and the variance process is nonstationary. This is called the integrated generalized autoregressive conditional heteroskedasticity (IGARCH) process. All shocks to the variance would then be permanent. A Wald test can be carried out to test either of these null hypotheses. The half-life (H) of shocks to the variance is given by

$$H = \log(0.5) \div \log(\psi + \chi) \quad \text{(A2.9)}$$

Each equation can be checked for adequate specification to ensure that the residuals from the estimated mean equation and the estimated squared residuals do not exhibit autocorrelation.

Once statistically significant results are obtained, they can be subjected to further checks. One is a Lagrange multiplier test for ARCH in the residuals. This test is motivated by the observation that, in many financial time series where GARCH tests have been most extensively used, the magnitude of residuals appears to be related to the magnitude of recent residuals. Referred to as the ARCH test in the rest of this report, this tests for serial correlation in the residuals. Other checks are that both ψ and χ are positive, and that ψ, χ, and their sum do not exceed unity.

A further extension of the GARCH model has been explored in certain studies on volatility in the oil market. The threshold GARCH (referred to as TARCH) model considers asymmetry in volatility and changes the variance equation by splitting the term in ARCH into two variables—one for "good" news corresponding to a positive residual, and one corresponding to "bad" news when the residual is negative. If bad and good news have different impacts on the future variance of the series, there is said to be a leverage effect. Tests for equality can be carried out.

Runs Tests

Autocorrelation tests will be most successful when there is a regular and constant relationship between observations a fixed number of periods apart. In the case where there are sequential patterns but their strength varies over time, these tests may be less effective. Nonparametric tests can be used to test for less structured patterns. A test based on sequences of positive or negative returns (runs) can be used to investigate this form of clustering in the data.

A runs test—also called the Wald-Wolfowitz test—is a nonparametric test that checks the randomness hypothesis of a two-valued data series. In this study, signs of returns (positive or negative) are subjected to runs tests. A run is a sequence of consecutive equal values. For example, if the signs of monthly returns from January to December in a year are given by + + + +− − + + +− − −, then there are four runs in total, consisting of one run of four positive signs; two runs of, respectively, three positive signs and three negative signs; and one run of two negative signs. The Wald-Wolfowitz test is based on a normal distribution in which the actual number of runs (w) is compared to the expected number of runs and the standard deviation of the number of runs. For this purpose, the z statistic is $(w - \mu) \div \sigma$, where μ, the expected number of runs, is given by $[2N^+N^- \div (N^+ + N^-)] + 1$, and σ, the standard deviation, equals $\sqrt{(\mu - 1)(\mu - 2) \div (N^+ + N^- - 1)}$. N^+ is the number of positive values and N^- the number of negative values in the series.

Annex 3

Statistical Analysis of U.S. Gulf Coast Prices

This annex complements the results presented in chapter 3. It covers the analysis of daily, weekly, and monthly prices of WTI crude and oil products in the U.S. Gulf Coast.

Data Coverage

The price data used in this annex are taken from the Web site of the U.S. Energy Information Administration. U.S. Gulf Coast prices were chosen partly because of the location's proximity to where WTI crude's prices are quoted (Cushing, Oklahoma). The data are not uniformly available over all time periods. For each commodity type, the first month for which data are available is given in table A3.1.

Table A3.1

First Month When Price Data Are Available

Commodity	Start date
WTI	Jan. 1986
U.S. Gulf Coast regular gasoline	June 1986
U.S. Gulf Coast jet kerosene	Apr. 1990
U.S. Gulf Coast heating oil	June 1986
U.S. Gulf Coast diesel	May 1995[a]
U.S. Gulf Coast residual fuel oil	July 1993
Mont Belvieu, Texas, propane	July 1992

Source: U.S. EIA 2008a.

a. Prices in the U.S. EIA database appear for the first time in May 1995, but consecutive daily prices are not available until September 1995.

Testing for Stationarity

ADF tests were performed on nominal and real prices. Real prices are expressed in constant January 2007 U.S. dollars, adjusted using the consumer price index. The null hypothesis is that the price series has a unit root. If the ADF test statistic is larger than the critical value (shown here for 5 percent), then the null hypothesis holds and prices are not stationary. The test equation includes a time-trend variable that creates a series beginning at 0 in the first observation of the sample and increasing by 1 for each subsequent observation. The insertion of this trend variable allows for removal of a systematic increase in prices, thereby focusing attention on nonsystematic price changes.

Are Crude Prices Mean-Reverting?

The results for crude oil prices are shown in table A3.2. In most cases, the prices are consistent with a unit root and the series not being stationary. Real and nominal prices yield similar results. However, during the first subperiod, there is some evidence for the rejection of the unit root hypothesis, suggesting that prices appear stationary during that subperiod.

If the series "almost" has a unit root, with very slow mean reversion, the value may be sufficiently close to unity to be included in the confidence interval based on the ADF test. In that case, the test may not indicate the presence of mean reversion and falsely identify a series as being nonstationary. To gain a better understanding of such borderline cases, Cochrane test statistics were calculated. The results are given in table A3.3. According to table A3.2, only daily and monthly prices up to December 1999 are stationary, and all others are nonstationary. For the price series identified as being nonstationary, in no case does R_k converge to unity as k is increased, but neither does R_k rapidly decline to zero. Shocks to the prices appear to have both permanent and temporary components.

Are Oil Product Prices Mean-Reverting?

ADF tests were applied to nominal and real oil product prices in the U.S. Gulf Coast market. The results are shown in tables A3.4 to A3.6. The results for daily and monthly oil product prices are largely similar to those for crude oil prices. With the exception of the first subperiod, all product prices, whether nominal or real, are nonstationary. With weekly prices, nominal gasoline prices in each subperiod

Table A3.2

ADF Test Statistics for WTI Crude Oil

Averaging period	Beginning–Mar. 2007	Beginning–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Daily, nominal	−2.55	**−3.56**	−2.90	−2.44
Critical value at 5%	−3.41	−3.41	−3.41	−3.42
Daily, real	−3.15	**−4.08**	−2.89	−2.49
Critical value at 5%	−3.41	−3.41	−3.41	−3.42
Weekly, nominal	−1.98	−3.22	−2.83	−2.48
Critical value at 5%	−3.41	−3.41	−3.43	−3.44
Weekly, real	−2.49	**−3.77**	−2.43	−2.49
Critical value at 5%	−3.41	−3.42	−3.43	−3.44
Monthly, nominal	−1.77	**−4.34**	−2.12	−1.75
Critical value at 5%	−3.43	−3.44	−3.51	−3.53
Monthly, real	−2.30	**−4.74**	−2.08	−1.73
Critical value at 5%	−3.43	−3.44	−3.51	−3.53

Source: Author calculations.

Note: Values significantly different from a unit root are indicated in **bold**.

Table A3.3

Cochrane Statistics for Nominal Crude Oil Prices

Parameter	Rk							
Days	20	50	100	200	350	700	1,000	1,500
Full period	0.75	0.67	0.56	0.40	0.43	0.38	0.31	0.25
To end 1999	0.70	0.74	0.68	0.40	0.31	0.17	0.12	n.a.
2000–03	0.72	0.52	0.36	0.29	0.26	n.a.	n.a.	n.a.
Jan. 2004–Mar. 2007	0.81	0.68	0.53	0.31	0.28	n.a.	n.a.	n.a.
Weeks	10	20	35	50	75	100	200	350
Full period	1.10	0.93	0.74	0.68	0.73	0.72	0.54	0.50
To end 1999	1.26	1.17	0.76	0.63	0.50	0.39	0.20	n.a.
2000–03	0.84	0.58	0.52	0.46	0.39	0.24	n.a.	n.a.
Jan. 2004–Mar. 2007	1.10	0.89	0.69	0.38	0.47	0.26	n.a.	n.a.
Interval in months	5	10	20	35	50	75	100	n.a.
Full period	1.21	0.72	0.78	0.72	0.60	0.52	0.51	n.a.
To end 1999	1.58	0.75	0.45	0.31	0.23	0.10	n.a.	n.a.
2000–03	0.90	0.61	0.45	n.a.	n.a.	n.a.	n.a.	n.a.
Jan. 2004–Mar. 2007	1.00	0.37	0.27	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable.

Table A3.4

ADF Test Statistics for Daily U.S. Gulf Coast Oil Product Prices

Fuel	Beginning–Mar. 2007	Jan. 1986–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Gasoline, nominal	−3.17	**−4.22**	−3.26	−2.75
5%	−3.41	−3.41	−3.41	−3.42
Diesel, nominal	−2.54	−1.11	−2.70	−2.89
5%	−3.41	−3.41	−3.41	−3.42
Heating oil, nominal	−2.20	**−3.65**	−2.84	−2.62
5%	−3.41	−3.41	−3.41	−3.42
Jet kerosene, nominal	−2.69	−2.76	−2.82	−2.71
5%	−3.41	−3.41	−3.41	−3.42
Residual fuel oil, nominal	−2.76	−2.21	−2.26	−1.67
5%	−3.41	−3.41	−3.41	−3.41
Propane, nominal	−3.10	−2.19	−2.96	−2.85
5%	−3.41	−3.41	−3.41	−3.42
Gasoline, real	−3.27	**−4.49**	−3.27	−2.82
5%	−3.41	−3.41	−3.41	−3.42
Diesel, real	−2.64	−1.21	−2.70	−2.88
5%	−3.41	−3.41	−3.41	−3.42
Heating oil, real	−2.25	**−4.04**	−2.84	−2.65
5%	−3.41	−3.41	−3.41	−3.42
Jet kerosene, real	−3.26	−2.84	−2.82	−2.72
5%	−3.41	−3.41	−3.41	−3.42
Residual fuel oil, real	−3.22	−2.30	−2.23	−1.67
5%	−3.41	−3.41	−3.41	−3.42
Propane, real	−3.40	−2.28	−2.94	−2.97
5%	−3.41	−3.41	−3.41	−3.42

Source: Author calculations.

Note: For figures in **bold**, the null hypothesis is rejected at a 5 percent confidence level and the price series is stationary.

Table A3.5

ADF Test Statistics for Weekly U.S. Gulf Coast Oil Product Prices

Fuel	Beginning–Mar. 2007	Jan. 1986–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Gasoline, nominal	−1.87	**−3.72**	**−3.43**	**−3.55**
5%	−3.41	−3.42	−3.43	−3.44
Diesel, nominal	−2.29	−0.66	−2.93	−2.88
5%	−3.41	−3.43	−3.43	−3.44
Heating oil, nominal	−1.78	**−3.53**	−2.89	−2.04
5%	−3.41	−3.42	−3.43	−3.44
Jet kerosene, nominal	−2.24	**−3.69**	−2.85	−2.74
5%	−3.41	−3.42	−3.43	−3.44
Residual fuel oil, nominal	**−3.72**	−3.08	−3.07	−2.73
5%	−3.42	−3.42	−3.43	−3.44
Propane, nominal	−2.87	−1.83	−2.59	−2.59
5%	−3.41	−3.42	−3.43	−3.44
Gasoline, real	−2.04	**−3.99**	−3.42	**−3.52**
5%	−3.41	−3.42	−3.43	−3.44
Diesel, real	−2.41	−0.75	−2.89	−2.88
5%	−3.42	−3.43	−3.43	−3.44
Heating oil, real	−2.19	**−3.57**	−2.85	−2.01
5%	−3.41	−3.42	−3.43	−3.44
Jet kerosene, real	−2.49	**−3.89**	−2.81	−2.73
5%	−3.41	−3.42	−3.43	−3.44
Residual fuel oil, real	−3.98	−3.17	−3.02	−2.73
5%	−3.41	−3.42	−3.43	−3.44
Propane, real	−3.17	−1.91	−2.57	−2.72
5%	−3.42	−3.42	−3.43	−3.44

Source: Author calculations.

Note: For figures in **bold**, the null hypothesis is rejected at a 5 percent confidence level and the price series is stationary.

Table A3.6

ADF Test Statistics for Monthly U.S. Gulf Coast Oil Product Prices

Fuel	Beginning–Mar. 2007	Jan. 1986–Dec. 1999	Jan. 2000–Dec. 2003	Jan. 2004–Mar. 2007
Gasoline, nominal	−1.76	−3.36	−3.02	−2.67
5%	−3.43	−3.44	−3.51	−3.53
Diesel, nominal	−2.03	−1.52	−2.15	−2.14
5%	−3.44	−3.50	−3.51	−3.53
Heating oil, nominal	−1.54	**−4.29**	−2.19	−1.80
5%	−3.43	−3.44	3.51	−3.53
Jet kerosene, nominal	−1.86	**−4.59**	−2.07	−2.25
5%	−3.43	−3.45	−3.51	−3.53
Residual fuel oil, nominal	−2.67	−2.19	−2.07	−1.90
5%	−3.43	−3.47	−3.51	−3.53
Propane, nominal	−2.23	−2.94	−1.48	−3.47
5%	−3.44	−3.46	−3.51	−3.53
Gasoline, real	−1.92	−3.62	−3.02	−2.71
5%	−3.43	−3.44	−3.51	−3.53
Diesel, real	−2.12	−1.57	−2.10	−2.10
5%	−3.44	−3.50	−3.51	−3.53
Heating oil, real	−2.15	**−4.72**	−2.06	−1.75
5%	−3.43	−3.44	−3.51	−3.53
Jet kerosene, real	−2.03	**−4.83**	−2.02	−2.21
5%	−3.43	−3.45	−3.51	−3.53
Residual fuel oil, real	−2.84	−2.27	−2.04	−1.88
5%	−3.44	−3.47	−3.51	−3.53
Propane, real	−2.47	−2.97	−1.47	−3.42
5%	−3.44	−3.46	−3.51	−3.53

Source: Author calculations.

Note: For figures in **bold**, the null hypothesis is rejected at a 5 percent confidence level and the price series is stationary.

are stationary. In addition, nominal residual fuel oil prices for the entire period are stationary.

Cochrane test statistics were calculated, and the results for nominal prices are shown in tables A3.7 to A3.9. The entire period is covered in these tables, from the time shown in table A3.1 to March 2007. During this period, the only series that is stationary is that for weekly residual fuel oil prices. However, the results show no clear patterns that would suggest that weekly residual fuel oil prices alone are stationary.

Testing Returns and Their Variance

The basic mean equation related the return to a constant and several lagged values, while the variance equation utilized a GARCH(1,1) or GARCH(1,0) formulation. Estimates were carried out for crude oil and all oil products in nominal terms for the entire time period as well as for three subperiods. The order of the ARCH test was 9. For the variance equation covering the entire period, various trend variables were tested, and the one giving rise to the highest coefficient of determination (R^2) was selected. The trend variables were

- @trend, a trend term, which is a linear time trend that increases by one for each observation in the series
- pd1, a dummy variable for subperiod 1 (beginning of the price series to December 1999)
- pd2, a dummy variable for subperiod 2 (January 2000 to December 2003)
- pd3, a dummy variable for subperiod 3 (January 2004 to end March 2007)
- pdmar, a dummy variable for the period from the beginning of the price series to end March 1999
- pdjun, a dummy variable for the period from the beginning of the price series to June 1999

The variable pdmar was selected based on the findings by Lee and Zyren (2007) that the March 1999 change in OPEC production policy was found to have a statistically significant effect on the variance equation, which could be captured by inserting this dummy variable. The variable pdjun was examined because prices in local currencies in the five developing countries treated in annex 4 appeared to have the first break approximately between June and July 1999.

TARCH did not yield meaningful equations. Monthly data on OPEC spare capacity were available beginning in January 2001, but inclusion of a variable for OPEC spare capacity did not yield statistically significant coefficients.

Table A3.7

Cochrane Statistics for Nominal Daily U.S. Gulf Coast Product Prices

	Days							
Fuel	**20**	**50**	**100**	**200**	**350**	**700**	**1,000**	**1,500**
WTI crude	0.75	0.67	0.56	0.40	0.43	0.38	0.31	0.25
Gasoline	0.73	0.61	0.42	0.24	0.23	0.18	0.15	0.12
Diesel	0.58	0.48	0.35	0.24	0.28	0.22	0.15	0.11
Heating oil	0.68	0.57	0.47	0.33	0.38	0.31	0.25	0.20
Jet kerosene	0.82	0.67	0.50	0.30	0.34	0.29	0.22	0.17
Residual fuel oil	1.52	1.23	0.96	0.84	0.78	0.31	0.32	0.12
Propane	0.79	0.70	0.53	0.38	0.37	0.24	0.18	0.13

Source: Author calculations.

Note: Period covered is from beginning to end March 2007.

Table A3.8

Cochrane Statistics for Nominal Weekly U.S. Gulf Coast Product Prices

	Weeks						
Fuel	**10**	**20**	**35**	**50**	**75**	**100**	**200**
WTI crude	1.10	0.93	0.74	0.68	0.73	0.72	0.54
Gasoline	0.81	0.58	0.38	0.28	0.30	0.26	0.20
Diesel	0.97	0.74	0.55	0.51	0.58	0.55	0.35
Heating oil	1.00	0.84	0.64	0.60	0.67	0.64	0.46
Jet kerosene	1.02	0.78	0.52	0.47	0.52	0.49	0.37
Residual fuel oil	1.10	0.83	0.81	0.75	0.70	0.52	0.31
Propane	0.92	0.71	0.55	0.51	0.50	0.43	0.24

Source: Author calculations.

Note: Period covered is from beginning to end March 2007.

Table A3.9

Cochrane Statistics for Nominal Monthly U.S. Gulf Coast Product Prices

	Months					
Fuel	**5**	**10**	**20**	**35**	**50**	**75**
WTI crude	1.21	0.72	0.78	0.72	0.60	0.52
Gasoline	0.90	0.38	0.38	0.32	0.28	0.24
Diesel	1.06	0.60	0.69	0.62	0.40	0.35
Heating oil	1.21	0.70	0.78	0.70	0.56	0.50
Jet kerosene	1.09	0.56	0.62	0.58	0.45	0.39
Residual fuel oil	1.00	0.76	0.64	0.29	0.32	0.15
Propane	1.15	0.67	0.62	0.43	0.33	0.26

Source: Author calculations.

Note: Period covered is from beginning to end March 2007.

In a number of cases, more than one formulation was statistically significant with meaningful coefficients—that is, ARCH and GARCH coefficients are positive, their sum does not exceed unity, and there is no evidence of serial correlation for the mean equation. The set of equations that gave the simplest mean equation with the highest R^2 was selected. If the first lag had a statistically significant coefficient, higher order lags were retained as long as they were consecutive. Therefore, if lags 1, 2, 3, 4, and 5 all had statistically significant coefficients, they were retained; but if lags 1, 2, and 4 had statistically significant coefficients, then only the first two lags were retained, because 2 and 4 are not consecutive. Where GARCH(1,1) and GARCH(1,0) formulations gave meaningful results, both are shown.

The results for daily prices are reported in tables A3.10 to A3.15 for the entire period as well as for three subperiods. The tables show the sum of the ARCH and GARCH coefficients and the significance of the hypothesis that their sum is not less than unity based on a Wald test, as well as the estimated half-life of shocks to the conditional variance of returns.

When data from the entire period are taken, inclusion of one of the time-dependent dummy variables in the variance equation increases the R^2. In the case of heating oil, where the time-dependent variable is @trend, the coefficient associated with this variable is positive, indicating that the conditional variance increases with increasing time. In all cases, the conditional variance

Table A3.10

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, Beginning–March 2007

Parameter	WTI	Gaso-line	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Pro-pane
Statistically significant equation?	Yes	Yes	Yes D[a]	Yes	Yes	Yes	Yes	Yes
Finite half-life?	Yes	Yes	n.a.	Yes	Yes	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	0.99	0.99	n.a.	0.97	0.96	0.73	0.24	0.99
Half-life in days	87	101	n.a.	21	18	2.2	0.5	63
Lagged variables in mean equation	3	3	n.a.	1	1	1,2	1,2	None
GARCH order	(1,1)	(1,1)	n.a.	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)
Trend variables in variance equation	pd2	None	n.a.	Trend	None	pd2	pd2	pd2

Source: Author calculations.

Note: n.a. = not applicable. pd2 is a dummy variable for subperiod 2 (January 2000–December 2003); trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A3.11

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, Beginning–November 14, 2007

Parameter	WTI	Gaso-line	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Pro-pane
Statistically significant equation?	Yes	Yes	Yes D[a]	Yes	Yes	Yes	Yes	Yes
Finite half-life?	Yes	Yes	n.a.	Yes	Yes	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	1.00	0.99	n.a.	0.97	0.96	0.76	0.24	0.99
Half-life in days	168	92	n.a.	24	19	2	0.5	75
Lagged variables in mean equation	3	3	n.a.	1	1	1,2	1,2	None
GARCH order	(1,1)	(1,1)	n.a.	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)
Trend variables in variance equation	pd3	None	n.a.	Trend	None	pd2	pd2	pd2

Source: Author calculations.

Note: n.a. = not applicable. pd2 is a dummy variable for subperiod 2 (January 2000–December 2003); pd3 is a dummy variable for period 3 (January 2004–end March 2007); trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A3.12

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, Beginning–December 1999

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes D[a]	Yes	Yes D[a]	Yes	Yes	Yes	Yes	Yes D[a]
Finite half-life?	n.a.	Yes	n.a.	Yes	Yes	Yes	Yes	n.a.
Sum of ARCH + GARCH coefficients	n.a.	0.98	n.a.	0.97	0.97	0.45	0.08	n.a.
Half-life in days	n.a.	44	n.a.	21	17	0.9	0.3	n.a.
Lagged variables in mean equation	n.a.	3,5	n.a.	3	2	1,2,3	1,2,3,4	n.a.
GARCH order	n.a.	(1,1)	n.a.	(1,1)	(1,1)	(1,1)	(1,0)	n.a.
Trend variables in variance equation	n.a.	None	n.a.	None	None	Trend	Trend	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A3.13

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, January 2000–December 2003

Parameter	WTI	Gasoline		Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	0.80	0.68	0.96	0.96	0.94	0.94	0.80	0.33	0.90
Half-life in days	3	2	19	19	11	12	3	0.6	7
Lagged variables in mean equation	None	None	None	None	None	None	1	1	3
GARCH order	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)
Trend variables in variance equation	None	None	None	None	None	None	Trend	Trend	Trend

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

Table A3.14

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, January 2004–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	0.91	0.96	0.96	0.94	0.94	0.71	0.39	0.86
Half-life in days	n.a.	15	16	12	10	2.0	0.7	5
Lagged variables in mean equation	1	None	None	None	None	None	1,2	1
GARCH order	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)
Trend variables in variance equation	None	None	Trend	None	None	None	Trend	None

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

Table A3.15

GARCH Analysis of Returns of Logarithms of Nominal Daily Prices, January 2004–November 14, 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	0.96	0.94	0.96	0.97	0.94	0.71	0.32	0.95
Half-life in days	n.a.	11	15	23	11	2	1	15
Lagged variables in mean equation	1	None	None	None	1	None	1,2	1
GARCH order	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)
Trend variables in variance equation	None	None	Trend	None	Trend	None	Trend	None

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

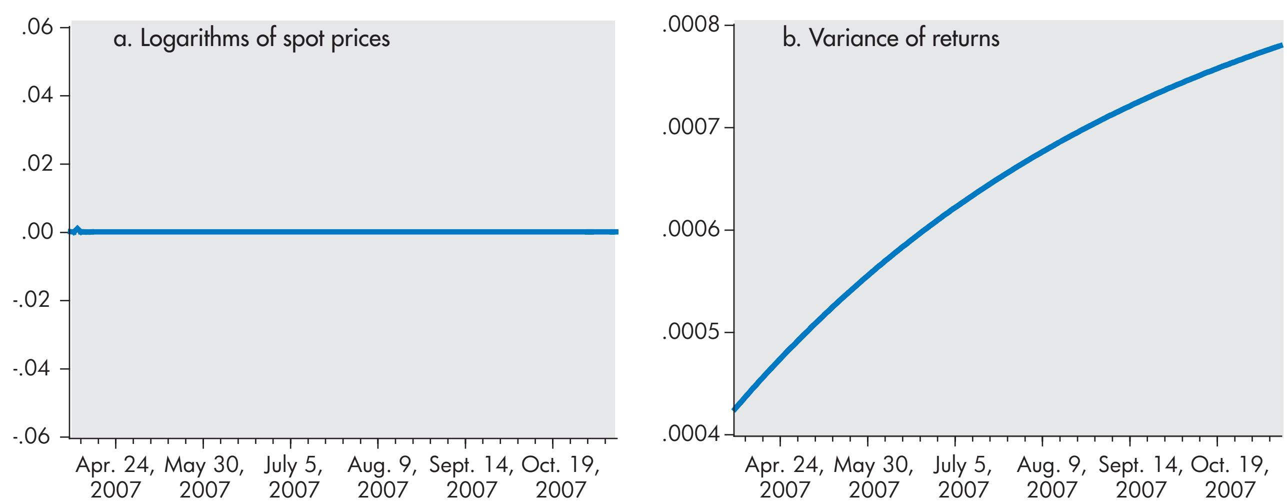
is stationary and has a half-life ranging from 0.5 days to more than 100 days. Residual fuel oil has two identical formulations, with and without the GARCH term. In the GARCH(1,1) formulation, the half-life is quadruple that for the GARCH(1,0) formulation.

The conditional variance generally is stationary in the subperiods, except WTI crude in the third subperiod. During the first subperiod, no set of meaningful mean and conditional variance equations could be found for WTI crude, jet kerosene, and propane. A longer half-life associated with a GARCH(1,1) formulation compared to a GARCH(1,0) formulation for residual fuel oil is observed in each of the three subperiods.

Comparison of tables A3.10 and A3.11, and of tables A3.14 and A3.15, shows that inclusion of data between the beginning of April and November 14, 2007, makes virtually no difference. The equation derived for WTI crude, shown in table A3.10, was used to perform out-of-sample testing and forecast returns and the variance of returns during this period. The forecast results were also compared with the actual price returns. These results are shown in figure A3.1. The mean absolute percentage error takes the absolute value of the ratio of the difference between the predicted and actual values (price return in this case) to the actual value. The result shows that the power of prediction is very poor. This is to be expected from the finding discussed in chapter 3

Figure A3.1

Forecast of Returns of Logarithms of WTI Crude Daily Spot Prices and Variance of Returns, April 4–November 14, 2007



Source: Author calculations.

that the systematic, predictable component of the variance has a weak correlation with historical variance and makes only a small contribution to the overall price volatility at each point in time in every case. Under the Theile inequality coefficient, the bias proportion indicates how far the mean of the forecast is from the mean of the actual series; the variance proportion indicates how far the variance of the forecast is from the variance of the actual series; and the covariance proportion measures the remaining unsystematic forecasting errors. These three components add up to unity. The results show that the forecast error is dominated by the variance proportion.

The results for weekly prices are shown in tables A3.16 to A3.19. For the entire period, the conditional variance is stationary and has a half-life ranging from less than a week to 12 weeks, except for a GARCH(1,1) formulation for propane. The GARCH(1,0) formulation, however, yields a stationary conditional variance. For the last subperiod, meaningful equations could not be found for WTI crude, diesel, and heating oil. Jet kerosene has a stationary conditional variance in all cases, except in the last subperiod. Propane has a stationary conditional variance in all cases if a GARCH(1,0) formulation is employed, but not GARCH(1,1).

Table A3.16

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices, Beginning–March 2007

Parameter	WTI	Gasoline		Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Sum of ARCH + GARCH coefficients	0.94	0.93	0.92	0.89	0.79	0.89	0.09	0.96	0.43
Half-life in weeks	12	10	8	6	3	6	0.3	n.a.	0.8
Lagged variables in mean equation	1,2	1	1,2	1	1	1,2	1,2	1	1
GARCH order	(1,1)	(1,1)	(1,1)	(1,1)	(1,0)	(1,1)	(1,0)	(1,0)	(1,0)
Trend variables in variance equation	Jun99	pd2	None	Jun99	None	None	Mar99	pd2	Trend

Source: Author calculations.

Note: n.a. = not applicable. pd2 is a dummy variable for subperiod 2 (January 2000–December 2003); Jun99 a dummy that is 1 for any week through June 1999; Mar99 a dummy that is 1 for any week through March 1999; trend is a linear time trend that increases by one for each observation in the series.

Table A3.17

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices, Beginning–December 1999

Parameter	WTI	Gasoline		Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes	Yes	No C[a]	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	No	Yes	n.a.	Yes	Yes	Yes	No	Yes	Yes
Sum of ARCH + GARCH coefficients	0.95	0.95	n.a.	0.91	0.92	0.33	0.96	0.33	0.43
Half-life in weeks	13	13	n.a.	7	9	0.6	n.a.	0.6	0.8
Lagged variables in mean equation	1	1	n.a.	1	1	None	1	1	1
GARCH order	(1,1)	(1,1)	n.a.	(1,1)	(1,1)	(1,0)	(1,0)	(1,0)	(1,0)
Trend variables in variance equation	None	None	n.a.	None	None	None	None	Trend	Trend

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A3.18

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices, January 2000–December 2003

Parameter	WTI	Gasoline		Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane
Statistically significant equation?	Yes D[a]	No C[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	n.a.	n.a.	Yes	Yes	Yes	Yes	No	Yes	Yes
Sum of ARCH + GARCH coefficients	n.a.	n.a.	0.14	0.14	0.15	0.90	1.0	0.42	0.43
Half-life in weeks	n.a.	n.a.	0.4	0.3	0.4	6.8	n.a.	0.8	0.8
Lagged variables in mean equation	n.a.	n.a.	None	None	1	1	1	1	1
GARCH order	n.a.	n.a.	(1,0)	(1,0)	(1,0)	(1,1)	(1,1)	(1,0)	(1,0)
Trend variables in variance equation	n.a.	n.a.	None	None	None	None	None	None	Trend

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A3.19

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices, January 2004–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil		Propane	
Statistically significant equation?	Yes D[a]	Yes	Yes	No C[a]	Yes D[a]	Yes	Yes	Yes	Yes
Finite half-life?	n.a.	Yes	No	n.a.	n.a.	No	Yes	Yes	Yes
Sum of ARCH + GARCH coefficients	n.a.	0.51	0.88	n.a.	n.a.	0.93	0.18	0.84	0.39
Half-life in weeks	n.a.	1	n.a.	n.a.	n.a.	n.a.	0.4	4	0.7
Lagged variables in mean equation	n.a.	None	1	n.a.	n.a.	1	None	1	1
GARCH order	n.a.	(1,0)	(1,1)	n.a.	n.a.	(1,1)	(1,0)	(1,1)	(1,0)
Trend variables in variance equation	n.a.	None	n.a.	n.a.	n.a.	None	None	None	Trend

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

The results for monthly prices are given in tables A3.20 to A3.25; there is no table for the last subperiod because no meaningful equations were found for any of the fuels. GARCH analysis was also carried out between June 1995 and March 2007, which corresponds to the time when price data are available for all fuels, which begins in June 1995. A meaningful equation could be found only for jet kerosene during this subperiod with a common database. Statistically significant equations exist in most cases, but they fail to satisfy the requirement that both the ARCH and GARCH coefficients be positive and sum to one or less or that there be no serial correlation. The conditional variance is stationary for heating oil (entire period and first subperiod), jet kerosene (entire period, first subperiod, and the subperiod beginning June 1995), and propane (first subperiod) only.

Tables A3.21 and A3.25 repeat GARCH analysis using data inclusive of October 2007. As with daily prices, the results are essentially the same as those not including the price series between April and October 2007. In particular, extending the price series examined in table A3.24 by 46 months does not yield statistically significant and meaningful equations for fuels that found none in table A3.24. While propane now has a finite half-life in table A3.25, the form of the mean equation in both tables A3.24 and A3.25 appears arbitrary, with lags of two and nine months (table A3.24) and of one and nine months (table A3.25) needed to satisfy statistical requirements.

Table A3.20

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, Beginning–March 2007

Parameter	WTI		Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Statistically significant equation?	Yes	Yes	Yes D[a]	Yes	Yes	Yes D[a]	Yes D[a]	Yes D[a]
Finite half-life?	No	Yes	n.a.	No	Yes	n.a.	n.a.	n.a.
Sum of ARCH + GARCH coefficients	0.82	0.29	n.a.	0.87	0.20	n.a.	n.a.	n.a.
Half-life in months	n.a.	0.6	n.a.	n.a.	0.4	n.a.	n.a.	n.a.
Lagged variables in mean equation	1	1	n.a.	1	1	n.a.	n.a.	n.a.
GARCH order	(1,1)	(1,0)	n.a.	(1,1)	(1,0)	n.a.	n.a.	n.a.
Trend variables in variance equation	None	None	n.a.	None	None	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.21

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, Beginning–October 2007

Parameter	WTI		Gasoline	Jet kerosene		Heating oil	Diesel	Residual fuel oil	Propane
Statistically significant equation?	Yes	Yes	Yes D[a]	Yes	Yes	Yes	Yes D[a]	Yes D[a]	Yes D[a]
Finite half-life?	No	Yes	n.a.	No	Yes	Yes	n.a.	n.a.	n.a.
Sum of ARCH + GARCH coefficients	0.82	0.29	n.a.	0.87	0.34	0.21	n.a.	n.a.	n.a.
Half-life in months	n.a.	0.6	n.a.	n.a.	0.6	0.4	n.a.	n.a.	n.a.
Lagged variables in mean equation	1	1	n.a.	1	None	1	n.a.	n.a.	n.a.
GARCH order	(1,1)	(1,0)	n.a.	(1,1)	(1,0)	(1,0)	n.a.	n.a.	n.a.
Trend variables in variance equation	None	None	n.a.	None	None	None	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.22

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, June 1995–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]
Finite half-life?	n.a.	n.a.	Yes	n.a.	n.a.	n.a.	n.a.
Sum of ARCH + GARCH coefficients	n.a.	n.a.	0.31	n.a.	n.a.	n.a.	n.a.
Half-life in months	n.a.	n.a.	0.6	n.a.	n.a.	n.a.	n.a.
Lagged variables in mean equation	n.a.	n.a.	10,13,15	n.a.	n.a.	n.a.	n.a.
GARCH order	n.a.	n.a.	(1,0)	n.a.	n.a.	n.a.	n.a.
Trend variables in variance equation	n.a.	n.a.	None	n.a.	n.a.	n.a.	n.a.

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.23

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, Beginning–December 1999

Parameter	WTI	Gaso-line	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Pro-pane
Statistically significant equation?	Yes	Yes D[a]	Yes	Yes	Yes D[a]	Yes D[a]	Yes
Finite half-life?	No	n.a.	Yes	Yes	n.a.	n.a.	Yes
Sum of ARCH + GARCH coefficients	0.87	n.a.	0.83	0.40	n.a.	n.a.	0.47
Half-life in months	n.a.	n.a.	4	0.8	n.a.	n.a.	0.9
Lagged variables in mean equation	1	n.a.	1	1	n.a.	n.a.	4
GARCH order	(1,1)	n.a.	(1,1)	(1,0)	n.a.	n.a.	(1,0)
Trend variables in variance equation	None	n.a.	None	None	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.24

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, January 2000–December 2003

Parameter	WTI	Gaso-line	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Pro-pane
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No
Sum of ARCH + GARCH coefficients	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.91
Half-life in months	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Lagged variables in mean equation	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2,9
GARCH order	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.25

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices, January 2000–end October 2007

Parameter	WTI	Gaso-line	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Pro-pane
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Yes
Sum of ARCH + GARCH coefficients	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.49
Half-life in months	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1
Lagged variables in mean equation	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1,9
GARCH order	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A3.26 compares the results from Lee and Zyren (2007) and those obtained following the procedures in this report (outlined above). Though comparable, one difference is that the weekly prices in Lee and Zyren represent prices on the last trading day of the week, whereas the weekly prices used here are averaged over the entire week. When the sum of the ARCH and GARCH coefficients is close to unity, as with WTI crude, a small difference in the sum leads to a noticeable difference in the half-life.

Table A3.26

GARCH Analysis of Returns of Logarithms of Nominal Weekly Prices, January 1990–May 2005

	Lee and Zyren		This report	
Fuel	Sum[a]	Half-life in weeks	Sum[a]	Half-life in weeks
WTI crude	0.93	10	0.95	14
Gasoline	0.93	10	0.92	8
Heating oil	0.88	5	0.86	5

Sources: Lee and Zyren 2007; author calculations.

a. Sum of ARCH and GARCH coefficients.

Runs Tests

The results of a series of runs tests performed on nominal and real daily prices are shown in tables A3.27 to A3.32. As mentioned in annex 2, prices here are not in logarithms. As expected, the results for returns and cycle returns are similar. Nominal and real prices return comparable results, except for maximum and minimum cumulative cycles where they can differ by up to a factor of nearly two. Taking the entire period, there are too few runs for gasoline, residual fuel oil, and propane (the first two rows of results in tables A3.27 and A3.28).

Table A3.27

Runs Tests on Nominal Daily Prices, Beginning–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	0.91	−2.86	−0.01	1.63	0.85	−14.17	−4.62
Cycle returns, $(w - \mu) \div \sigma$	1.24	−2.19	0.53	1.63	0.44	−21.96	−6.64
Cumulative cycles							
Maximum (US$)	244	596	498	335	428	223	160
Minimum (US$)	−291	−332	−328	−307	−315	−118	−171
Average (US$)	0	25	9	0.5	−12	7	0
Percentage negative	54	38	49	52	64	48	50
Maximum sojourn, months	9.3	4.7	4.6	5.9	6.5	4.7	7.2

Source: Author calculations.

Table A3.28

Runs Tests on Real Daily Prices, Beginning–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	0.91	−2.68	0.11	1.74	1.01	−13.95	−4.79
Cycle returns, $(w - \mu) \div \sigma$	1.44	−2.19	0.47	1.98	0.74	−21.12	−6.62
Cumulative cycles							
Maximum (US$)	304	608	494	324	414	223	204
Minimum (US$)	−442	−332	−495	−465	−299	−112	−173
Average (US$)	−4	34	12	1	−13	9	0
Percentage negative	56	37	48	52	64	47	50
Maximum sojourn, months	9.3	4.8	4.6	5.9	6.5	4.6	7.1

Source: Author calculations.

Table A3.29

Runs Tests on Nominal Daily Prices, Beginning–December 1999

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w-\mu) \div \sigma$	0.76	–3.17	0.02	0.88	0.91	–10.73	–4.26
Cycle returns, $(w-\mu) \div \sigma$	1.01	–2.45	0.24	1.45	0.79	–18.75	–6.96
Cumulative cycles							
Maximum (US$)	203	202	299	209	95	92	160
Minimum (US$)	–291	–222	–328	–307	–106	–50	–135
Average (US$)	–4	15	6	0	–5	6	0
Percentage negative	55	38	47	50	62	51	48
Maximum sojourn, months	9.3	4.7	4.6	5.4	5.5	4.7	7.2

Source: Author calculations.

Table A3.30

Runs Tests on Real Daily Prices, Beginning–December 1999

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w-\mu) \div \sigma$	0.77	–3.01	0.19	1.08	0.91	–10.67	–4.39
Cycle returns, $(w-\mu) \div \sigma$	1.38	–2.52	0.40	1.75	0.91	–18.39	–7.14
Cumulative cycles							
Maximum (US$)	304	306	453	315	122	115	204
Minimum (US$)	–442	–332	–495	–465	–135	–61	–173
Average (US$)	–9	22	9	0	–7	7	–1
Percentage negative	57	37	45	51	62	51	49
Maximum sojourn, months	9.3	4.8	4.6	5.5	5.6	4.6	7.1

Source: Author calculations.

Table A3.31

Runs Tests on Nominal Daily Prices, January 2000–December 2003

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w-\mu) \div \sigma$	–0.46	–1.44	–0.60	1.60	0.22	–6.77	–0.54
Cycle returns, $(w-\mu) \div \sigma$	0.04	–1.50	–0.29	0.67	–0.06	–9.19	–1.09
Cumulative cycles							
Maximum (US$)	134	218	230	241	213	144	195
Minimum (US$)	–99	–146	–145	–130	–134	–132	–68
Average (US$)	10	45	14	19	0	–26	44
Percentage negative	43	30	48	47	58	78	27
Maximum sojourn, months	1.9	2.1	2.4	5.3	6.3	3.8	9.3

Source: Author calculations.

Table A3.32

Runs Tests on Nominal Daily Prices, January 2004–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	1.37	0.82	0.60	0.48	0.32	–5.98	–2.22
Cycle returns, $(w - \mu) \div \sigma$							
Cumulative cycles	1.05	1.10	1.07	0.51	0.07	–8.16	–2.09
Maximum (US$)	275	684	538	360	486	205	203
Minimum (US$)	–118	–245	–247	–207	–257	–137	–111
Average (US$)	43	137	59	21	35	–7	59
Percentage negative	33	23	37	44	44	60	27
Maximum sojourn, months	2.2	2.2	2.7	4.5	4.4	2.9	7.2

Source: Author calculations.

The percentage of months when the cumulative cycles are negative varies from fuel to fuel and from subperiod to subperiod. The lowest is 23 percent for gasoline between January 2004 and March 2007; the largest is residual fuel oil between January 2000 and December 2003. For the former, the cumulative cycles average US$137 per barrel; for the latter, they average –US$26. The largest maximum sojourn for cumulative cycles is nine months for WTI crude in 1986 and 1987, and the cumulative cycles are negative during that period.

The results for nominal weekly prices are shown in tables A3.33 to A3.36. When the entire period is considered, there are too few runs for returns for every fuel. One marked difference from daily prices is that the maximum sojourns for cumulative cycles are significantly longer. For example, when the entire period is considered, the maximum sojourns vary from 21 months to as long as 46 months, compared to the range of 5 months to 9 months observed with daily prices. The percentage of months when cumulative cycles are negative is larger for weekly WTI crude and gasoline prices than for daily prices when the full period and first subperiod are considered, but markedly smaller between January 2000 and December 2003. In all cases, both the maximum and minimum cumulative cycles are smaller in magnitude for weekly prices than for daily prices.

The results for nominal monthly prices are given in tables A3.37 to A3.39. There are no cases with too few runs for price returns. Maximum sojourns for cumulative cycles are longer than weekly prices. The percentages of the time when cumulative cycles are negative are markedly smaller for monthly prices than for other averaging periods between January 2000 and March 2007; correspondingly, the percentage of months when cumulative cycles are positive is high, which means that the balance of an oil account for price smoothing based on an HP filter and started in January 2000 would have been negative most of the time. The maximum and minimum cumulative cycles are smaller in magnitude than those for daily and weekly prices.

Table A3.33

Runs Tests on Nominal Weekly Prices, Beginning–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–2.94	–4.97	–2.53	–4.25	–3.72	–9.19	–5.39
Cycle returns, $(w - \mu) \div \sigma$	–2.08	–4.97	–2.45	–3.38	–3.63	–8.06	–3.71
Cumulative cycles							
Maximum (US$)	95	186	129	115	154	81	92
Minimum (US$)	–103	–120	–127	–96	–110	–96	–61
Average (US$)	–10	0	0	0	0	0	0
Percentage negative	63	48	48	49	53	47	52
Maximum sojourn, months	26	24	46	26	26	21	25

Source: Author calculations.

Table A3.34

Runs Tests on Nominal Weekly Prices, Beginning–December 1999

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–2.28	–5.11	–2.20	–3.23	–1.63	–6.89	–3.03
Cycle returns, $(w - \mu) \div \sigma$	–1.35	–4.96	–2.45	–2.41	–1.89	–7.12	–1.26
Cumulative cycles							
Maximum (US$)	63	58	103	82	41	39	47
Minimum (US$)	–103	–79	–127	–96	–69	–51	–55
Average (US$)	–11	–1	–1	–1	–3	–1	–1
Percentage negative	63	48	43	48	50	48	48
Maximum sojourn, months	26	24	46	26	26	16	25

Source: Author calculations.

Table A3.35

Runs Tests on Nominal Weekly Prices, January 2000–December 2003

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–1.03	–0.81	–0.69	–2.37	–2.93	–5.44	–3.05
Cycle returns, $(w - \mu) \div \sigma$	–1.05	–0.42	–0.40	–2.37	–2.97	–3.79	–2.47
Cumulative cycles							
Maximum (US$)	108	164	143	141	135	112	138
Minimum (US$)	–3	–4	2	0	–7	–24	–9
Average (US$)	54	76	71	70	66	42	50
Percentage negative	5	2	0	0	6	33	11
Maximum sojourn, months	25	47	48	48	29	20	30

Source: Author calculations.

Table A3.36

Runs Tests on Nominal Weekly Prices, January 2004–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–1.87	–1.22	–1.22	–1.81	–2.09	–3.28	–3.66
Cycle returns, $(w - \mu) \div \sigma$	–1.65	–1.84	–1.02	–1.30	–1.61	–2.46	–3.51
Cumulative cycles							
Maximum (US$)	114	223	137	111	155	43	70
Minimum (US$)	–54	–83	–113	–100	–110	–133	–48
Average (US$)	2	31	–1	–14	–10	–41	12
Percentage negative	63	37	51	62	67	90	26
Maximum sojourn, months	11	11	11	20	10	30	11

Source: Author calculations.

Tables A3.40 to A3.42 compare the results of runs tests for the longest period when a full set of price data is available for all fuels and all averaging periods—September 1995 to March 2007. Runs on returns show that there are too few runs when weekly prices are examined, but only for residual fuel oil and propane in the case of daily prices and none for monthly prices. The average of cumulative cycles is positive for each fuel when monthly prices are used, but negative for more than half the fuels with weekly and daily prices. The greatest negative average cumulative cycles is –US$45 a barrel, observed with daily gasoline prices. The percentage of months when cumulative cycles are negative is largest for daily prices, followed by weekly, and then by monthly. The maximum sojourns for cumulative cycles are 4 to 8 months with daily prices, 21 to 28 months with weekly prices, and 27 to 40 months with monthly prices. The sign of the balance of the hypothetical oil account for price smoothing based on an HP filter changes on average from positive when daily prices are used to negative when monthly prices are used. To take advantage of the positive balance in the daily series, prices would have to be adjusted on a daily basis, leading to greater price fluctuations as well as higher administrative costs.

Table A3.37

Runs Tests on Nominal Monthly Prices, Beginning–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	−1.63	0.41	−1.80	−1.99	−1.38	0.21	−1.56
Cycle returns, $(w - \mu) \div \sigma$	−0.99	1.03	−1.04	−1.32	−0.28	−0.53	−0.97
Cumulative cycles							
Maximum (US$)	41	76	65	61	70	39	53
Minimum (US$)	−55	−59	−66	−65	−66	−47	−42
Average (US$)	−8	0	0	0	0	0	0
Percentage negative	61	50	45	46	46	49	53
Maximum sojourn, months	35	39	35	42	36	30	33

Source: Author calculations.

Table A3.38

Runs Tests on Nominal Monthly Prices, Beginning–December 1999

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	−1.01	0.23	−1.29	−1.57	−0.66	0.22	−1.48
Cycle returns, $(w - \mu) \div \sigma$	−1.31	0.79	−1.30	−1.25	−0.66	0.09	−0.62
Cumulative cycles							
Maximum (US$)	27	40	39	39	37	27	30
Minimum (US$)	−55	−52	−58	−56	−55	−40	−42
Average (US$)	−6	−1	−1.	−1	−3	−1	−2
Percentage negative	62	51	48	50	55	54	53
Maximum sojourn, months	35	39	30	42	25	30	33

Source: Author calculations.

Table A3.39

Runs Tests on Nominal Monthly Prices, January 2000–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	−0.80	0.25	−0.91	−0.81	−0.80	−0.08	−0.91
Cycle returns, $(w - \mu) \div \sigma$	0.32	0.61	−0.05	−0.39	0.32	−0.95	−0.95
Cumulative cycles							
Maximum (US$)	87	125	117	112	120	74	91
Minimum (US$)	−4	−9	−14	−14	−17	−11	5
Average (US$)	40	51	54	52	51	37	39
Percentage negative	6	8	17	16	17	9	0
Maximum sojourn, months	54	89	53	53	53	61	89

Source: Author calculations.

Table A3.40

Runs Tests on Nominal Daily Prices, September 1995–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–0.42	–0.60	0.24	1.78	0.85	–12.94	–3.34
Cycle returns, $(w - \mu) \div \sigma$	0.08	–0.26	0.99	1.73	0.44	–18.71	–4.66
Cumulative cycles							
Maximum (US$)	230	512	497	333	427	216	156
Minimum (US$)	–164	–417	–288	–234	–316	–125	–175
Average (US$)	–10	–45	9	–2	–13	0	–4
Percentage negative	66	79	52	58	65	53	55
Maximum sojourn, months	5.3	6.5	4.6	8.0	6.5	4.7	5.6

Source: Author calculations.

Table A3.41

Runs Tests on Nominal Weekly Prices, September 1995–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–3.15	–2.19	–1.93	–4.20	–3.91	–7.90	–5.72
Cycle returns, $(w - \mu) \div \sigma$	–2.00	–2.36	–1.38	–3.13	–3.82	–6.81	–4.02
Cumulative cycles							
Maximum (US$)	101	166	142	126	157	79	89
Minimum (US$)	–68	–140	–108	–85	–107	–98	–65
Average (US$)	–5	–21	13	10	2	–2	–4
Percentage negative	58	63	45	46	51	51	56
Maximum sojourn, months	24	23	28	27	26	21	25

Source: Author calculations.

Table A3.42

Runs Tests on Nominal Monthly Prices, September 1995–March 2007

Parameter	WTI	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil	Propane
Returns, $(w - \mu) \div \sigma$	–0.73	0.13	–1.20	–1.20	–1.27	0.05	–1.69
Cycle returns, $(w - \mu) \div \sigma$	0.56	0.19	–0.41	–0.72	–0.18	–0.73	–1.60
Cumulative cycles							
Maximum (US$)	61	86	84	80	79	43	64
Minimum (US$)	–35	–49	–47	–46	–58	–42	–31
Average (US$)	12	10	19	19	9	5	11
Percentage negative	34	36	32	32	39	39	42
Maximum sojourn, months	40	39	40	40	38	32	27

Source: Author calculations.

Annex 4

Statistical Analysis of Developing Country Prices

This annex supplements chapter 4 and provides additional results from the analysis of fuel prices in Chile, Ghana, India, the Philippines, and Thailand. To this end, international crude and oil product prices appropriate for each country were examined in U.S. dollars and in the respective local currency. These prices do not include taxes and other fuel charges or transportation, distribution, and retail costs and margins.

Data Coverage and Methodology

The source of price information other than that in the U.S. Gulf Coast was Energy Intelligence, which provides only monthly data. U.S. Gulf prices were taken from the U.S. Energy Information Administration Web site and used to compute equivalent domestic prices in Chile. Singapore product prices were used for the Philippines and Thailand, Rotterdam prices for Ghana, and Persian Gulf prices for India. For ease of comparison, all prices are given on a per barrel basis. Table A4.1 gives the first month for which data are available for each commodity considered. For all but U.S. Gulf Coast prices, the data begin in January 1987.

Differences in price level and price volatility were examined for three subperiods—the first beginning with the first month in which the prices were available (table A4.1) to June 1999, the second from July 1999 to December 2003, and the third from January 2004 to January 2008—and for the entire period. Augmented Dickey-Fuller tests, GARCH analysis, and runs tests were performed for the period beginning with the first month in which prices were available to March 2007. They were also conducted for two subperiods, the first ending in June 1999 and the second one beginning in July 1999 and ending in March 2007. The second subperiod was not split further because, when monthly prices were tested, most fuel prices did not yield meaningful equations even when the longer time span from July 1999 to March 2007 was used; further subdivision thus would have yielded no meaningful equations.

The results of ADF tests are summarized in chapter 4 and are not given here. This annex presents the results of GARCH analysis and runs tests. In addition to testing

Table A4.1

First Month in the Price Data Series

Commodity	Start date
WTI	Jan. 1986
U.S. Gulf Coast regular gasoline	June 1986
U.S. Gulf Coast jet kerosene	Apr. 1990
U.S. Gulf Coast heating oil	June 1986
U.S. Gulf Coast diesel	May 1995
U.S. Gulf Coast residual fuel oil	July 1993
Mont Belvieu, Texas, propane	July 1992
Indonesia Minas-34	Jan. 1987
Singapore premium gasoline	Jan. 1987
Singapore jet kerosene	Jan. 1987
Singapore gasoil	Jan. 1987
Singapore residual fuel oil, 3.5% sulfur, 180 centistokes	Jan. 1987
Nigeria Bonny Light-37	Jan. 1987
Rotterdam regular gasoline	Jan. 1987
Rotterdam jet kerosene	Jan. 1987
Rotterdam gasoil	Jan. 1987
Rotterdam residual fuel oil, 3.5% sulfur	Jan. 1987
Dubai Fateh-32	Jan. 1987
Persian Gulf premium gasoline	Jan. 1987
Persian Gulf jet kerosene	Jan. 1987
Persian Gulf gasoil	Jan. 1987
Persian Gulf residual fuel oil, 3.5% sulfur, 380 centistokes	Jan. 1987

Sources: U.S. EIA 2008a and Energy Intelligence 2008.

@trend (see annex 3) and pd1 (defined in this annex as covering the period from beginning through June 1999) as dummy variables in the conditional variance equation in GARCH analysis, pd3 (covering January 2004 to March 2007) was also tested, and the equation with the highest R^2, everything else being equal, is reported here. For runs tests, values for (w – μ) ÷ σ (defined in annex 2), are reported. Cycles in local currency are based on Hodrick-Prescott filters calculated from local prices.

Chile

Mean prices in the three subperiods (beginning to June 1999, July 1999 to December 2003, and January 2004 to January 2008) and for the entire period (beginning to January 2008) are shown in table A4.2. The differences between U.S. dollar and Chilean peso price increases are given in table 4.1.

Table A4.3 gives the ratio of fuel prices in January 2008 to those in January 2004. The ratio is consistently lower for Chilean peso prices, signifying appreciation of the Chilean peso against the U.S. dollar. The largest price increase is observed with residual fuel oil.

Table A4.2

Period Average Prices in Chile

Price (units)	Period	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Nominal (US$)	1	18.91	22.98	20.86	22.31	21.12	12.48
	2	27.79	32.43	31.04	31.61	30.32	20.35
	3	59.76	70.07	72.65	73.32	69.15	40.55
	Entire	28.27	36.15	42.01	33.64	31.88	19.28
Nominal (Ch$)	1	6,584	9,046	9,038	7,741	7,336	4,316
	2	17,436	20,340	19,469	19,806	19,024	12,821
	3	32,617	38,293	39,591	39,979	37,697	22,029
	Entire	13,609	18,592	23,150	16,160	15,332	9,324
Real (US$)	1	27.89	31.51	26.38	32.97	31.20	18.47
	2	31.75	37.04	35.46	36.12	34.64	23.23
	3	60.51	70.97	73.50	74.21	69.99	40.96
	Entire	34.71	41.94	45.55	41.24	39.07	23.60
Real (Ch$)	1	15,093	15,933	12,128	17,875	16,909	9,999
	2	19,849	23,151	22,165	22,557	21,657	14,577
	3	33,130	38,930	40,189	40,593	38,273	22,304
	Entire	19,397	23,020	25,258	23,030	21,827	13,207
Nominal (% increase for prices in US$)	2/1[a]	47	41	49	42	44	63
	3/2[a]	115	116	134	132	128	99
	3/1[a]	216	205	248	229	227	225
Nominal (% increase for prices in Ch$)	2/1[a]	165	125	115	156	159	197
	3/2[a]	87	88	103	102	98	72
	3/1[a]	395	323	338	416	414	410
Real (% increase for prices in US$)	2/1[a]	14	18	34	10	11	26
	3/2[a]	91	92	107	105	102	76
	3/1[a]	117	125	179	125	124	122
Real (% increase for prices in Ch$)	2/1[a]	32	45	83	26	28	46
	3/2[a]	67	68	81	80	77	53
	3/1[a]	120	144	231	127	126	123

Sources: U.S. EIA 2008a; author calculations.

Note: Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008. Real prices are in January 2007 currency units.

a. The price increase from subperiod 1 to subperiod 2 (percentage increase in subperiod 2 over subperiod 1) computed in U.S. dollars is subtracted from the price increase between the same two subperiods in Chilean pesos.

Standard deviations of returns for logarithms of monthly prices and exchange rates are shown in table A4.4. Aside from the first subperiod, price volatility was the same or greater in Chilean pesos. Volatility increased with increasing exchange rate volatility.

The results of GARCH analysis of the returns of logarithms of local monthly prices are given in tables A4.5 to A4.7. The presence of lag 15 in the equation for residual fuel oil in the first subperiod appears arbitrary, but this is the only formulation that does not exhibit serial correlation and passes the ARCH test. Similarly, the presence of lags 1, 2, 4, and 7 for the ARCH (1,1) formulation for the conditional mean equation for gasoil in the first subperiod appears arbitrary, but retaining fewer terms does not yield a statistically significant equation. For this reason, the GARCH(1,0) formulation seems more credible.

The results of runs tests on prices in U.S. dollars and in Chilean pesos are shown in tables A4.8 to A4.13. On the whole, runs on returns yield similar results, while cumulative returns tend to be more positive in local currency than in U.S. dollars.

Table A4.3

Ratio of January 2008 Prices to January 2004 Prices in Chile

Currency	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
US$ nominal	2.7	2.3	2.7	2.6	2.6	3.1
Ch$ nominal	2.3	2.0	2.2	2.2	2.2	2.6
US$ real	2.4	2.1	2.3	2.3	2.3	2.7
Ch$ real	1.9	1.7	1.9	1.9	1.9	2.2

Sources: U.S. EIA 2008a; author calculations.

Table A4.4

Standard Deviation of Returns for Logarithms of Prices and Exchange Rate in Chile

Price (units)	Period	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil	Exchange rate
Nominal (US$)	1	0.087	0.102	0.081	0.091	0.086	0.130	n.a.
	2	0.081	0.120	0.089	0.088	0.089	0.118	n.a.
	3	0.070	0.116	0.086	0.091	0.080	0.090	n.a.
	Entire	0.083	0.110	0.086	0.091	0.086	0.121	n.a.
Nominal (Ch$)	1	0.087	0.099	0.079	0.090	0.087	0.130	0.015
	2	0.087	0.124	0.095	0.095	0.095	0.121	0.025
	3	0.074	0.116	0.088	0.093	0.081	0.092	0.021
	Entire	0.085	0.110	0.088	0.092	0.087	0.122	0.019
Real (US$)	1	0.086	0.101	0.080	0.090	0.085	0.130	n.a.
	2	0.080	0.119	0.088	0.088	0.088	0.117	n.a.
	3	0.068	0.113	0.084	0.088	0.078	0.088	n.a.
	Entire	0.082	0.108	0.084	0.090	0.085	0.120	n.a.
Real (Ch$)	1	0.085	0.097	0.079	0.089	0.084	0.129	n.a.
	2	0.086	0.123	0.095	0.095	0.095	0.121	n.a.
	3	0.073	0.116	0.087	0.091	0.080	0.091	n.a.
	Entire	0.083	0.108	0.087	0.091	0.086	0.121	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008.

Table A4.5

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Chilean Pesos, Beginning–March 2007

Parameter	Crude		Gaso-line	Diesel	Jet kerosene	Gasoil		Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes D[a]	Yes D[a]	Yes	Yes	Yes	Yes
Finite half-life?	No	Yes	n.a.	n.a.	Yes	No	Yes	Yes
Sum of ARCH + GARCH coefficients	0.84	0.30	n.a.	n.a.	0.18	0.90	0.16	0.33
Half-life in months	n.a.	0.6	n.a.	n.a.	0.4	n.a.	0.4	0.6
Lagged variables in mean equation	1	1	n.a.	n.a.	2	1	1	1,2
GARCH order	(1,1)	(1,0)	n.a.	n.a.	(1,0)	(1,1)	(1,0)	(1,0)
Trend variables in variance equation	None	None	n.a.	n.a.	None	None	None	pd3

Source: Author calculations.

Note: n.a. = not applicable; pd3 is a dummy variable that is 1 for any data from January 2004 to end March 2007.

a. Results are classified into the four categories defined on p. 13.

Table A4.6

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Chilean Pesos, Beginning–June 1999

Parameter	Crude		Gaso-line	Diesel	Jet kerosene	Gasoil		Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes D[a]	No C[a]	Yes	Yes	Yes	Yes
Finite half-life?	No	Yes	n.a.	n.a.	Yes	No	Yes	Yes
Sum of ARCH + GARCH coefficients	0.87	0.50	n.a.	n.a.	0.21	0.87	0.30	0.26
Half-life in months	n.a.	1	n.a.	n.a.	0.4	n.a.	0.6	0.5
Lagged variables in mean equation	1	1	n.a.	n.a.	2,4	1,2,4,7	1	15
GARCH order	(1,1)	(1,0)	n.a.	n.a.	(1,0)	(1,1)	(1,0)	(1,0)
Trend variables in variance equation	None	None	n.a.	n.a.	Trend	None	None	None

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A4.7

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Chilean Pesos, July 1999–March 2007

Parameter	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	n.a.	n.a.	n.a.	n.a.	Yes
Sum of ARCH + GARCH coefficients	n.a.	n.a.	n.a.	n.a.	n.a.	0.42
Half-life in months	n.a.	n.a.	n.a.	n.a.	n.a.	0.8
Lagged variables in mean equation	n.a.	n.a.	n.a.	n.a.	n.a.	1,2
GARCH order	n.a.	n.a.	n.a.	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	n.a.	n.a.	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.8

Runs Tests on Nominal Monthly Prices in Chile, in U.S. Dollars, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	−1.63	−0.49	−0.89	−1.72	−1.52	−2.07
Cycle returns, $(w - \mu) \div \sigma$	−1.00	−0.23	−0.23	−1.76	−11.84	−1.10
Cumulative cycles						
Maximum (US$)	67	92	12	−2	103	−5
Minimum (US$)	−97	−111	−227	−225	−136	−158
Average (US$)	−7	0	−98	−101	0	−85
Percentage negative	60	48	97	100	40	100
Maximum sojourn, months	57	41	182	254	36	254

Source: Author calculations.

Table A4.9

Runs Tests on Nominal Monthly Prices in Chile, in Chilean Pesos, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	−1.42	−0.99	−1.02	−1.73	−0.86	−2.32
Cycle returns, $(w - \mu) \div \sigma$	−0.50	−0.80	−0.48	−1.76	−0.40	−1.13
Cumulative cycles						
Maximum (Ch$)	23,234	38,703	19,462	15,069	33,556	9,726
Minimum (Ch$)	−34,127	−36,098	−66,056	−63,368	−51,432	−35,523
Average (Ch$)	−1,591	0	−14,134	−14,202	0	−9,519
Percentage negative	48	38	82	83	41	84
Maximum sojourn, months	92	96	93	92	36	124

Source: Author calculations.

Table A4.10

Runs Tests on Nominal Monthly Prices in Chile, in U.S. Dollars, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	−0.85	−1.14	−0.24	−1.15	−0.40	−1.13
Cycle returns, $(w - \mu) \div \sigma$	−1.13	−1.31	0.08	−1.49	−6.89	−0.50
Cumulative cycles						
Maximum (US$)	43	57	−8	−5	63	−5
Minimum (US$)	−48	−45	−167	−171	−41	−116
Average (US$)	−2	9	−93	−96	26	−82
Percentage negative	60	40	100	100	16	100
Maximum sojourn, months	57	39	161	161	36	161

Source: Author calculations.

Table A4.11

Runs Tests on Nominal Monthly Prices in Chile, in Chilean Pesos, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–1.50	–1.10	–0.47	–1.49	–0.50	–1.08
Cycle returns, $(w - \mu) \div \sigma$	–0.85	–1.12	–0.24	–2.40	–0.40	–0.55
Cumulative cycles						
Maximum (Ch$)	23,234	27,959	15,078	14,697	33,556	9,726
Minimum (Ch$)	–32,625	–34,859	–48,531	–47,594	–27,926	–33,800
Average (Ch$)	1,967	6,117	–9,834	–9,941	14,769	–7,108
Percentage negative	39	14	85	85	16	86
Maximum sojourn, months	92	96	93	92	36	124

Source: Author calculations.

Table A4.12

Runs Tests on Nominal Monthly Prices in Chile, in U.S. Dollars, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–0.78	0.66	–0.81	–0.81	–0.78	–1.86
Cycle returns, $(w - \mu) \div \sigma$	0.09	0.94	–0.43	–0.89	–9.92	–1.15
Cumulative cycles						
Maximum (US$)	115	137	151	139	144	69
Minimum (US$)	–49	–66	–88	–83	–95	–43
Average (US$)	32	34	33	32	29	26
Percentage negative	28	26	30	31	32	22
Maximum sojourn, months	49	50	47	46	48	59

Source: Author calculations.

Table A4.13

Runs Tests on Nominal Monthly Prices in Chile, in Chilean Pesos, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Heating oil	Diesel	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–0.20	–0.20	–0.99	–0.31	–0.13	–2.42
Cycle returns, $(w - \mu) \div \sigma$	0.37	0.09	–0.43	0.51	0.15	–1.15
Cumulative cycles						
Maximum (Ch$)	54,454	73,563	67,993	62,663	61,477	43,034
Minimum (Ch$)	–1,502	–1,238	–17,525	–15,774	–23,506	–1,723
Average (Ch$)	24,875	27,558	26,953	26,016	21,098	20,107
Percentage negative	5	6	24	23	26	4
Maximum sojourn, months	56	62	50	50	50	66

Source: Author calculations.

Ghana

Prices averaged over each subperiod as well as over the entire period and percentage price increases between subperiods are shown in table A4.14. Nominal price increases in local currency units are extremely large, reaching as high as 3,000 percent in the third subperiod over the first subperiod—or 15 times the percentage increases in nominal terms—signifying high inflation rates during the study period. For real prices, the price series had to be terminated in November 2007 because the consumer price index was available only up to that month.

Table A4.15 gives the ratio of fuel prices in January 2008 to those in January 2004. The ratios are consistently higher for nominal cedi prices, and lower for real cedi prices.

Table A4.14

Period Average Prices in Ghana

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal (US$)	1	18.25	21.78	23.77	22.14	13.42
	2	26.33	30.72	32.96	30.59	20.81
	3	59.56	66.01	74.82	69.95	40.87
	Entire	27.97	32.25	35.62	33.21	20.31
Nominal (₵)	1	16,263	19,272	21,140	19,783	12,420
	2	181,950	211,561	227,680	212,032	144,100
	3	548,207	606,956	688,294	643,567	376,502
	Entire	154,652	174,134	194,435	181,628	111,039
Real (US$)	1	26.52	31.67	34.54	32.15	19.49
	2	30.08	35.11	37.67	34.95	23.77
	3	58.96	65.85	74.39	69.44	40.15
	Entire	33.36	38.81	42.67	39.73	24.28
Real (₵)	1	181,372	215,909	236,412	220,173	134,006
	2	375,426	437,910	471,619	438,033	295,460
	3	572,464	641,074	723,990	675,490	388,461
	Entire	296,353	343,283	378,314	352,302	216,388
Nominal (% increase for prices in US$)	2/1	44	41	39	38	55
	3/2	126	115	127	129	96
	3/1	226	203	215	216	205
Nominal (% increase for prices in ₵)	2/1	1,019	998	977	972	1,060
	3/2	201	187	202	204	161
	3/1	3,271	3,049	3,156	3,153	2,932
Real (% increase for prices in US$)	2/1	13	11	9	9	22
	3/2	96	88	97	99	69
	3/1	122	108	115	116	106
Real (% increase for prices in ₵)	2/1	107	103	99	99	120
	3/2	52	46	54	54	31
	3/1	216	197	206	207	190

Sources: U.S. EIA 2008a; author calculations.

Note: For definitions and calculations, see the notes to table A4.2.

Table A4.15

Ratio of January 2008 Prices to January 2004 Prices in Ghana

Currency	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$ nominal	3.0	2.5	2.7	2.9	3.2
₵ nominal	3.3	2.7	3.0	3.2	3.5
US$ real[a]	2.7	2.3	2.5	2.6	3.0
₵ real[a]	2.1	1.8	2.0	2.1	2.4

Sources: U.S. EIA 2008a; author calculations.

a. Ratio of real prices in November 2008 to those in January 2004.

Standard deviations of returns for logarithms of monthly prices and exchange rates are shown in table A4.16. In nominal terms, local currency prices were consistently more volatile, with exchange rate volatility seemingly amplifying the local currency unit-price volatility. In real terms, prices in cedis were more volatile except for the residual fuel oil price in the third subperiod.

Table A4.16

Standard Deviation of Returns for Logarithms of Prices and Exchange Rate in Ghana

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil	Exchange rate
Nominal (US$)	1	0.086	0.083	0.089	0.083	0.119	n.a.
	2	0.098	0.105	0.087	0.088	0.105	n.a.
	3	0.083	0.103	0.072	0.071	0.075	n.a.
	Entire	0.089	0.092	0.086	0.083	0.109	n.a.
Nominal (₵)	1	0.095	0.093	0.094	0.089	0.123	0.045
	2	0.106	0.113	0.098	0.099	0.111	0.033
	3	0.083	0.104	0.072	0.072	0.075	0.003
	Entire	0.095	0.099	0.091	0.088	0.112	0.039
Real (US$)	1	0.086	0.082	0.089	0.083	0.118	n.a.
	2	0.097	0.104	0.086	0.087	0.104	n.a.
	3	0.081	0.101	0.070	0.069	0.073	n.a.
	Entire	0.088	0.091	0.085	0.082	0.108	n.a.
Real (₵)	1	0.097	0.092	0.099	0.093	0.126	n.a.
	2	0.107	0.112	0.097	0.098	0.113	n.a.
	3	0.084	0.102	0.072	0.072	0.072	n.a.
	Entire	0.097	0.098	0.094	0.091	0.115	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008.

GARCH analysis of local prices is shown in tables A4.17 and A4.18. The results of the second subperiod are not shown because no meaningful equations could be found for any of the fuels. No valid equation could be found for gasoil in any of the subperiods examined. No equation appears arbitrary, with the possible exception of that for gasoline in the first subperiod.

The results of the runs tests are shown in tables A4.19 to A4.24. During the first subperiod, cumulative returns in cedis tend to be more positive, but this trend appears to be reversed during the second subperiod. Cumulative returns in local currency are, on average, positive in each of the three subperiods examined.

Table A4.17

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Ghanaian Cedis, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil	
Statistically significant equation?	Yes	Yes	Yes	Yes D[a]	Yes	Yes
Finite half-life?	Yes	Yes	Yes	n.a.	No	Yes
Sum of ARCH + GARCH coefficients	0.25	0.25	0.90	n.a.	0.90	0.23
Half-life in months	0.5	0.5	7	n.a.	n.a.	0.5
Lagged variables in mean equation	1	1	1[b]	n.a.	1,2	1,2
GARCH order	(1,0)	(1,0)	(1,1)	n.a.	(1,1)	(1,0)
Trend variables in variance equation	pd3	None	None	n.a.	None	pd3

Source: Author calculations.

Note: n.a. = not applicable; pd3 is a dummy variable for period 3 (January 2004–end March 2007).

a. Results are classified into the four categories defined on p. 13.

b. An equation with lags 1, 2, and 3 passes all the tests (statistical significance of each coefficient, ARCH test), but the half-life becomes infinite.

Table A4.18

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Ghanaian Cedis, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes	Yes D[a]	Yes
Finite half-life?	Yes	Yes	No	n.a.	Yes
Sum of ARCH + GARCH coefficients	0.45	0.51	0.97	n.a.	0.37
Half-life in months	0.9	1	n.a.	n.a.	0.7
Lagged variables in mean equation	1	4	1,2	n.a.	1,2
GARCH order	(1,0)	(1,0)	(1,1)	n.a.	(1,0)
Trend variables in variance equation	None	None	None	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.19

Runs Tests on Nominal Monthly Prices in Ghana, in U.S. Dollars, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–0.77	–1.99	–2.27	–2.23	–1.25
Cycle returns, $(w - \mu) \div \sigma$	–1.03	–1.53	–2.06	–1.55	–1.27
Cumulative cycles					
Maximum (US$)	73	99	97	86	35
Minimum (US$)	–99	–95	–141	–137	–85
Average (US$)	–1	0	–15	–14	–10
Percentage negative	46	48	57	56	61
Maximum sojourn, months	42	51	47	48	40

Source: Author calculations.

Table A4.20

Runs Tests on Nominal Monthly Prices in Ghana, in Ghanaian Cedis, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–2.67	–1.88	–2.72	–2.23	–2.57
Cycle returns, $(w - \mu) \div \sigma$	–1.67	–1.38	–3.99	–1.67	–1.92
Cumulative cycles					
Maximum (₵)	456,515	620,504	667,971	605,049	238,336
Minimum (₵)	–758,411	–755,834	–1,048,142	–1,020,468	–608,976
Average (₵)	389	3,898	2,095	1,591	3,646
Percentage negative	32	40	40	35	21
Maximum sojourn, months	102	103	101	102	143

Source: Author calculations.

Table A4.21

Runs Tests on Nominal Monthly Prices in Ghana, in U.S. Dollars, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–1.17	–1.39	–1.81	–1.52	–0.89
Cycle returns, $(w - \mu) \div \sigma$	–1.83	–1.39	–1.81	–1.87	–0.90
Cumulative cycles					
Maximum (US$)	52	54	55	55	35
Minimum (US$)	–47	–74	–99	–89	–44
Average (US$)	4	2	–11	–10	–8
Percentage negative	42	44	54	54	68
Maximum sojourn, months	42	51	47	48	38

Source: Author calculations.

Table A4.22

Runs Tests on Nominal Monthly Prices in Ghana, in Ghanaian Cedis, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–3.07	–1.04	–1.94	–1.53	–2.22
Cycle returns, $(w - \mu) \div \sigma$	–2.51	–1.56	–3.45	–1.75	–1.39
Cumulative cycles					
Maximum (₵)	327,500	353,255	407,297	389,427	232,827
Minimum (₵)	–163,681	–219,123	–199,347	–171,245	–176,838
Average (₵)	74,560	86,444	95,035	89,855	55,177
Percentage negative	18	26	30	23	4
Maximum sojourn, months	102	103	101	102	143

Source: Author calculations.

Table A4.23

Runs Tests on Nominal Monthly Prices in Ghana, in U.S. Dollars, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	0.58	–1.26	–0.59	–0.92	–0.64
Cycle returns, $(w - \mu) \div \sigma$	0.88	–0.76	–0.76	–0.01	–0.81
Cumulative cycles					
Maximum (US$)	117	145	154	136	71
Minimum (US$)	–55	–49	–83	–86	–42
Average (US$)	34	42	37	30	31
Percentage negative	28	26	31	31	20
Maximum sojourn, months	52	50	46	46	60

Source: Author calculations.

Table A4.24

Runs Tests on Nominal Monthly Prices in Ghana, in Ghanaian Cedis, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–0.37	–1.72	–1.77	–1.59	–1.26
Cycle returns, $(w - \mu) \div \sigma$	0.51	–0.34	–1.79	–0.34	–1.24
Cumulative cycles					
Maximum (₵)	620,196	839,627	867,318	776,294	415,174
Minimum (₵)	–594,730	–536,711	–848,795	–849,223	–432,138
Average (₵)	45,237	90,771	52,540	31,425	97,924
Percentage negative	47	42	45	46	35
Maximum sojourn, months	37	35	35	35	47

Source: Author calculations.

India

Prices averaged over each subperiod as well as the entire period and the percentage price increases between subperiods are shown in table A4.25. Nominal price increases in Indian rupees in the third subperiod over the first subperiod are about three times those in real terms.

Table A4.26 gives the ratio of fuel prices in January 2008 to those in January 2004. The ratios are consistently lower for Indian rupee prices in both nominal and real terms. Crude oil prices rose the most for the set of benchmark fuels selected for India.

Standard deviations of returns for logarithms of monthly prices and exchange rates are shown in table A4.27.

Table A4.25

Period Average Prices in India

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal (US$)	1	16.10	22.37	22.59	21.36	12.35
	2	24.46	30.46	28.77	27.53	21.28
	3	53.90	62.85	69.37	69.05	41.69
	Entire	25.21	31.93	32.97	31.91	19.94
Nominal (Rs)	1	430	602	597	567	331
	2	1,136	1,414	1,336	1,279	991
	3	2,348	2,739	3,025	3,009	1,814
	Entire	952	1,189	1,225	1,192	759
Real (US$)	1	23.35	32.33	32.81	30.99	17.91
	2	27.94	34.81	32.89	31.44	24.30
	3	54.48	63.62	70.19	69.83	42.09
	Entire	30.36	38.92	40.06	38.61	23.96
Real (Rs)	1	965	1,343	1,355	1,284	738
	2	1,434	1,785	1,687	1,613	1,248
	3	2,444	2,857	3,154	3,136	1,886
	Entire	1,351	1,731	1,774	1,713	1,069
Nominal (% increase for prices in US$)	2/1	52	36	27	29	72
	3/2	120	106	141	151	96
	3/1	235	181	207	223	238
Nominal (% increase for prices in Rs)	2/1	164	135	124	126	200
	3/2	107	94	126	135	83
	3/1	446	355	406	431	449
Real (% increase for prices in US$)	2/1	20	8	0	1	36
	3/2	95	83	113	122	73
	3/1	133	97	114	125	135
Real (% increase for prices in Rs)	2/1	49	33	24	26	69
	3/2	70	60	87	94	51
	3/1	153	113	133	144	156

Sources: U.S. EIA 2008a; author calculations.

Note: For definitions and calculations, see the notes to table A4.2.

Table A4.26

Ratio of January 2008 Prices to January 2004 Prices in India

Currency	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$ nominal	3.1	2.5	2.9	3.0	3.0
Rs nominal	2.7	2.2	2.6	2.6	2.6
US$ real	2.7	2.2	2.6	2.6	2.6
Rs real	2.2	1.8	2.1	2.1	2.1

Sources: U.S. EIA 2008a; author calculations.

In real terms, local currency prices have higher volatility for every fuel and every subperiod. In nominal terms, local currency prices have the same or greater volatility than prices denominated in U.S. dollars.

GARCH analysis results are shown in tables A4.28 to A4.30. In table A4.28, the equation for residual fuel oil looks quite arbitrary, but retaining fewer lagged terms for the mean equation makes the equation fail the ARCH test. During the first subperiod, two GARCH(1,0) formulations are shown for jet kerosene. In the first, lags 4 and 6 are retained, and the conditional variance has a finite half-life. In the second, where only one lag (lag 3) is kept, the null hypothesis cannot be rejected.

The results of the runs tests are given in tables A4.31 to A4.36. For the entire period, cumulative returns in local currency are negative more frequently than in U.S. dollars; this occurs primarily during the first subperiod. However, the average cumulative cycles are negative in U.S. dollars and positive in local currency for every fuel. Maximum sojourns are longer for prices in local currency.

Table A4.27

Standard Deviation of Returns for Logarithms of Prices and Exchange Rate in India

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil	Exchange rate
Nominal (US$)	1	0.086	0.076	0.109	0.093	0.145	n.a.
	2	0.085	0.083	0.094	0.093	0.100	n.a.
	3	0.062	0.066	0.119	0.071	0.074	n.a.
	Entire	0.082	0.076	0.108	0.089	0.125	n.a.
Nominal (Rs)	1	0.089	0.079	0.112	0.097	0.146	0.024
	2	0.085	0.083	0.095	0.094	0.100	0.006
	3	0.064	0.067	0.120	0.072	0.074	0.014
	Entire	0.084	0.078	0.110	0.092	0.126	0.020
Real (US$)	1	0.086	0.075	0.109	0.093	0.144	n.a.
	2	0.084	0.081	0.093	0.091	0.099	n.a.
	3	0.061	0.063	0.117	0.069	0.072	n.a.
	Entire	0.081	0.075	0.107	0.088	0.124	n.a.
Real (Rs)	1	0.089	0.080	0.112	0.097	0.146	n.a.
	2	0.086	0.085	0.096	0.094	0.100	n.a.
	3	0.064	0.066	0.120	0.072	0.073	n.a.
	Entire	0.084	0.078	0.110	0.092	0.126	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008.

Table A4.28

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Indian Rupees, Beginning–March 2007

Parameter	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes D[a]	Yes
Finite half-life?	No	Yes	Yes	Yes	n.a.	Yes
Sum of ARCH + GARCH coefficients	0.91	0.31	0.65	0.74	n.a.	0.38
Half-life in months	n.a.	0.6	2	2	n.a.	0.7
Lagged variables in mean equation	1	1	1,4	1	n.a.	1,2,4,8, 11,14,16
GARCH order	(1,1)	(1,0)	(1,0)	(1,1)	n.a.	(1,0)
Trend variables in variance equation	None	None	None	pd3	n.a.	Trend

Source: Author calculations.

Note: n.a. = not applicable; pd3 is a dummy variable for period 3 (January 2004–end March 2007); trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A4.29

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Indian Rupees, Beginning–June 1999

Parameter	Crude		Gasoline		Jet kerosene		Gasoil		Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	No	No	No	No	Yes	No	No	Yes	Yes
Sum of ARCH + GARCH coefficients	0.99	0.86	0.88	0.77	0.48	0.93	0.97	0.35	0.39
Half-life in months	n.a.	n.a.	n.a.	n.a.	1	n.a.	n.a.	0.7	0.7
Lagged variables in mean equation	4	1	1	1	4,6	3	4	4,6	1,2,4,5
GARCH order	(1,1)	(1,0)	(1,1)	(1,0)	(1,0)	(1,0)	(1,1)	(1,0)	(1,0)
Trend variables in variance equation	None	None	None	None	None	None	None	None	None

Source: Author calculations.

Note: n.a. = not applicable.

Table A4.30

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Indian Rupees, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	n.a.	n.a.	n.a.	No
Sum of ARCH + GARCH coefficients	n.a.	n.a.	n.a.	n.a.	0.58
Half-life in months	n.a.	n.a.	n.a.	n.a.	n.a.
Lagged variables in mean equation	n.a.	n.a.	n.a.	n.a.	None
GARCH order	n.a.	n.a.	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	n.a.	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.31

Runs Tests on Nominal Monthly Prices in India, in U.S. Dollars, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–1.49	–2.54	–2.25	–2.95	–1.90
Cycle returns, $(w - \mu) \div \sigma$	–0.93	–2.31	–2.16	–2.49	–1.73
Cumulative cycles					
Maximum (US$)	67	70	84	83	32
Minimum (US$)	–98	–86	–128	–130	–85
Average (US$)	–2	–7	–13	–6	–13
Percentage negative	46	57	55	49	64
Maximum sojourn, months	40	50	47	47	47

Source: Author calculations.

Table A4.32

Runs Tests on Nominal Monthly Prices in India, in Indian Rupees, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–0.93	–2.45	–2.28	–2.40	–1.82
Cycle returns, $(w - \mu) \div \sigma$	–1.54	–2.57	–2.52	–3.08	–3.04
Cumulative cycles					
Maximum (Rs)	2,873	2,466	3,423	3,162	1,279
Minimum (Rs)	–4,140	–3,541	–5,636	–5,954	–3,593
Average (Rs)	2,873	2,466	3,423	3,162	1,279
Percentage negative	43	68	69	65	69
Maximum sojourn, months	42	66	75	74	108

Source: Author calculations.

Table A4.33

Runs Tests on Nominal Monthly Prices in India, in U.S. Dollars, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–1.54	–2.20	–2.21	–1.89	–2.05
Cycle returns, $(w - \mu) \div \sigma$	–1.22	–2.18	–2.21	–1.21	–1.71
Cumulative cycles					
Maximum (US$)	45	47	64	74	32
Minimum (US$)	–38	–86	–99	–83	–52
Average (US$)	3	–6	–10	–2	–12
Percentage negative	43	56	54	49	72
Maximum sojourn, months	40	50	47	47	47

Source: Author calculations.

Table A4.34

Runs Tests on Nominal Monthly Prices in India, in Indian Rupees, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–1.17	–2.51	–2.21	–1.55	–2.00
Cycle returns, $(w - \mu) \div \sigma$	–1.83	–2.86	–2.54	–1.55	–2.71
Cumulative cycles					
Maximum (Rs)	1,505	985	1,970	2,172	996
Minimum (Rs)	–1,909	–2,347	–2,585	–2,328	–2,392
Average (Rs)	105	–492	–499	–356	–317
Percentage negative	38	72	75	70	81
Maximum sojourn, months	42	66	75	74	108

Source: Author calculations.

Table A4.35

Runs Tests on Nominal Monthly Prices in India, in U.S. Dollars, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	0.00	–0.99	–0.15	–1.96	–0.37
Cycle returns, $(w - \mu) \div \sigma$	0.15	–0.70	–0.47	–2.47	–0.76
Cumulative cycles					
Maximum (US$)	105	101	128	112	76
Minimum (US$)	–60	–40	–84	–101	–35
Average (US$)	29	22	25	16	36
Percentage negative	30	34	34	38	18
Maximum sojourn, months	53	49	48	46	61

Source: Author calculations.

Table A4.36

Runs Tests on Nominal Monthly Prices in India, in Indian Rupees, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	0.32	–0.70	–0.31	–1.70	–0.47
Cycle returns, $(w - \mu) \div \sigma$	0.15	–0.34	–0.47	–2.93	–1.61
Cumulative cycles					
Maximum (Rs)	4,782	4,581	5,846	5,134	3,671
Minimum (Rs)	–2,231	–1,427	–3,213	–3,982	–1,200
Average (Rs)	1,598	1,388	1,429	1,019	1,852
Percentage negative	27	30	33	37	15
Maximum sojourn, months	56	53	50	47	63

Source: Author calculations.

The Philippines

Prices averaged over each subperiod as well as over the entire period and the percentage price increases between subperiods are shown in table A4.37. Nominal price increases in local currency units are larger in every case examined, and especially relative to the first subperiod.

Table A4.38 gives the ratio of fuel prices in January 2008 to those in January 2004. The ratios are consistently lower for Philippine peso prices in both nominal and real terms. Crude oil prices rose the most for the set of benchmark fuels selected for the Philippines.

Standard deviations of returns for logarithms of monthly prices and exchange rates are shown in table A4.39. Prices in

Table A4.37

Period Average Prices in the Philippines

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal (US$)	1	17.84	23.56	23.96	22.87	14.23
	2	26.37	30.07	30.38	29.11	23.61
	3	58.06	67.25	71.33	68.63	45.61
	Entire	27.45	33.41	34.51	33.07	22.31
Nominal (₱)	1	472	623	634	605	378
	2	1,300	1,482	1,495	1,436	1,164
	3	2,954	3,435	3,640	3,499	2,317
	Entire	1,129	1,351	1,400	1,343	921
Real (US$)	1	25.90	34.29	34.80	33.18	20.64
	2	30.11	34.35	34.72	33.25	26.96
	3	58.70	68.10	72.20	69.44	46.10
	Entire	33.15	40.85	42.02	40.22	26.92
Real (₱)	1	1,126	1,497	1,514	1,442	895
	2	1,696	1,933	1,954	1,874	1,518
	3	3,087	3,602	3,811	3,663	2,421
	Entire	1,627	1,998	2,053	1,964	1,324
Nominal (% increase for prices in US$)	2/1	48	28	27	27	66
	3/2	120	124	135	136	93
	3/1	225	185	198	200	221
Nominal (% increase for prices in ₱)	2/1	175	138	136	137	208
	3/2	127	132	143	144	99
	3/1	526	451	474	478	514
Real (% increase for prices in US$)	2/1	16	0	0	0	31
	3/2	94	51	95	98	108
	3/1	144	156	127	99	107
Real (% increase for prices in ₱)	2/1	51	29	29	30	69
	3/2	82	86	95	95	60
	3/1	174	141	152	154	170

Sources: U.S. EIA 2008a; author calculations.

Note: For definitions and calculations, see the notes to table A4.2.

Table A4.38

Ratio of January 2008 Prices to January 2004 Prices in the Philippines

Currency	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$ nominal	3.1	2.3	2.7	2.7	2.8
₱ nominal	2.3	1.7	2.0	2.0	2.1
US$ real	2.7	2.0	2.4	2.4	2.5
₱ real	1.8	1.3	1.6	1.6	1.6

Sources: U.S. EIA 2008a; author calculations.

Table A4.39

Standard Deviation of Returns for Logarithms of Prices and Exchange Rate in the Philippines

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil	Exchange rate
Nominal (US$)	1	0.082	0.080	0.101	0.087	0.120	n.a.
	2	0.079	0.105	0.090	0.088	0.089	n.a.
	3	0.092	0.090	0.076	0.071	0.062	n.a.
	Entire	0.083	0.088	0.094	0.085	0.105	n.a.
Nominal (₱)	1	0.085	0.084	0.103	0.090	0.121	0.023
	2	0.080	0.107	0.094	0.092	0.089	0.017
	3	0.093	0.092	0.078	0.074	0.062	0.013
	Entire	0.086	0.091	0.096	0.087	0.105	0.021
Real (US$)	1	0.081	0.079	0.100	0.087	0.119	n.a.
	2	0.078	0.104	0.089	0.086	0.088	n.a.
	3	0.090	0.088	0.074	0.069	0.059	n.a.
	Entire	0.082	0.087	0.093	0.084	0.104	n.a.
Real (₱)	1	0.086	0.086	0.103	0.090	0.121	n.a.
	2	0.080	0.107	0.094	0.093	0.089	n.a.
	3	0.093	0.092	0.078	0.074	0.062	n.a.
	Entire	0.086	0.092	0.097	0.088	0.106	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008.

local currency units for all fuels are consistently more volatile for each subperiod, both in nominal and real terms.

GARCH analysis results are shown in tables A4.40 and A4.41. The results from the second subperiod are not given because no meaningful equations could be found for any of the fuels. In table A4.40, retaining fewer terms in the GARCH(1,0) formulation for jet kerosene and in the GARCH(1,1) formulation for gasoil makes each respective equation fail the ARCH test. Similarly, in the first subperiod, retaining fewer lags in the equation for residual fuel oil makes it fail the ARCH test.

The results of the runs tests are given in tables A4.42 to A4.47. The cumulative cycles in local currency are negative for every fuel for the entire period. With the exception of crude oil, the cumulative cycles are negative more than half the time.

Table A4.40

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Philippine Pesos, Beginning–March 2007

Parameter	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes	Yes	Yes	Yes	Yes D[a]
Finite half-life?	n.a.	Yes	Yes	Yes	No	n.a.
Sum of ARCH + GARCH coefficients	n.a.	0.31	0.90	0.61	0.97	n.a.
Half-life in months	n.a.	0.6	7	1	n.a.	n.a.
Lagged variables in mean equation	n.a.	1,2	1,2	1,2,3,4,6	1,2,4,6	n.a.
GARCH order	n.a.	(1,0)	(1,1)	(1,0)	(1,1)	n.a.
Trend variables in variance equation	n.a.	None	None	None	None	n.a.

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.41

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Philippine Pesos, Beginning–June 1999

Parameter	Crude	Gasoline	Diesel	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes	Yes	Yes	Yes	Yes D[a]	Yes
Finite half-life?	Yes	Yes	No	No	n.a.	Yes
Sum of ARCH + GARCH coefficients	0.62	0.65	0.98	0.91	n.a.	0.30
Half-life in months	1	2	n.a.	n.a.	n.a.	0.6
Lagged variables in mean equation	1	4	1,2,3,4	1,2	n.a.	1,2,4,6
GARCH order	(1,0)	(1,0)	(1,1)	(1,0)	n.a.	(1,0)
Trend variables in variance equation	None	None	None	None	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.42

Runs Tests on Nominal Monthly Prices in Philippines, in U.S. Dollars, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–3.19	–1.54	–2.47	–3.90	–2.23
Cycle returns, $(w - \mu) \div \sigma$	–2.94	–1.03	–2.29	–3.98	–1.99
Cumulative cycles					
Maximum (US$)	73	80	92	89	38
Minimum (US$)	–101	–94	–131	–108	–85
Average (US$)	0	–7	–11	–1	–10
Percentage negative	43	51	53	47	60
Maximum sojourn, months	42	48	46	48	47

Source: Author calculations.

Table A4.43

Runs Tests on Nominal Monthly Prices in Philippines, in Philippine Pesos, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, (w — μ) ÷ σ	–3.14	–0.23	–2.97	–3.93	–1.79
Cycle returns, (w — μ) ÷ σ	–2.70	0.00	–3.31	–3.48	–1.71
Cumulative cycles					
Maximum (₱)	3,142	3,326	3,708	3,307	1,836
Minimum (₱)	–4,662	–5,129	–7,318	–6,403	–3,996
Average (₱)	–18	–667	–760	–535	–485
Percentage negative	36	55	57	52	57
Maximum sojourn, months	95	55	48	52	38

Source: Author calculations.

Table A4.44

Runs Tests on Nominal Monthly Prices in Philippines, in U.S. Dollars, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, (w — μ) ÷ σ	–2.37	–1.89	–2.16	–2.37	–2.37
Cycle returns, (w — μ) ÷ σ	–2.71	–1.69	–2.20	–2.38	–2.36
Cumulative cycles					
Maximum (US$)	52	53	68	80	38
Minimum (US$)	–44	–93	–100	–81	–52
Average (US$)	5	–3	–7	3	–9
Percentage negative	38	46	52	45	65
Maximum sojourn, months	42	48	46	48	47

Source: Author calculations.

Table A4.45

Runs Tests on Nominal Monthly Prices in Philippines, in Philippine Pesos, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, (w — μ) ÷ σ	–2.05	–0.71	–2.55	–2.37	–1.98
Cycle returns, (w — μ) ÷ σ	–2.35	–0.35	–2.88	–1.75	–2.03
Cumulative cycles					
Maximum (₱)	1,214	1,100	897	1,307	481
Minimum (₱)	–1,827	–3,271	–3,519	–3,046	–2,431
Average (₱)	286	–333	–420	–174	–284
Percentage negative	26	48	53	44	50
Maximum sojourn, months	95	55	48	52	38

Source: Author calculations.

Table A4.46

Runs Tests on Nominal Monthly Prices in Philippines, in U.S. Dollars, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	−1.93	0.15	−0.15	−2.87	−0.70
Cycle returns, $(w - \mu) \div \sigma$	0.88	−0.76	−0.76	−0.01	−0.81
Cumulative cycles					
Maximum (US$)	117	118	136	118	88
Minimum (US$)	−57	−56	−87	−79	−33
Average (US$)	35	26	27	21	39
Percentage negative	28	32	34	40	17
Maximum sojourn, months	52	46	47	44	60

Source: Author calculations.

Table A4.47

Runs Tests on Nominal Monthly Prices in Philippines, in Philippine Pesos, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	−2.30	0.66	−1.26	−3.04	−0.47
Cycle returns, $(w - \mu) \div \sigma$	−1.35	0.51	−1.56	−3.27	−0.34
Cumulative cycles					
Maximum (₱)	4,969	5,396	5,979	5,151	4,267
Minimum (₱)	−2,836	−3,060	−5,047	−4,559	−1,564
Average (₱)	1,323	868	967	731	1,625
Percentage negative	29	33	33	37	18
Maximum sojourn, months	47	43	43	40	57

Source: Author calculations.

Thailand

Prices averaged over each subperiod as well as over the entire period and the percentage price increases between subperiods are shown in table A4.48. In both nominal and real terms, the percentage price increases in the third subperiod over the second subperiod were 20 to 25 percent.

Table A4.49 gives the ratio of fuel prices in January 2008 to those in January 2004. The ratios are consistently lower for Thai baht prices in both nominal and real terms. In real terms, fuel prices effectively doubled in the intervening four years.

Standard deviations of returns for logarithms of monthly prices and exchange rates are shown in table A4.50. Local currency prices exhibited the same or greater volatility in both nominal and real terms, except for the nominal residual fuel oil price during the first subperiod.

GARCH analysis results are shown in tables A4.51 to A4.53. In table A4.51, although the GARCH(1,0) formulation for jet kerosene appears arbitrary, retaining fewer lagged variables makes the equation fail the ARCH test. Similarly, in the first subperiod, if fewer lagged variables are retained in the equation for residual fuel oil, the equation fails the ARCH test. Lastly, in the second subperiod, keeping fewer lagged terms for residual fuel oil, including omission of all lagged variables, makes the equation statistically insignificant.

The results of the runs tests are shown in tables A4.54 to A4.56 for local prices. The results for prices expressed in U.S. dollars are in the Philippines section of this annex. For the whole period, cumulative cycles in local currency tend to be more positive, with the exception of crude oil. During the first subperiod, however, cumulative cycles tend to be more positive in U.S. dollars.

Table A4.48

Period Average Prices in Thailand

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Nominal (US$)	1	17.84	23.56	23.96	22.87	14.23
	2	26.37	30.07	30.38	29.11	23.61
	3	58.06	67.25	71.33	68.63	45.61
	Entire	27.45	33.41	34.51	33.07	22.31
Nominal (B)	1	484	639	649	619	388
	2	1,103	1,257	1,271	1,219	987
	3	2,182	2,533	2,687	2,583	1,713
	Entire	945	1,138	1,176	1,127	773
Real (US$)	1	25.90	34.29	34.80	33.18	20.64
	2	30.11	34.35	34.72	33.25	26.96
	3	58.70	68.10	72.20	69.44	46.10
	Entire	33.15	40.85	42.02	40.22	26.92
Real (B)	1	782	1,036	1,048	1,000	624
	2	1,276	1,453	1,470	1,409	1,141
	3	2,234	2,598	2,754	2,647	1,753
	Entire	1,168	1,428	1,469	1,406	953
Nominal (% increase for prices in US$)	2/1	48	28	27	27	66
	3/2	120	124	135	136	93
	3/1	225	185	198	200	221
Nominal (% increase for prices in B)	2/1	128	97	96	97	154
	3/2	98	102	112	112	74
	3/1	350	296	314	317	341
Real (% increase for prices in US$)	2/1	16	0	0	0	31
	3/2	95	98	108	109	71
	3/1	127	99	107	109	123
Real (% increase for prices in B)	2/1	63	40	40	41	83
	3/2	75	79	87	88	54
	3/1	186	151	163	165	181

Sources: U.S. EIA 2008a; author calculations.

Note: For definitions and calculations, see the notes to table A4.2.

Table A4.49

Ratio of January 2008 Prices to January 2004 Prices in Thailand

Currency	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
US$ nominal	3.1	2.3	2.7	2.7	2.8
B nominal	2.7	1.9	2.3	2.3	2.4
US$ real	2.7	2.0	2.3	2.4	2.4
B real	2.3	1.6	1.9	2.0	2.0

Sources: U.S. EIA 2008a; author calculations.

Table A4.50

Standard Deviation of Returns for Logarithms of Prices and Exchange Rate in Thailand

Price (units)	Period	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil	Exchange rate
Nominal (US$)	1	0.082	0.080	0.101	0.087	0.120	n.a.
	2	0.079	0.105	0.090	0.088	0.089	n.a.
	3	0.092	0.090	0.076	0.071	0.062	n.a.
	Entire	0.083	0.088	0.094	0.085	0.105	n.a.
Nominal (B)	1	0.085	0.084	0.102	0.089	0.118	0.032
	2	0.084	0.107	0.094	0.092	0.092	0.017
	3	0.093	0.091	0.078	0.073	0.064	0.014
	Entire	0.087	0.090	0.096	0.087	0.104	0.026
Real (US$)	1	0.081	0.079	0.100	0.087	0.119	n.a.
	2	0.078	0.104	0.089	0.086	0.088	n.a.
	3	0.090	0.088	0.074	0.069	0.059	n.a.
	Entire	0.082	0.087	0.093	0.084	0.104	n.a.
Real (B)	1	0.085	0.084	0.102	0.088	0.119	n.a.
	2	0.082	0.105	0.092	0.091	0.091	n.a.
	3	0.092	0.088	0.076	0.071	0.062	n.a.
	Entire	0.086	0.090	0.095	0.086	0.104	n.a.

Source: Author calculations.

Note: n.a. = not applicable. Subperiod 1 is from beginning to June 1999; subperiod 2 is from July 1999 to December 2003; subperiod 3 is from January 2004 to January 2008; the entire period is from beginning to January 2008.

Table A4.51

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Thai Bahts, Beginning–March 2007

Parameter	Crude	Gasoline		Jet kerosene		Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes	Yes	Yes	Yes	Yes	Yes
Finite half-life?	n.a.	No	Yes	Yes	No	No	No
Sum of ARCH + GARCH coefficients	n.a.	0.81	0.25	0.89	0.84	0.97	0.35
Half-life in months	n.a.	n.a.	0.5	6	n.a.	n.a.	n.a.
Lagged variables in mean equation	n.a.	1	1,2	1,2	1,2,4,6	4	2
GARCH order	n.a.	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
Trend variables in variance equation	n.a.	None	None	None	None	None	Trend

Source: Author calculations.

Note: n.a. = not applicable; trend is a linear time trend that increases by one for each observation in the series.

a. Results are classified into the four categories defined on p. 13.

Table A4.52

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Thai Bahts, Beginning–June 1999

Parameter	Crude	Gasoline		Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes	Yes	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	Yes	No	n.a.	n.a.	Yes
Sum of ARCH + GARCH coefficients	n.a.	0.70	0.77	n.a.	n.a.	0.42
Half-life in months	n.a.	3	n.a.	n.a.	n.a.	0.8
Lagged variables in mean equation	n.a.	3,5,6	3,5	n.a.	n.a.	1,2,3 4, 6,13
GARCH order	n.a.	(1,0)	(1,0)	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	None	None	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.53

GARCH Analysis of Returns of Logarithms of Nominal Monthly Prices in Thai Bahts, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Statistically significant equation?	Yes D[a]	Yes D[a]	Yes D[a]	Yes D[a]	Yes
Finite half-life?	n.a.	n.a.	n.a.	n.a.	No
Sum of ARCH + GARCH coefficients	n.a.	n.a.	n.a.	n.a.	0.68
Half-life in months	n.a.	n.a.	n.a.	n.a.	0.7
Lagged variables in mean equation	n.a.	n.a.	n.a.	n.a.	2,9,16
GARCH order	n.a.	n.a.	n.a.	n.a.	(1,0)
Trend variables in variance equation	n.a.	n.a.	n.a.	n.a.	None

Source: Author calculations.

Note: n.a. = not applicable.

a. Results are classified into the four categories defined on p. 13.

Table A4.54

Runs Tests on Nominal Monthly Prices in Thailand, in Thai Bahts, Beginning–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w - \mu) \div \sigma$	–2.82	–0.99	–2.19	–3.14	–2.16
Cycle returns, $(w - \mu) \div \sigma$	–2.96	–0.51	–2.04	–2.71	–2.54
Cumulative cycles					
Maximum (B)	502	907	998	751	504
Minimum (B)	–459	–566	–490	–481	–336
Average (B)	–11	28	62	59	8
Percentage negative	58	47	39	36	48
Maximum sojourn, months	97	96	97	96	96

Source: Author calculations.

Table A4.55

Runs Tests on Nominal Monthly Prices in Thailand, in Thai Bahts, Beginning–June 1999

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w-\mu) \div \sigma$	–2.66	–1.71	–1.54	–1.40	–2.33
Cycle returns, $(w-\mu) \div \sigma$	–2.71	–1.04	–1.88	–1.19	–2.04
Cumulative cycles					
Maximum (B)	1,146	1,192	792	1,305	278
Minimum (B)	–1,959	–2,603	–2,750	–2,237	–2,406
Average (B)	151	–384	–530	–218	–409
Percentage negative	26	62	63	51	77
Maximum sojourn, months	61	51	47	49	48

Source: Author calculations.

Table A4.56

Runs Tests on Nominal Monthly Prices in Thailand, in Thai Bahts, July 1999–March 2007

Parameter	Crude	Gasoline	Jet kerosene	Gasoil	Residual fuel oil
Returns, $(w-\mu) \div \sigma$	–1.13	0.66	–0.78	–3.11	–0.70
Cycle returns, $(w-\mu) \div \sigma$	–1.35	0.41	–0.70	–2.96	–1.73
Cumulative cycles					
Maximum	4,905	4,739	5,808	5,050	3,740
Minimum	–1,907	–1,902	–3,117	–2,806	–1,017
Average	1,715	1,366	1,505	1,247	1,874
Percentage negative	24	27	27	31	12
Maximum sojourn, months	52	49	49	45	63

Source: Author calculations.

Annex 5

Hedging Parameters

This annex derives the values of the risk-minimizing and optimal hedge ratios as well as other associated hedging performance parameters for an agent that has physical crude oil or oil products to sell. It is assumed that the agent has N units to sell on the spot market and desires to hedge M (where M is smaller than or equal to N) of these units through a futures transaction. In the first case, the goal is to choose M to minimize the overall risks as measured by the variance of the return to the portfolio of M futures contracts and N spot sales.

Let

- $f(0,1)$ denote the futures prices quoted at current time 0 for delivery at time 1,
- $f(1,1)$ denote the futures price at time 1 for delivery at time 1,
- $p(0)$ denote the spot price at time 0,
- $p(1)$ the spot price at time 1.

Without a hedge, the oil producer would receive the uncertain amount $p(1)$ at time 1. To effect a hedge, the producer sells M futures at time 0, and offsets this position at time 1 with the purchase of M units for immediate delivery at time 1. At time 1, the gain (loss) on the futures contracts is

$$[f(0,1) - f(1,1)] \times M. \tag{A5.1}$$

The overall value of the hedged portfolio, denoted $W(1)$, is

$$W(1) = p(1) \times N + [f(0,1) - f(1,1)] \times M. \tag{A5.2}$$

If the hedged commodity and the physical commodity are identical in all respects (quality, location, and timing) then $p(1) = f(1,1)$, and a choice of $M = N$ would eliminate all price risk from the contract. It is important to note that the change in futures prices is the change in the price at a fixed time (1) between the dates of opening and closing the hedge.

Equation A5.2 can be rewritten by incorporating the certain initial value of wealth, as determined by the spot price of the physical asset at time 0, $W(0) = p(0) \times N$. The change in wealth over the life of the hedge is[1]

$$\Delta W = W(1) - W(0) = [p(1) - p(0)] \times N + [f(0,1) - f(1,1)] \times M, \tag{A5.3}$$

and the change in the value of the wealth per unit of production is

$$\Delta W \div N = [p(1) - p(0)] + h \times [f(0,1) - f(1,1)], \tag{A5.4}$$

where h denotes the hedge ratio, the proportion of physical units for which futures contracts are taken out. This equation can be rewritten as

$$\Delta W \div N = \Delta p - h \times \Delta f, \tag{A5.5}$$

where $\Delta p = [p(1) - p(0)]$ and $\Delta f = [f(1,1) - f(0,1)]$.

The objective of hedging in this case is to minimize the total risk on the sale of oil. Measuring risk by the variance of the change in wealth per unit sold requires that the variance of equation A5.5 be minimized. The variance can be written as

$$\text{Var}\,[\Delta W \div N] = \text{Var}\,\Delta p - 2h\,\text{Cov}\,[\Delta p, \Delta f\,] + h^2\,\text{Var}\,\Delta f, \tag{A5.6}$$

where Var Δp and Var Δf are the variances of Δp and Δf, respectively, and Cov $[\Delta p, \Delta f]$ denotes the covariance of Δp and Δf. The variance-minimizing value of the hedge ratio is given by

$$h^* = \text{Cov}\,[\Delta p, \Delta f\,] \div \text{Var}\,\Delta f. \tag{A5.7}$$

Alternatively,

$$h^* = \rho\,\sqrt{(\text{Var}\,\Delta p \div \text{Var}\,\Delta f)}, \tag{A5.8}$$

where ρ is the (unsquared) correlation between the two changes in prices. The hedge ratio determined in equation

[1] The equation formulation is not intended to imply that the seller is weighing the option of selling today versus a few months from now. Subtracting $W(0)$ from equation A5.2, which introduces a constant, is a device for expressing the equations that follow in terms of Δp and Δf.

A5.7 is termed the risk-minimizing hedge ratio. The value of the minimum risk attainable is given by

$$\text{Var}\ [\Delta W \div N] = \text{Var}\ \Delta p - (h^*)^2\ \text{Var}\ \rho f. \qquad \text{(A5.9)}$$

If the two price changes (Δp and Δf) are perfectly correlated, the hedge is perfect and removes all uncertainty. Where the correlation is substantially less than unity, the fraction of the physical commodity that should be hedged to minimize risks will be correspondingly lower. The existence of the basis risk that leads to this lack of perfect correlation means that the producer must balance the risk of not hedging part or all of the production against the risk entailed from the basis on the part that is hedged. Hedging efficiency is measured by the percentage reduction in the variance of the unhedged portfolio achieved by the portfolio of physical and futures. At the risk-minimizing value, the ratio of the variance of the hedged portfolio to the variance of the unhedged portfolio is given by

$$\text{Var}\ [\Delta W \div N] \div \text{Var}\ \Delta p = 1 - \rho^2. \qquad \text{(A5.10)}$$

The squared correlation between the two changes in prices thus measures hedging effectiveness. It is assumed that the short hedger is constrained not to hedge more than is available to sell of the physical commodity. If the value of the risk-minimizing hedge ratio is greater than unity, this is assumed to be an infeasible portfolio; a value of unity is taken as the feasible risk-minimizing hedge.

Equation A5.7 gives the key to estimating the risk-minimizing hedge ratio. Since the formula given is identical to that used to estimate the regression coefficient when the change in the spot price is regressed on the change in the futures price, the risk-minimizing hedge ratio can be obtained by the regression

$$\Delta p = y + h\Delta f + \varepsilon, \qquad \text{(A5.11)}$$

where the estimated return on the portfolio is given by

$$y^* = E(\Delta p) - h^* E(\Delta f), \qquad \text{(A5.12)}$$

and $E(\Delta p)$ and $E(\Delta f)$ are the expected values of the arguments Δp and Δf, respectively.[2]

Using previous data for futures and spot prices for the commodity in question, the regression coefficient can be estimated. Hedging effectiveness is estimated by the squared correlation coefficient from the regression, and the risk-minimizing hedge ratio by the regression coefficient on the change in futures prices. The estimated value of y^* is the expected return from the risk-minimizing portfolio over the period, measured relative to the set of opening spot prices at the beginning of every futures contract. The increment in the return due to hedging, relative to this set of fixed prices, is therefore accounted by the second term on the right-hand side of equation A5.12. When futures prices rise (as the closing date approaches), the return to the hedger falls depending on how much was hedged.

Equation A5.11 can be estimated by using historical data on changes in prices. The use of sample data to estimate a theoretical concept relies on there being no shifts in the underlying variances and covariances. If there had been such a structural shift, the regression coefficient would also change over the period as would the risk-minimizing hedge ratio and the effectiveness of hedging. More sophisticated models use dynamic hedging strategies where the risk-minimizing hedge ratio changes over time and are estimated through a model such as a GARCH process.

The estimation of the risk-minimizing hedge ratio from a given data period can be used to simulate the benefits of a hedging strategy for that same period—the ex post hedge in which the agent has made an estimate of the risk-minimizing hedge ratio using data from that period itself. It can also be used to simulate a hedging strategy outside that period—the ex ante hedge in which it is assumed that the same hedge ratio would minimize risks if all the data were available to estimate it. If the data changed over time such that the regression coefficients in equation A5.11 changed, then the ex post and ex ante hedges would give different risk reductions and returns. The results of calculations for ex post risk-minimizing six-month hedged and unhedged returns for various crudes covering the period February 1988 to December 2006 are given in table A5.1.

An extension to the risk-minimizing hedge is to take into account the expected returns from hedging versus not hedging. To balance risk against return, a utility function must be specified. The utility function U to be maximized is usually assumed to be of the form

$$U = E[\Delta W \div N] - \alpha\ \text{Var}\ [\Delta W \div N], \qquad \text{(A5.13)}$$

where α is a measure of the preference for risk. The higher the value of α, the more important it is to choose a hedged portfolio that reduces risk. The optimal hedge ratio, $\hat{h}$ can be shown to be

$$\hat{h} = h^* - E(\Delta f) \div (2\alpha\ \text{Var}\ \Delta f\,) \qquad \text{(A5.14)}$$

and is estimated from the value of the risk-minimizing hedge ratio, the mean and variance of the change in futures prices, and the risk preference parameter α.

The value of the optimal hedge variance is given by substituting equation A5.14 into equation A5.6:

[2] This can be seen by noting that regressions pass through the point of means.

Table A5.1

Ex Post Risk-Minimizing Six-Month Hedged Return and Unhedged Return for Various Crudes, February 1988–December 2006

Crude, country	Feb. '88–Dec. '06 Hedged return	Feb. '88–Dec. '06 Unhedged return	Feb. '88–Dec. '99 Hedged return	Feb. '88–Dec. '99 Unhedged return	Jan. '00–Dec. '03 Hedged return	Jan. '00–Dec. '03 Unhedged return	Jan. '04–Dec. '06 Hedged return	Jan. '04–Dec. '06 Unhedged return
Brega, Libya	−0.58	0.74	−0.37	0.50	−1.56	0.94	0.16	1.44
Cabinda, Angola	−0.52	0.71	−0.33	0.51	−1.38	0.90	0.12	1.31
Cossack, Australia	−0.57	0.76	−0.37	0.46	−1.50	1.25	0.02	1.32
Dukhan, Qatar	−0.50	0.75	−0.35	0.45	−1.24	1.05	0.26	1.48
Es Sider, Libya	−0.58	0.72	−0.38	0.49	−1.53	0.91	0.10	1.35
Forcados, Nigeria	−0.62	0.74	−0.43	0.47	−1.46	0.99	0.14	1.47
Iran Heavy, Iran, Islamic Rep. of	−0.52	0.64	−0.35	0.45	−1.30	0.72	0.22	1.33
Iran Light, Iran, Islamic Rep. of	−0.55	0.67	−0.39	0.45	−1.30	0.79	0.22	1.39
Kole, Cameroon	−0.58	0.77	−0.38	0.51	−1.10	0.97	0.14	1.52
Mandji, Gabon	−0.58	0.74	−0.34	0.52	−1.15	0.84	0.15	1.51
Marine, Qatar	−0.50	0.70	−0.36	0.45	−1.24	0.95	0.21	1.37
Murban, Abu Dhabi, UAE	−0.50	0.75	−0.35	0.46	−1.28	1.08	0.23	1.46
Oriente, Ecuador	−0.65	0.57	−0.35	0.49	−1.90	0.55	−0.21	0.94
Saharan, Algeria	−0.60	0.73	−0.42	0.48	−1.57	0.96	0.15	1.42
Urals, Russian Federation	−0.57	0.67	−0.42	0.45	−1.29	0.80	0.22	1.40
Widuri, Indonesia	−0.61	0.68	−0.37	0.46	−1.82	0.86	0.07	1.33
WTI, U.S.	0.10	1.22	−0.31	0.51	−1.54	1.16	3.20	4.12

Sources: Futures prices from Energy Intelligence 2008; author calculations.
Note: UAE = United Arab Emirates.

$$\text{Var}\,[\Delta W \div N] = \text{Var}\,\Delta p + (\hat{h}^2 - 2\,\hat{h}h^*)\,\text{Var}\,\Delta f \qquad \text{(A5.15)}$$

The expected return on the optimal hedged portfolio is

$$\hat{y} = E(\Delta p) - \hat{h}E(\Delta f). \qquad \text{(A5.16)}$$

The risk reduction (hedging efficiency) of the optimal hedge can be derived by dividing equation A5.15 by the variance of the spot price change.

For a long hedger that intends to buy the physical commodity after a specified number of months and that hedges with an immediate buy hedge coupled with an equivalent sell of the futures contract for immediate delivery at the time of expiration of the original futures purchase, the overall change in the value of the portfolio is given by the negative of equation A5.3. The risk-minimizing hedge ratio continues to be given by equation A5.8, the expected return on the hedge is equal to the negative of equation A5.12, and the expected unhedged return is equal to the negative of the change in the spot price over the duration of the hedge.

Annex 6

Price-Smoothing Formulae

This annex accompanies chapter 7 and uses the following definitions:

- $p(t)$ is the spot price of a commodity (crude oil or oil product) at time t
- $p(t, i)$ is the futures price at time t, for delivery i periods in the future.

The n month moving average of past prices at time t is

$$P_m(t,n) = [\sum_{i=1}^{i=n} p(t-i)] \div n.$$

The average futures price at time t taken over the next m contract durations is

$$P_f(t,m) = [\sum_{i=1}^{i=m} p(t,i)] \div m.$$

The average of n past prices and m futures prices set in period $t-1$ to be used as a target price for period t is given by

$$P_v(t) = [\sum_{i=1}^{i=n} p(t-i)] + \sum_{i=1}^{i=m} p(t,i)] \div (n+m).$$

Glossary

Arc-sine law	A theorem, also known as the law of long leads, that shows that, when a coin is tossed repeatedly with equal chances of heads and tails, the proportion of the time that the total number of heads is greater than the total number of tails follows a certain mathematical function. This theorem implies that often very large numbers of trials are needed before the lead switches from heads to tails (or vice versa).
Autocorrelation	The correlation of a variable measured at a number of successive time intervals with the values of the same variable a fixed number of periods earlier
Barrels	A unit of volume, equal to 42 U.S. gallons and equivalent to 159 liters
Brent crude	One of the major crude oil classifications used as a benchmark for pricing, produced in the North Sea
Basis risk	The risk associated with imperfect hedging using futures, arising from differences in the qualities of the commodity to be hedged and of the reference commodity underlying the futures (for example, West Texas Intermediate or Brent crude)
Conditional variance	The forecast of the variance of a series at a point in time based on information available in the previous period
Correlation	A measure of the extent to which two variables move together or oppositely over time
Cumulative sum	The sum of all past values of a series until that time
Cycle	The difference between a given data series and a trend fitted to that series ("the filter")
Distillate fuel oil	Products of refinery distillation, sometimes referred to as middle distillates, consisting of kerosene, diesel fuel, and heating oil
Filter	A smooth estimate of the long-term trend of a data series
F-test	A test that checks if the variances of two separate series are equal
GARCH	Generalized autoregressive conditional heteroskedasticity—a statistical model to represent a situation in which the variance of shocks to a given series changes over time
Gasoil	European designation for the medium oil from the refining process used as a fuel in diesel engines, burned in central heating systems, and used as a feedstock for the chemical industry
Heating oil	A distillate fuel oil used for domestic heating and in medium-capacity commercial-industrial burner units
Heteroskedasticity	The nonconstancy of the variance of a series over time
Homoskedasticity	The constancy of the variance of a series over time
Lagged variable	With respect to the current value of a series, the value lagged *k* periods is the value of that same series *k* periods earlier
Mean	The average of a set of data

Mean reversion	A series is mean-reverting if values eventually return to the average
Nonparametric test	A nonparametric or distribution-free test is one that makes no assumption about the underlying frequency distribution of the variable being assessed
Nonstationary	A process is nonstationary if its probability distribution varies over time; the mean or variance of such a process can therefore be nonconstant
Null hypothesis	A hypothesis set up in statistics to be invalidated (nullified) in order to support an alternative hypothesis. A null hypothesis is presumed true until statistical tests indicate otherwise.
One-sided 5 percent test	Also called a one-tailed test of significance. A statistical hypothesis test in which the values for rejecting the null hypothesis are located entirely in one tail of the probability distribution (for example, all values are positive instead of covering positive and negative numbers), and the null hypothesis is rejected if there is only a 5 percent or lower probability that it is true.
Propane	One of two important components of liquefied petroleum gas, the other being butanes
Random walk	A process where each successive step is in a random direction. It can be shown that the distance from the starting point in a one-dimensional random walk (moving forward and backward on a straight line) with n steps asymptotically approaches $0.8 \sqrt{n}$.
Return	The difference between the current and previous value of a variable (typically the price); in chapter 5 and annex 5, a change in the value of an investment or a portfolio over a given period of time
Residual fuel oil	Heavy fuel oil produced from the residue in the fractional distillation process
Runs test	A test for the randomness of a series of data over time utilizing information on the number of unbroken sequences of positive or negative values
Shock	Any external factor that causes an unpredicted change in the variable under consideration, typically prices
Sojourn	The number of periods a cumulative sum stays positive (or negative) before changing sign
Standard deviation	The square root of the variance of a series
Stationary	A process is stationary if its probability distribution does not vary over time; the mean and variance of such a process are constant
Time series	A series of data points measured at successive times, typically at uniform time intervals
Unit root	A series has a unit root when the current value is equal to the previous value plus a random term
U.S. gallon	A unit of volume, equivalent to 3.79 liters
Variance	A measure of the dispersion or variability of a series based on the average squared values above and below the mean
West Texas Intermediate (WTI)	One of the major crude oil classifications used as a benchmark for oil pricing, with price settlement in Cushing, Oklahoma

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