Chapter 8

Industry Dynamics – Oil Price and the Global Oil Producers

- Problem Articulation – Puzzling Dynamics of Oil Price
- Model Development Process
- A Closer Look at the Stakeholders and Their Investment Decision Making
- Connecting the Pieces – A Feedback Systems View
- A Simple Thought Experiment: Green Mindset and Global Recession
- Using the Model to Generate Scenarios
- Devising New Scenarios
- Endnote: A Brief History of the Oil Producers' Project

Previous chapters have dealt with firm-level dynamics of cyclicality, growth, stagnation and decline. In this chapter, we turn our attention to the dynamics of an entire industry, global oil, comprising thousands of firms and billions of consumers around the world. At first glance, this shift of perspective may seem ambitious, requiring an immensely large model to capture the vast web of interactions among so many players. What is really required is a shift in the unit of analysis, away from the individual firm and its functions to major groupings in the industry. Industries, as a whole, exhibit interesting and puzzling dynamics. The modeller's task is to discover feedback loops that explain observed dynamics. As always, the conceptual challenge is to adopt an appropriate perspective from which to view the situation and interpret its dynamic complexity. In this case, the model arose from a team model-building project with planners at Royal Dutch/Shell (Morecroft and van der Heijden, 1992).[1] The team wanted to develop a simulation model of global oil markets.

[1]The oil producers' project was part of a larger initiative at Shell International to reposition corporate planning as a process for organisational learning. This important role for planning is described by de Geus (1988) and is further developed in an influential book *The Living Company* (de Geus, 1999). Firms that successfully adapt and survive are those where important decisions and actions are embedded within an effective learning cycle.

The project was part of a broad ranging scenario exercise to explore the strategic implications of changes in the structure of the energy industry.

In Shell, scenario planning is viewed as a way to discover new concepts and language that enable the organisation to become more agile in recognising significant industry trends, defining emerging business problems and preparing the minds of senior managers to deal with such problems. Scenario planning is not a way of predicting the future. Instead it works by the development of consistent stories about alternative futures, as the basis for what-if thinking in the organisation (van der Heijden, 1996). A consistent story traces a time path into the future that forces managers and planners to think 'what would I do, within my area of business responsibility, if this future were to unfold?' The internal consistency of the stories, creating credibility and persuasiveness, is an important factor in evaluating the usefulness of scenarios – much more important than the ex-post accuracy of the time paths. Scenarios are selected on their ability to make the organisation a skilful observer of the business environment. As such they do not have to describe the most likely future, but the reasoning behind the scenarios must be plausible.

Problem Articulation – Puzzling Dynamics of Oil Price

The long-term behaviour of oil price reveals striking contrasts between periods of price stability, mild price fluctuations, dramatic price surges and equally dramatic collapses. Figure 8.1 shows world oil price spanning 142 years, from 1869 to 2011; a remarkably long time series. The vertical axis is on a scale from zero to 100 dollars per barrel in 2010 dollars. Lying behind this price trajectory is the turbulent history of the oil industry as vividly told in *The Prize: The Epic Quest for Oil Money and Power* (Yergin, 1991) and *The Quest: Energy, Security and the Remaking of the Modern World* (Yergin, 2011).

Between 1869 and 1880 there was extreme price volatility. This period corresponds to the early pioneering days of the oil industry in the Pennsylvania Oil Regions of the United States. The chaotic mix of speculators, fortune-seeking prospectors and their greedy exploitation of newly discovered reserves led to extraordinary periods of overproduction – too many wells and too much oil. The price trajectory in Figure 8.1 gyrates wildly, starting at $58 per barrel in 1869, rising to $75 per barrel by 1872, and falling to only $20 per barrel in 1874. Over the next two years to 1876, the price rose sharply to $50 per barrel before falling again to $18 in 1879. Then followed an interval of relatively low and stable oil price in the decade to 1889.

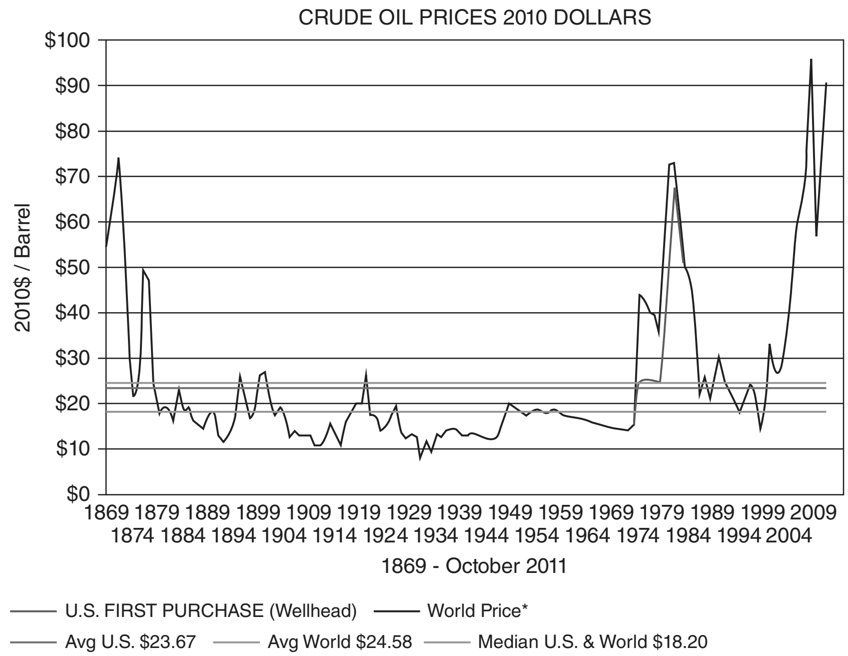

Figure 8.1 Historical oil price

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This shift to stability was imposed on the industry through the vision and will of John D. Rockefeller, founder of Standard Oil. His objective was to end what he described as a cut-throat policy of making no profits and instead make the oil business safe and profitable – by controlling supply and especially refining and distribution. The long-term results of Rockefeller's efforts are evident in the relative calm between 1889 and 1939, when the price moved in a range between $10 and $25 per barrel. There is some evidence of a short-term price cycle with an interval of about four years from peak to peak. Nevertheless, there is much greater price stability than in the pioneering early days. Rockefeller's era of supply discipline, ruthlessly imposed on a naturally chaotic industry and its fledgling markets, led to the rise of the integrated oil company and the enduring legacy of the 'Seven Sisters'. (The Seven Sisters is a term credited to Italian Enrico Mattei to describe the close association of the major oil companies: the four Aramco partners – Jersey (Exxon), Socony-Vacuum (Mobil), Standard of California and Texaco, together with Gulf, Royal Dutch/Shell and British Petroleum.)

In the post-war era from 1945 to 1970, this legacy and stable industry structure remained in place – almost unchallenged – even as the Seven Sisters expanded their operations internationally on the back of colossal oil reserves in the Arabian Peninsula. Despite these huge reserves, and the rapid expansion of oil output in the post-war era, prices were remarkably stable as Figure 8.1 shows. The price tranquillity was a far cry from the chaos of the Pennsylvania Oil Regions at the birth of the industry. Throughout this era, which spanned two and a half decades, supply and demand were in almost perfect balance – an astonishing achievement when one considers the complexity of the industry, its global reach, the diversity of stakeholders (encompassing producers, consumers and nations), and the array of objectives sought by these stakeholders from their share in the oil bonanza.

Already, however, new forces were at work, stronger even than the Seven Sisters, ushering in a new era of oil supply politics. As the locus of production moved to the Middle East, so the global political power of the region was awakened, feeding on western industrial countries' appetite for Arabian oil to sustain energy-intensive economies and lifestyles. Control over Middle Eastern oil was seized by the newly formed OPEC – the Organisation of Petroleum Exporting Countries. In 1974, and again in 1978, OPEC exercised its power by withholding production and forcing up the price of oil. As Figure 8.1 shows, the price doubled and continued to rise to a peak of more than 70 dollars per barrel by 1979 – a peak not seen since the early days of the Pennsylvania Oil Regions. Hence, in the 1970s, after two decades of managed calm and predictability, chaos returned to global oil markets.

After 1979, price fell sharply to only \$20 per barrel by the mid-1980s. For almost 20 years price fluctuated in the range \$15 to \$30 per barrel, but there were no further upheavals to match the dramatic variations of the 1970s. As the turn of the century approached, oil price was still low. In fact, many industry observers at the time believed it would remain low for the foreseeable future. However, the industry proved them wrong. Price began to rise again in 2001, reaching more than \$30 per barrel by 2004 and \$90 per barrel in 2009. By 2013 price had risen to more than \$100 per barrel. Yet as 2014 drew to a close press reports began to appear suggesting that a new era of lower price, below \$80 per barrel, was dawning.

Towards a Dynamic Hypothesis

An explanation of price behaviour lies in the feedback processes that balance supply and demand in the global oil markets. Periods of price stability correspond to times in which supply and demand are more or less in balance. Price spikes in the 1860s and 1970s correspond to times in which demand greatly exceeded supply. The gentle price roller-coaster of the early 1900s corresponds to a period in which supply sometimes exceeds and sometimes falls short of demand, but never by much. The remarkable price stability of the 1960s corresponds to a golden age of perfect supply management.

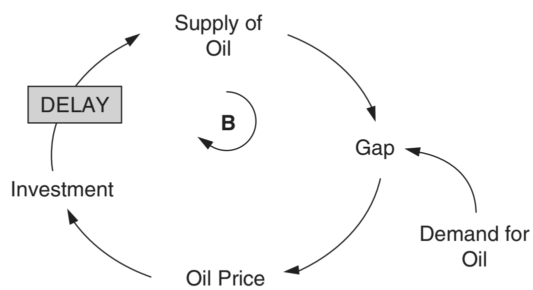


Figure 8.2 Simple balancing loop with delay in the oil industry

A useful template to begin conceptualisation of the oil industry is a balancing loop with delay as shown in Figure 8.2, the same as in Chapter 5's production and employment model, but this time conceived at the industry level and applying to upstream investment in oil rigs and platforms. Broadly speaking, if demand for oil exceeds supply then the gap (excess demand) leads to an increase in oil price that stimulates additional investment. After a delay of several years to open new oil fields, the supply of oil increases to eliminate the supply gap. Due to the long time delay in capacity expansion, it is difficult for the industry to achieve a balance of supply and demand and so oil price can be volatile. This explanation provides a preliminary dynamic hypothesis.

However, such a simple feedback loop by itself cannot explain the sustained price stability of the 1960s and 1970s. The corrective mechanism of capital investment, with its construction delay of almost five years, is simply not responsive enough to guarantee the near perfect balance of supply and demand that price stability requires. Equally, the invisible hand of balancing feedback alone cannot explain the wild price gyrations of the 1860s and 1870s, or the memorable price hikes of the 1970s and early 2010s. Reasoned commercial investment decisions should not result in oil famines and feasts with such extreme price movements. Obviously there are other feedback processes at work in the global oil system. Some must be fast-acting to prevent temporary imbalances and to short-circuit the inevitable time lags of commercial investment. Others must work to sustain imbalances, yet be powerful enough to override the natural balancing tendency of market forces and the invisible hand.

Model Development Process

There is clearly more to the global oil system than a simple balancing loop with delay. To gain more insight into the structure of the industry the project team (10 people in all) came together to share their knowledge about oil companies, oil producing nations and motives for investment and production. The team met three times for working sessions lasting three hours each. The meetings were facilitated by an experienced system dynamics modeller. One member of the team kept detailed minutes of the meetings (including copies of flip-chart notes and diagrams) in order to preserve a permanent trace of the model's conceptualisation. A sub-group of the project team met separately to develop and test a full-blown algebraic model.

Figure 8.3 shows the resulting overview of global oil producers comprising five main sectors. On the right are the independent producers making commercial investment decisions in response to the needs of the market and oil consumers. On the left are the swing producer and the opportunists that make up the oil producers' organisation OPEC. This powerful group of producers has access to very large reserves of low-cost oil. Their production decisions are motivated principally by political and social pressures, in contrast to the commercial logic of the independents. They coordinate production through quota setting. The opportunists agree to abide by quota, but will sometimes cheat by producing above quota in order to secure more oil revenues. The combined output of all three producer groups supplies the market where both price and demand are set.

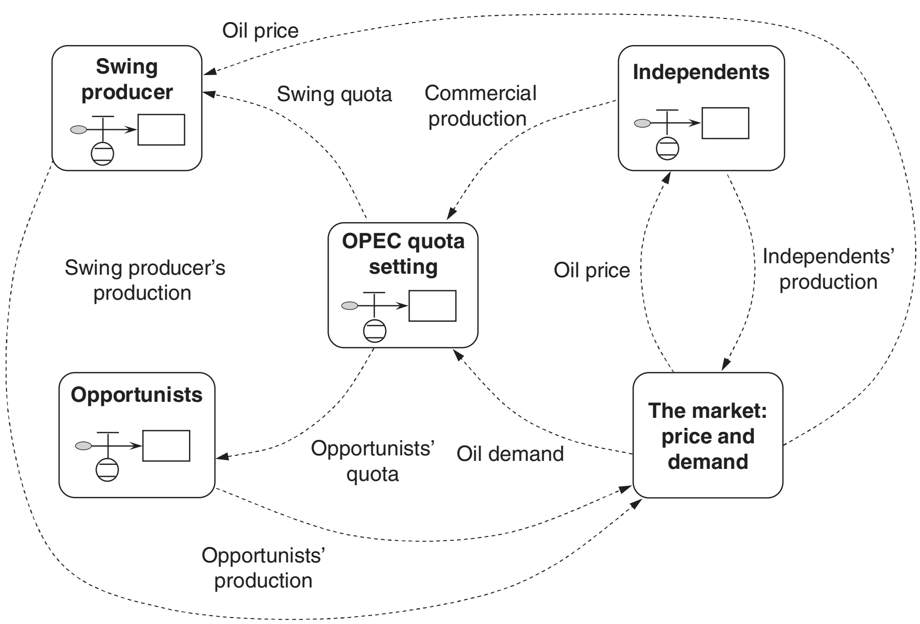


Figure 8.3 Overview of global oil producers

Price responds to imbalances in supply and demand and then feeds back to influence both demand and the behaviour of producers.

Now consider, in broad terms, how these five sectors are linked. In a purely commercial oil world there are only two sectors: the independents and the market. The market establishes the oil price and also consumers' demand for oil at the prevailing price. The oil price drives independents' investment and, eventually, leads to a change in production, which then feeds back to the market. The closed loop connecting the two sectors is none other than the balancing loop with delay mentioned earlier.

OPEC's involvement begins with quota setting. The nations of OPEC must collectively decide on an appropriate production quota. They do this by monitoring oil demand from the market and subtracting their estimate of independents' production. This difference is known as the call on OPEC and is the benchmark relative to which overall quota is set. The agreed quota is then allocated among member states. A portion called the swing quota goes to the swing producer and the rest to the opportunists. If OPEC is unified then all members follow quota, with the exception of the swing producer who makes tactical adjustments to production to ensure that oil price remains close to OPEC's target. In order to control oil price, the swing producer must closely monitor oil price and demand. Production from both the swing producer and opportunists then feeds back to the market, thereby completing the supply loop. As we shall see later there is much additional detail within each sector. For now, however, there is enough: five sectors with nine interconnecting lines to begin representing the rich and complex feedback structure of the global oil industry.

Why these five sectors? Why not lots more? Of course there is no one correct or best way to represent the industry. In reality, there are hundreds of companies and dozens of nations engaged in oil exploration and production. The project team was well aware of this detail complexity, but through experience had learned useful ways of simplifying the detail. In this case, the team agreed a unique conceptualisation of industry supply that focuses attention on the internal structure and political pressures governing a producers' organisation (OPEC) and its commercial rivals.

Models that fit the needs of executives and scenario planners do not have to be accurate predictive models. They should, however, have the capability to stimulate novel thinking about future business options. Moreover, models that are used to construct consistent stories about alternative futures need to be understood by the story writers (often senior planners) in order to be communicated effectively to corporate executives and business unit managers. A black-box predictor will not lead to the desired result, even if it has a good record of predictive power. These criteria help explain the style of modelling adopted – the need for a comparatively simple model, the relatively closed process (the project did not make direct use of other world oil market models or enlist the aid of world oil market experts as consultants) and the intense participation of senior planners in model conceptualisation. The project was not intended as an exercise in developing another general model of the oil trade to forecast better. The project team wanted to model their understanding of the oil market. Within the group, there was an enormous amount of experience, reflecting knowledge about the actors in the oil market and observations about market behaviour. But the knowledge was scattered and anecdotal, and therefore not very operational. The group also recognised that the interlinkages in the system were complex. The desire of the group was to engage in a joint process through which their knowledge could be pooled in a shared model and used to interpret real events. Most of the group members were not professional modellers. To them, other existing energy models were non-transparent black boxes, useful as a reflection of other's views, but quite unsuitable for framing their own knowledge.

A Closer Look at the Stakeholders and Their Investment Decision Making

To uncover the feedback structure of the oil industry the modeller led a discussion of the investment decision making of each main producer group. The same formulation principles introduced in Chapter 7 apply once again, including the Baker criterion, fit to industry practice, robustness and recognition of bounded rationality. For example, what do executives in commercial oil companies know and pay attention to as they make their upstream investment decisions? What information really matters to OPEC oil ministers as they agree quotas and set production targets? Which organisational, social and political factors shape and filter the signals used by different producer groups and their leaders to justify investment and production decisions? The diagrams that follow are similar to the flip-chart drawings from team meetings in which all these questions, and more, were thoroughly explored. Three versions of the model are described that differ only in their assumptions about the available pool of commercial reserves and development cost per barrel. The first version of the model reflects conditions starting in 1988, during the Soviet era, when the oil market excluded communist areas. The second version reflects conditions starting in 1995 when Russian oil was trading in the world market. The third version reflects conditions starting in 2010 when Russia had become the world's largest oil producer and when hydraulic fracturing technology, 'fracking', had been successfully adapted to begin exploiting large shale oil reserves (particularly in the US). A selection of equation formulations is included in the description that follows. Full documentation of the equation formulations can be found in the file named Oil World 1988 Equation Description in the learning support folder for Chapter 8.

Investment by the Independent Producers

The independents are all those producers – state-owned oil companies, the majors and other private producers – who are not part of OPEC and who expand crude oil output on the basis of commercial criteria. This category includes international oil companies such as BP Amoco, ExxonMobil and Shell, and non-OPEC nations such as Norway. The independents are assumed to produce at economic capacity all the time. Their production rate is therefore dictated by available capacity. The rationale for capacity expansion is dominated by commercial factors as shown in Figure 8.4. The circular symbol represents independent producers' upstream investment or capacity expansion policy – often known as 'capex'. The independents add new capacity when they judge it is profitable to do so.

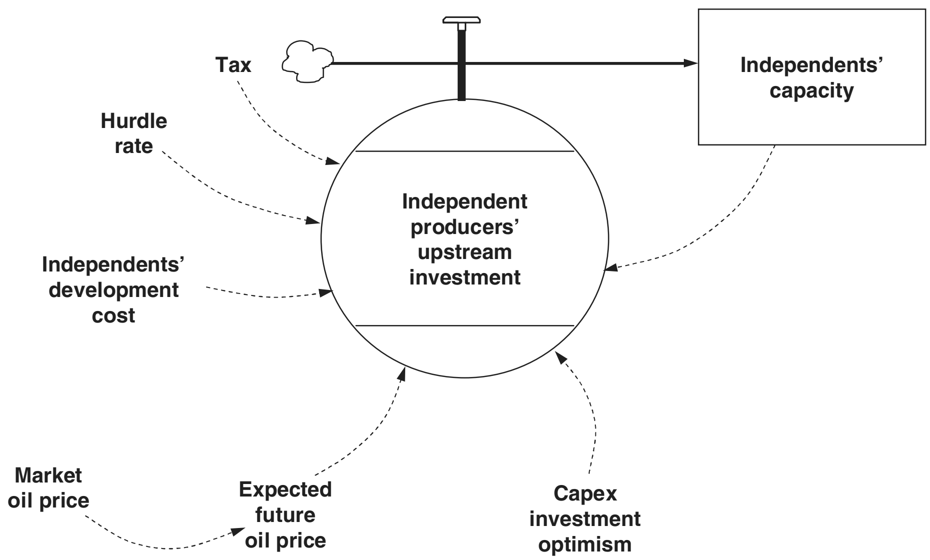


Figure 8.4 Independents' upstream investment

The figure shows the main information inputs to upstream investment decisions used to calculate the average profitability of potential projects. Independents estimate the development costs of new fields and the expected future oil price over the lifetime of the field. Knowing future cost, oil price, the likely size of a new field and the tax regime, financial analysts can calculate the future profit stream and apply a hurdle rate to identify acceptable projects. In reality, each project undergoes a thorough and detailed screening, using well-tried upstream investment appraisal methods. The greater the estimated profitability, the more projects exceed the hurdle rate and the greater the recommended expansion of capacity. There is a scale effect too represented by information feedback from independents' capacity. The more capacity, the bigger are the independents and the more projects in their portfolio of investment opportunities.

Executive control of recommended expansion is exercised through capex investment optimism that captures collective investment bias among top management teams responsible for independents' investment (rather like 'delivery delay bias' in the market growth model of Chapter 7). Optimism can be viewed on a scale from low to high. High optimism means that oil company executives are bullish about the investment climate and approve more capacity expansion than financial criteria alone would suggest. Low optimism means executives are cautious and approve less expansion than recommended. It is important to appreciate the distance from which we are viewing investment appraisal and approval. We are not concerned with the detail of individual oil field projects. Rather, we are seeing investment in terms of commercial pressures that lead to fractional growth of existing capacity, where the growth rate is typically between 5 and 10% per year but can be up to 25% per year when profitability is exceptionally high. The formulation is explained in more detail later.

Development Costs

Development costs in Figure 8.5 are experts' views of industry marginal costs as a function of remaining undeveloped reserves (excluding OPEC reserves). In 1988, experts estimated remaining reserves to be 580 billion barrels of oil.

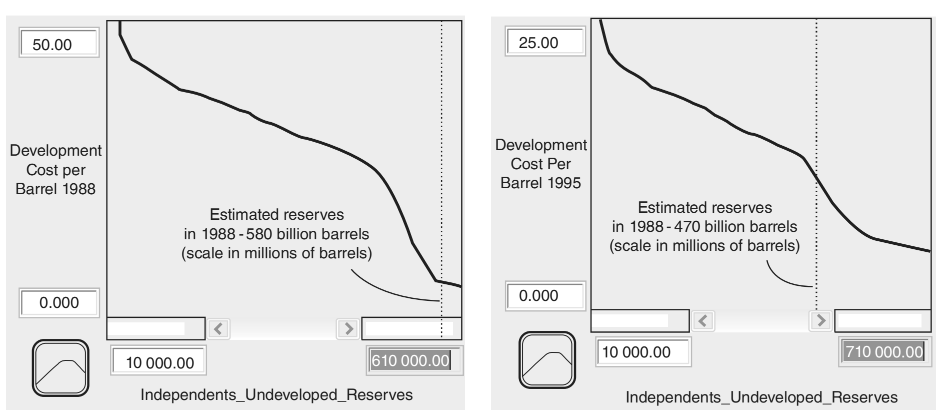


Figure 8.5 Estimated development costs in 1988 (left) and in 1995 (right)

Of this quantity, about 30 billion barrels (in the decreasing range 580 to 550 on the graph) were believed to be low-cost reserves recoverable at less than $9 per barrel. Once these low-cost reserves are used up there is a steep shoulder to the cost profile. Development cost rises from $9 per barrel to $26 per barrel as reserves fall from 550 billion to 450 billion barrels. Then the cost profile stays quite flat, rising gently to 40 dollars per barrel as reserves fall from 450 billion to 100 billion barrels. Thereafter, the cost rises gently to 44 dollars as reserves fall to 50 billion barrels. Cost rises sharply to 1000 dollars per barrel as reserves are exhausted reflecting an assumed finite supply of commercially viable oil.

By 1995, experts' views had changed. Remaining reserves were now thought to be about 470 billion barrels – down by more than 100 billion barrels from the 1988 estimate of 580 billion barrels due to usage. However, the cost is much lower and the profile is flatter than before meaning that cost is expected to rise less steeply with depletion. Cost rises gently from 12 dollars per barrel to 20 dollars per barrel as reserves fall from 470 to 100 billion barrels. Moreover, there is a new possibility of replenishing low cost reserves by adopting 225 billion additional barrels of Russian oil. For this reason the scale for reserves runs out to 710 billion barrels. The process of adoption is described later in the section entitled 'The Rise of Russian Oil'. The overall effect is to further flatten development cost. The reserve and cost assumptions for the model that starts in 2010 are also described later in the section entitled 'The Shale Gale'.

Technology can undoubtedly be expected to lower cost as more efficient production and recovery methods are devised. In both the 1988 and 1995 models the effect of technology on cost starts at a neutral value of 1 as shown in Figure 8.6.

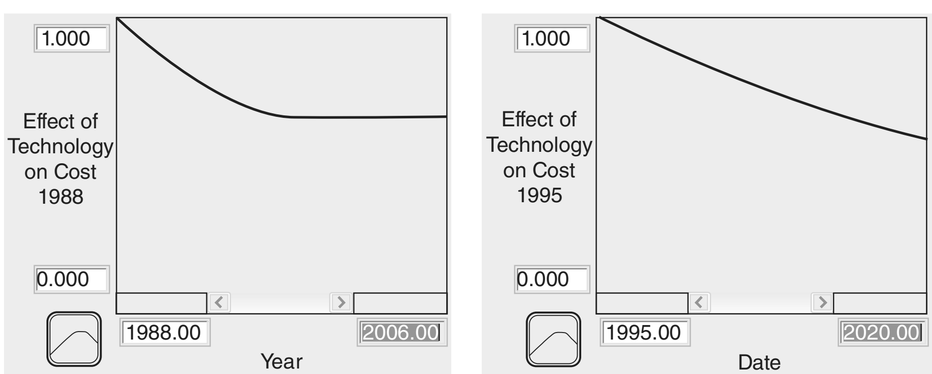


Figure 8.6 Estimated effect of technology on cost in 1988 (left) and in 1995 (right)

In 1988, experts anticipated that technology would improve rapidly over the decade 1988 to 1998, so the effect of technology on cost falls to a value of 0.64 by 1998. This fall means that technology improvements were expected to cut development cost by 36% (1–0.64) over the decade. Interestingly, the experts in 1988 were very conservative beyond a 10-year technology horizon, anticipating no further efficiency improvement. Hence, after 1998 the effect of technology on cost remains constant at 0.64. By 1995, experts' views of technology were more optimistic for the long term and they were prepared to look across a 25-year horizon. The effect of technology on cost falls steadily to a value of 0.5 by 2020. This fall means that technology improvements were expected to cut development cost by a further 50% relative to the advances already made by the end of 1995. For the model that starts in 2010 there is a less optimistic view of technology improvement. The effect of technology falls steadily to a value of 0.74 across a 25-year horizon to 2034.

Policy Structure and Formulations for Upstream Investment – Fractional Asset Stock Adjustment

More detail about the formulations behind the investment policy is shown in Figure 8.7. Notice the two-stage accumulation for capacity that distinguishes capacity in construction from independents' capacity in operation. The annual onstream rate is assumed to be a quarter of capacity in construction to represent an average construction delay of four years. Independents' production is exactly equal to production capacity, reflecting an important assumption that commercial producers fully utilise capacity once it comes onstream.

The grey region contains all the variables used to operationalise the investment policy. Capacity initiation (the rate of approval of new upstream investment) is a fractional asset stock adjustment formulation, similar to capital investment in the market growth model in Chapter 7, but driven by financial rather than operational pressures. The units of measure are millions of barrels per day, per year. The equation is written as the product of independents' capacity, viable fractional increase in capacity and capex optimism.

Capacity Initiation = Independents' Capacity * Viable Fractional Increase in Capacity * Capex Optimism {millions of barrels/day/year}

Upstream investment projects are deemed attractive when the profitability of new capacity exceeds the hurdle rate. In the equation below this condition is met when the profitability ratio is greater than 1. The hurdle rate is set at (0.15) 15% per year, a high value that reflects the inherent risk of upstream investment. The profitability of new capacity depends on the total profit expected from a new oil field in relation to its development costs.

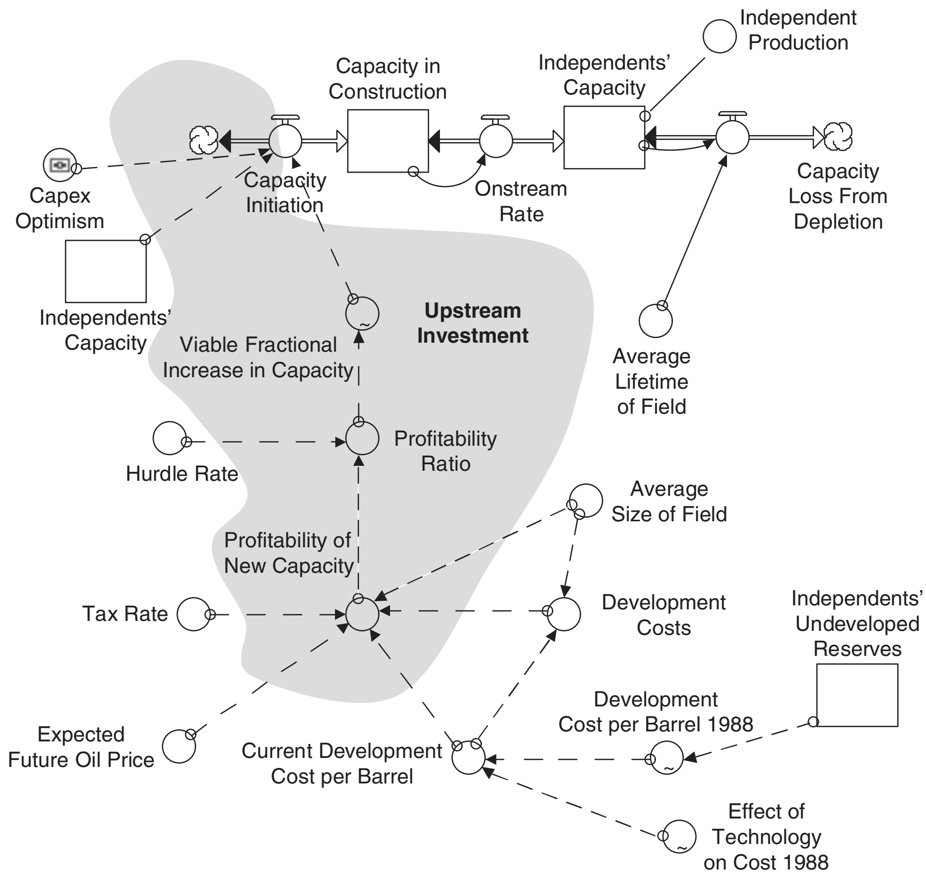


Figure 8.7 Policy structure and formulations for independents' upstream investment

Total profit is defined as the difference between expected future oil price and current development cost per barrel multiplied by the average size of a field in millions of barrels. This gross profit is adjusted for tax according to the expression (1 – tax rate). The ratio of total profit to overall development cost then yields profitability expressed as a fraction per year.

Profitability Ratio = Profitability of New Capacity/Hurdle Rate {dimensionless}
Profitability of New Capacity = (1 – Tax Rate) ∗ (Expected Future Oil Price – Current Development Cost per Barrel) ∗ Average Size of Field/Development Costs {fraction/year}

The profitability ratio determines the viable fractional increase in capacity through the non-linear function in the equation below. When the profitability ratio takes a value of 1 the fractional increase in capacity is a modest 6% per year (0.06). The function is upward sloping. When the profitability ratio is 1.5, the fractional increase in capacity is 18% per year. At even higher profitability the function levels off at a fractional increase of 25% per year, which is assumed to be the maximum rate of capacity expansion achievable in the industry.

Viable Fractional Increase in Capacity = GRAPH(Profitability Ratio)
(0.00, 0.00), (0.1, 0.00), (0.2, 0.00), (0.3, 0.00), (0.4, 0.00), (0.5, 0.00), (0.6, 0.00), (0.7, 0.01), (0.8, 0.02), (0.9, 0.04), (**1.00**, **0.06**), (1.10, 0.08), (1.20, 0.1), (1.30, 0.12), (1.40, 0.15), (1.50, 0.18), (1.60, 0.2), (1.70, 0.22), (1.80, 0.24), (1.90, 0.25), (2.00, 0.25)

Oil Price and Demand

It is common to think that market forces simultaneously determine price and demand. But in dynamical models it is important to capture the separate processes that adjust price and demand and the information on which they depend.

Figure 8.8 shows demand for oil as a stock that accumulates change in demand. Similarly market oil price is a stock that accumulates change in price. The influences on these two processes of change were the focus of attention in conversations with the project team.

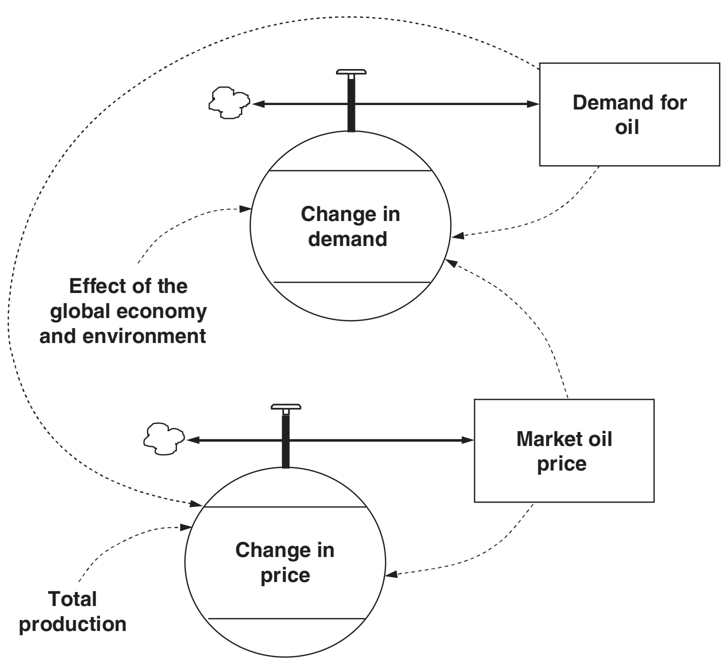


Figure 8.8 Demand and price setting

Change in demand responds to market oil price, the effect of the global economy and environment, and to the level of demand itself. In the short to medium term, the basic rationale behind demand changes is straightforward. When price goes up, demand goes down and vice versa. In reality, there are more subtle dynamics of demand. For example, if there is a shock price increase, the resulting reduction in demand will be greater than if the same price increase were spread over a few years. Consumers modify demand quickly in the short run by conservation and easy substitution. But they can also continue adjusting in the long run by making improvements in energy efficiency – with more fuel-efficient cars, or more heat-efficient homes.

Price sensitivity combines short- and medium-term dynamic effects. A numerical example illustrates the idea. Suppose price is steady at $60 per barrel, then rises suddenly to $90 per barrel and settles at this new and higher value. The model assumes that consumers faced with this 50% price hike set out with the intention of reducing demand by 20%. Yet radical cuts in consumption are slow to implement. It takes years for people to switch to more fuel-efficient cars or better insulated homes. In the meantime, they get used to a higher oil price and the pressure to reduce consumption declines. What began as an intention to reduce demand by 20% is much diluted as time passes, to 5% or less. Effectively, people are hooked on oil, and consumption depends not on the absolute oil price but on the difference between the current oil price and the price people are used to.

In the long term, there are broad societal and global pressures on demand, captured in the effect of the economy and environment. This effect is formulated as a bias so that indicated demand for oil is either magnified or diminished relative to current demand. For example, in the period between 1990 and 2008 the global economy grew strongly, led by China and India, resulting in steady upward pressure on demand for oil. On the other hand, if, in response to global warming, society curbs its use of fossil fuels, then there will be steady downward pressure on demand for oil. These long-term pressures are superimposed on the price effect.

In the lower half of Figure 8.8 the change in market oil price responds to differences between demand and total production. If demand exceeds total production then there is persistent pressure for price to rise. A fractional formulation is used in which the change in price is a fraction of the current market oil price. Therefore, as long as a demand surplus persists, price will move steadily upwards. Conversely, if production exceeds demand, there is persistent pressure for price to fall. Note there is no pre-defined ceiling or floor on oil price and the development cost of oil does not directly influence change in price. Only when demand and production are exactly equal does the change in price become zero. Hence, oil price can drift across a wide range of values, far removed from the underlying development cost incurred by commercial producers. A numerical example, based on the formulations used in Oil World 1988 and Oil World 1995, reveals the sensitivity of the modelled oil price to production and demand imbalances. When there is a shortfall of 2 million barrels per day, price is assumed to increase at a rate of 4% per month. The rate of increase rises to 7.5% per month if the shortfall reaches 4 million barrels per day. There are corresponding rates of price decline resulting from a glut of production. These numbers produce plausible price profiles in the simulator. Note that the sensitivity of price change has been deliberately reduced in Oil World 2010 to compensate for the fact that both oil price and total oil production were much higher by then than they were in the 1980s and 1990s.

The Swing Producer

The role of the swing producer is to supply just enough oil to defend OPEC's intended price, known in the industry as the 'marker price'. A producer taking on this role must have both the physical and economic capacity to increase or decrease production quickly, by as much as 2 million barrels per day or more in a matter of weeks or months, in order to absorb unexpected variations in demand (due say to an unusually mild winter) or to compensate for cuts in the output of other producers. The model makes the important assumption that the swing producer always has adequate capacity to meet any call. The project team felt this assumption was reasonable given the large capacity surplus of Saudi Arabia, estimated at 5 million barrels per day under normal supply conditions. A similar surplus remains today. As long as Saudi maintains this huge surplus then there is no need to model explicitly the capacity expansion policy of the swing producer, since capacity is never a constraint on output. Instead, the focus switches to the rationale for changes in crude oil production.

The swing producer (Saudi Arabia) operates in either swing mode or punitive mode. Most of the time Saudi is in swing mode, abiding by and supporting the production quotas set by OPEC. Occasionally, Saudi switches into punitive mode, by abandoning agreed quotas and rapidly cranking up production in order to discipline the other producers.

Figure 8.9 shows the factors influencing Saudi production policy when operating in normal swing mode. Production responds to pressure from both quota and oil price. There are two stock adjustment processes operating simultaneously. Saudi ministers change production in order to meet the swing producer's quota, but they also take corrective action whenever the market oil price deviates from the intended price that OPEC members collectively wish to achieve. When the price is too low, Saudi production is reduced below quota thereby undersupplying the market and pushing up the market price.

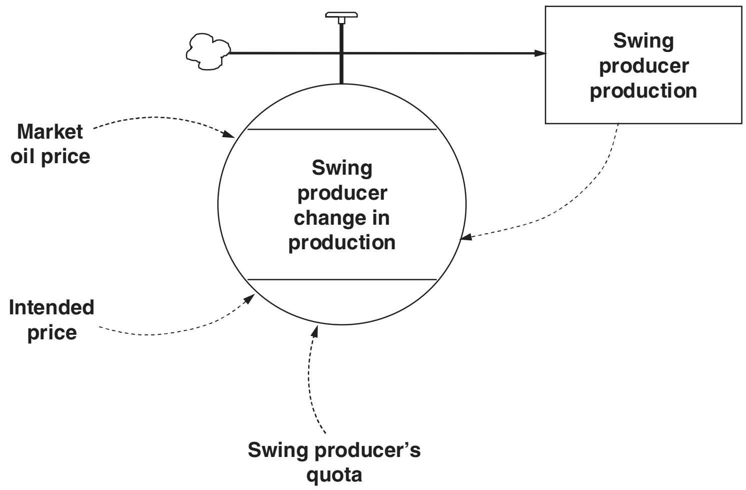


Figure 8.9 Swing producer in swing mode

Similarly, when the price is too high, Saudi production is increased above quota to oversupply the market and reduce price to the level OPEC is trying to defend. Such willingness to adjust production in the short term is in sharp contrast to the independent producers and is a defining characteristic of any swing producer.

In punitive mode, Saudi oil ministers feel that production is inadequate and they are not getting a fair share of the market. They decide to re-establish a strong position by increasing production regardless of the price consequences, thereby also punishing the other producers. The resulting punitive production policy is shown in Figure 8.10. The swing producer sets a minimum threshold for share of global demand (estimated to be 8%) and will not tolerate anything less. Whenever market share falls below the threshold the volume of production is increased rapidly in order to flood the market with oil and quickly lower the price.

The team spent some time discussing the detail of punitive behaviour. For example, how does the swing producer decide on the volume of punitive production, and when do policymakers switch back to swing mode? The team's proposal was to include a punitive price, a low target price, for teaching a lesson to the other producers. Punitive production continues to expand until market oil price reaches the punitive price, or until the swing producer regains an acceptable market share (which is the signal to return to swing mode). The switch to punitive mode can send a powerful price signal to discipline the other producers. It is an act of last resort, however, because in this mode the swing producer has abandoned the role of price regulator – essentially the market is no longer managed.

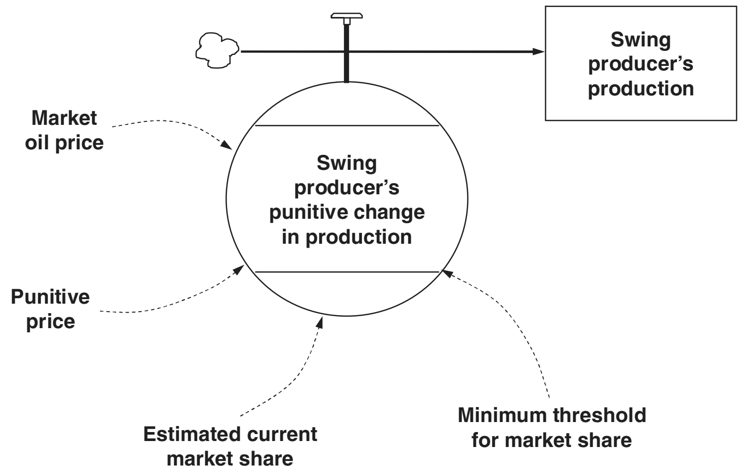


Figure 8.10 Swing producer in punitive mode

Quota Setting

Quota setting takes place in two stages. First, OPEC members agree on a quota for the cartel as a whole. Then, member states negotiate individual quotas by allocating the total quota among themselves.

How much should OPEC produce? The main influences are shown in Figure 8.11. The members need to form a view of the likely 'call on OPEC' over the time period covered by the quota agreement.

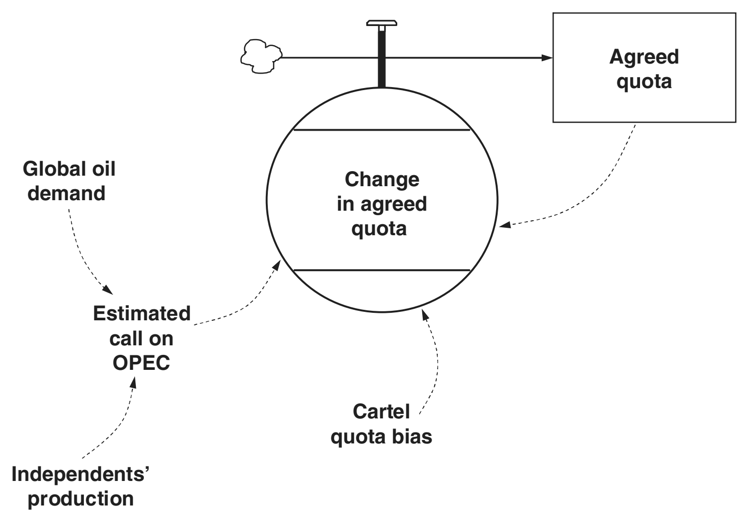


Figure 8.11 Quota setting

To do this, they estimate both global oil demand and the independents' production. The difference between these two quantities is the estimated call on OPEC which is just a best guess of the volume of OPEC oil required to balance supply and demand. But the estimate need not be spot-on. In practice, it could differ from the actual call by as much as 1 or 2 million barrels per day. The swing producer will compensate for any mis-estimation by OPEC through swing changes to production. More important than spot-on estimation of the call is for OPEC members to agree on whether to set an overall quota that is deliberately less than the estimated call, or deliberately more. By setting a quota that is less than the call, the member states are pursuing a policy aimed at increasing market prices. Their decision to over- or under-produce is politically and economically motivated and is represented by the scenario parameter 'cartel quota bias'.

Quota negotiation, shown in Figure 8.12, allocates OPEC's agreed quota among members. In reality, the negotiation is a highly political process, though a benchmark allocation is established based on objective criteria that include member states' oil reserves, production capacity and population. In the model, quota is allocated in proportion to each member's share of OPEC's total operating capacity. Although this formulation is a simplification, it does capture the flavour of political bargaining by making the members' bargaining strength proportional to capacity share.

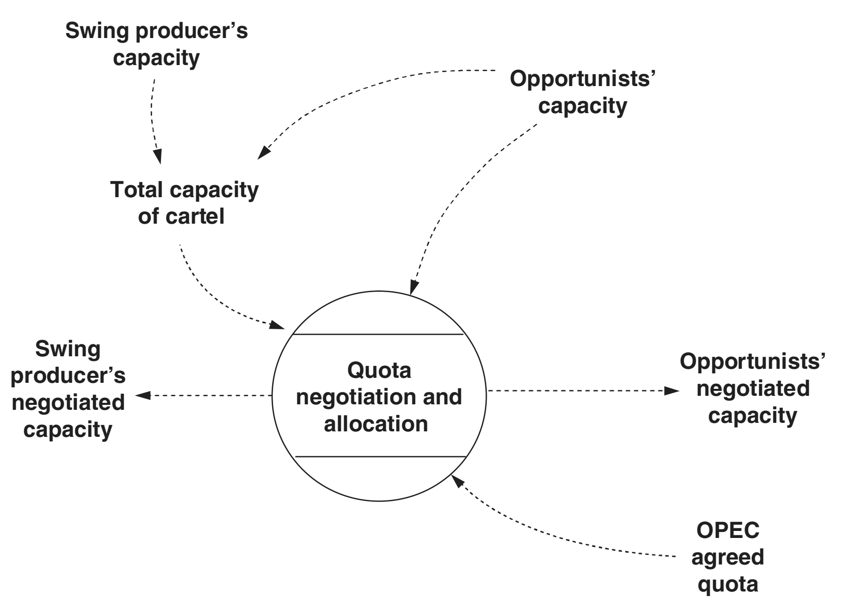


Figure 8.12 Quota negotiation and allocation

The Opportunists

The opportunists are all the other member states of OPEC besides the swing producer. The list of countries includes Algeria, Iran, Kuwait, Nigeria and Venezuela. Some of the opportunists are known to adhere strictly to quota, so their production policy is straightforward – it is simply equal to negotiated quota. Other countries, however, have a huge appetite for oil revenue to support their growing populations and developing economies. This need for revenue, coupled with underutilised production capacity, provides opportunists with the motivation to exceed quota and to strengthen their quota negotiating position by deliberately over-expanding capacity.

Figure 8.13 shows the main influences on opportunists' production and capacity. First, focus on change in capacity shown in the lower half of the figure. Generally speaking, opportunists aim for surplus capacity, at least 2 or 3% more than negotiated quota, partly to provide flexibility, but also to improve their bargaining position in future quota negotiations. The size of the surplus depends on a scenario parameter called capacity bias, which represents the tendency of opportunists to overbuild capacity. Opportunists' change in capacity is formulated as an asset stock adjustment process where the effective target for capacity is equal to negotiated quota multiplied by the capacity bias.

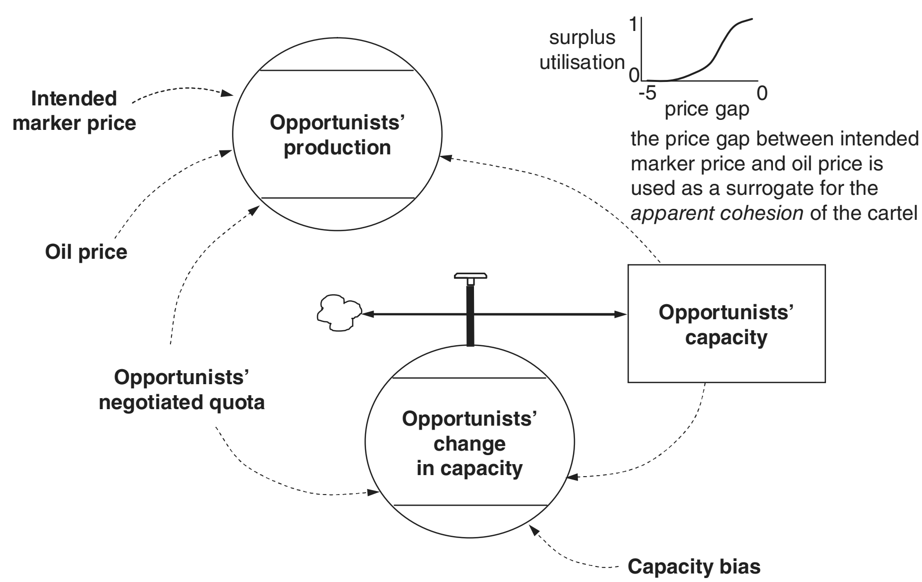


Figure 8.13 Opportunists' production and capacity

Now consider opportunists' production shown in the upper half of the figure. When opportunists are fully cooperating within the framework of the cartel they produce at a rate equal to the negotiated quota. But there is always the temptation for opportunists to exceed quota and fully utilise capacity – if only they can get away with it. How do opportunists know whether conditions are right for utilising surplus capacity and quota busting? The project team felt that the 'apparent cohesion' of the cartel would be an important factor. Cohesion is high when the market oil price is close to the intended marker price – in other words, when OPEC is successfully defending its intended price. Under these price conditions, quota busting may go unnoticed. Cohesion is low when the intended marker price is greater than the market price. Under these price conditions, quota busting is likely to be visible and to incur the wrath of the other member states, especially the swing producer. Figure 8.13 shows that both the intended marker price and oil price influence opportunists' production, and the inset on the upper right shows the assumed shape of the relationship between the price gap and surplus utilisation. When the price gap is in the range minus $4 to minus $5 per barrel surplus utilisation is zero. As the price gap diminishes surplus utilisation rises, slowly at first and then more rapidly. When the price gap is zero then opportunists fully utilise surplus capacity.

The Rise of Russian Oil – Incorporating Unforeseen Political Change

No scenario planning exercise has perfect foresight and the oil producers' project was no exception. The model was originally built in 1988 and then updated some years later to fit the global oil industry of the mid-to-late 1990s. The most significant political change during the interval was the break up of the Soviet Union. Before the Soviet break-up, oil companies and scenario planners ignored oil production from communist areas. This assumption was justified on the grounds that little if any such oil was traded outside the communist block. However, President Gorbachev's perestroika and peaceful restructuring eventually brought Russian oil to world markets. Moreover, Russian reserves are huge – estimated at the time to be about 225 billion barrels, almost 6% of proven global reserves and more than 50% of non-OPEC reserves. Freely-traded Russian oil can therefore have a big impact on the global balance of supply and demand.

A member of the original scenario modelling team helped revise the model to include Russian oil. A key issue was how to classify Russian reserves – do they fall within the influence of OPEC, or are they best viewed as purely commercial reserves? After careful thought, the industry expert recommended that all Russian oil should be added to independents' reserves. In other words, in his view, the oligarchs controlling Russian oil have commercial rather than political instincts. They prefer to develop reserves in response to market forces rather than OPEC political pressure. Profit matters. However, the industry expert also recognised that Russian reserves are not instantly available for commercial exploitation, even if the economics look favourable. There is still a political dimension to Russian oil representing the time it takes to build the trust required for long-term commercial contracts and to agree rights in the key Russian oil regions.

When viewed in this quasi-commercial way, Russian oil adds two new stock accumulations and six new concepts to the original model – only a small increase in complexity for such an important structural change in the oil world.

Figure 8.14 shows the change exactly as it appears in the revised oil producers' model. A huge pool of risky Russian reserves, approximately 225 billion barrels, is available to commercial producers. Gradually, over time, these reserves come to be viewed by investors as secure. Secure Russian reserves are then adopted by commercial producers into the pool of independents' undeveloped reserves. The pace of adoption depends on the time to agree rights, which is set at three years.

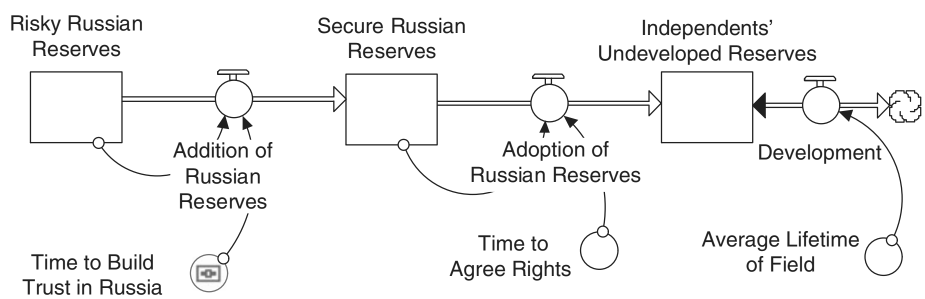


Figure 8.14 Replenishing independents' reserves with Russian reserves

The crucial limiting process for commercialisation is the rate at which investors reclassify risky reserves. This rate depends on a vital scenario parameter called 'time to build trust in Russia', which can be anywhere in the range 5–40 years. If the time is short (say 10 years), then Russian oil fields are commercialised quickly. If the time to build trust is very long (say 40 years), then Russian oil, though economically attractive, is commercialised slowly.

The Shale Gale – Incorporating Unforeseen Technological Change

The existence of 'tight oil' reserves, trapped in oil-bearing shale rocks, has been known about for centuries. Patented extraction processes date from the late 1600s and extraction industries became widespread during the 19th century. However, the industry shrank and virtually disappeared in the 20th century following the discovery of large reserves of cheaper and more easily extracted conventional oil. Tight oil was no longer commercially viable.

Recently the shale industry has staged a remarkable comeback through a combination of radical technology change and high oil price. Around 2008 specialist commercial oil producers began adapting the new technologies of hydraulic fracturing and horizontal drilling first used to tap shale gas. This technology breakthrough lowered the breakeven cost of tight oil below $70 per barrel, making it competitive with some of the more expensive conventional oil from offshore fields. As a result, between 2008 and 2013 shale oil production in the US rose swiftly from 0.5 to 3.5 million barrels per day, a 'shale gale' that surprised the industry and was entirely unforeseen in the original oil producers' project.

What difference might commercially abundant shale oil make to the structure of the global oil industry and to long-term oil price dynamics? The oil producers' model has been further updated to investigate this important question, using publicly available information on reserves and production gleaned from the internet and the business press. The updated model starts in 2010 at the end of a decade in which the oil price had risen dramatically. This extended period of rising price unleashed the shale gale. Shale oil brings extra commercial reserves to the independent producers, a bit like Russian oil in the mid-1990s, but without the commercialisation delays stemming from political risk and the economic uncertainty it engenders. Independents' undeveloped reserves are initialised in 2010 at 300 billion barrels of discovered oil, including shale reserves. A particularly significant change to the model is a boost to independents' capacity made possible by shale oil. Capacity starts at 47 million barrels per day in 2010, more than 50% of global oil demand, and poised to grow still further as swathes of new commercial upstream capacity projects are approved and developed, many of them for shale oil. The initial growth rate of capacity is 4% per year, a rate destined to increase as swelling capacity in construction (26 million barrels per day in 2010) comes onstream.

Three versions of the oil producers' model are available in the learning support folder for Chapter 8: Oil World 1988, Oil World 1995 and Oil World 2010. Readers are invited to browse the models and find the parameter and formulation changes used to capture the rise of Russian oil and the resurgence of shale oil. A tour of the icons in the Independents sector will reveal many of the changes. Simulations of these three models later in the chapter show the impact on industry dynamics of surprise political and technological changes that have each released vast new reserves of oil. At the start of the oil producers' project in 1988 nobody in the industry expected these extra reserves to become available in world oil markets.

Connecting the Pieces – A Feedback Systems View

As we have seen, the project team supplied their knowledge and opinions on the pieces of the global oil industry. Now let's see how the pieces fit together. Figure 8.15 shows the main concepts necessary to describe the industry. Take a few minutes to inspect this scatter list of words and phrases. Altogether, there are 37 phrases on the page which record shared vocabulary developed from team dialogue. Some phrases are specialised industry jargon such as intended marker price, call on OPEC, agreed quota, negotiated quota, and cartel quota bias. As a list for describing a large and complex industry it is short, but as nodes of a web it is quite daunting. Potentially, there are an enormous number of ways to connect 37 concepts. In fact, the team's knowledge of industry structure greatly reduced the raw combinatorial problem. The modelling process pinned down, with some confidence, eight feedback loops that capture (at least for team members) the essence of the industry's enduring feedback structure and the basis of its dynamic complexity.

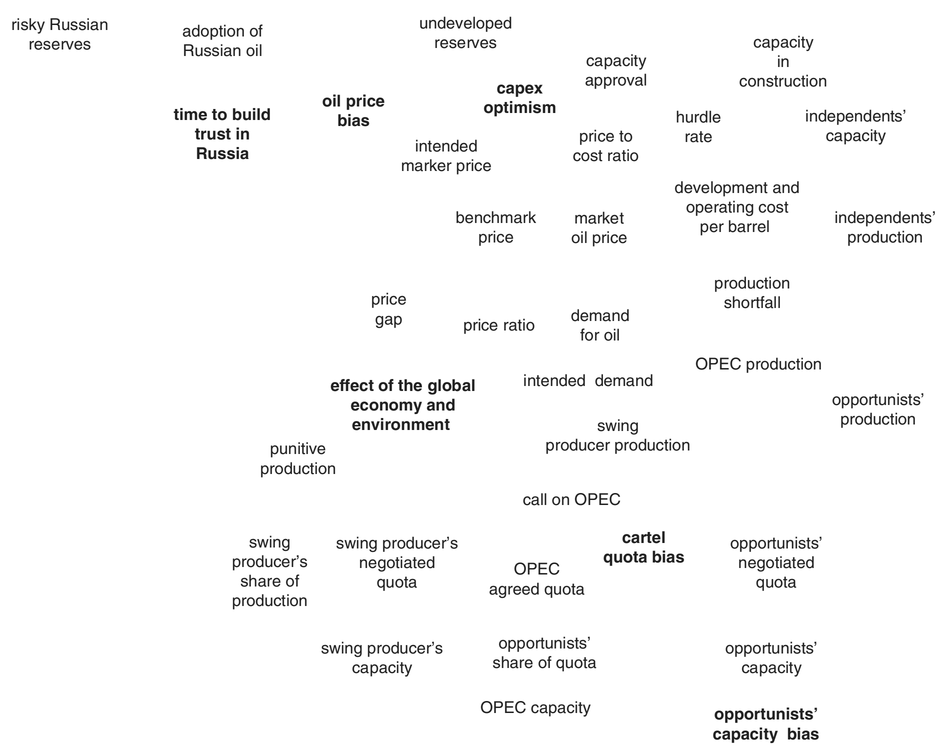


Figure 8.15 Scatter list of phrases describing the global oil industry

Two Invisible Hands and More

Figure 8.16 shows six feedback loops within and between the independents' and market sectors. (By the way, you can create your own industry web by photocopying Figure 8.15 and then drawing the connections.) Our review starts with commercial supply loop B1. A production shortfall stimulates a rise in market oil price and an increase in the price to cost ratio which, through capacity approval and construction, leads to expansion of independents' capacity and production. Extra production corrects the shortfall and completes loop B1 – the first invisible hand. A new loop B2 arises from reserve depletion. The price to cost ratio is influenced by development and operating cost per barrel, which rises as undeveloped reserves fall. Reserves are depleted by capacity approval, thereby completing the new balancing loop B2 that captures the economics of finite global oil reserves as described earlier in Figure 8.5.

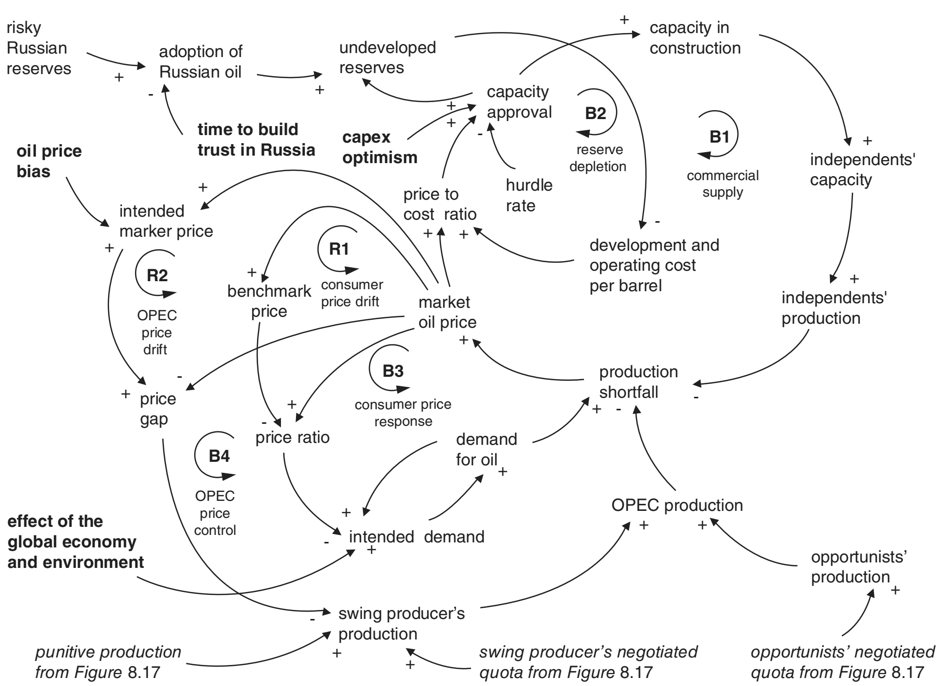


Figure 8.16 Feedback loops in the oil producers' model

In the 1995 version of the model, reserves are replenished by the adoption of Russian oil. The rate of adoption depends on the magnitude of risky Russian reserves and the time to build trust in Russia which is a scenario parameter. Time to build trust can take a value anywhere in the range 5–40 years. If the time is short (say 10 years), then Russian oil fields are commercialised quickly, giving rise to a surge of commercial development and production exploiting the favourable economics of Russian oil regions. If the time to build trust is very long (say 40 years), then Russian oil, though economically attractive, is commercialised slowly.

Now we turn to the demand side to find a second invisible hand. The production shortfall is the difference between demand for oil and the sum of independents' and OPEC production. Demand for oil falls as price rises and vice versa. But consumers take time to adapt and to some extent they are addicted to oil. These behavioural factors are captured in loops B3 and R1. Demand for oil adjusts with a time lag to consumers' intended demand. Intended demand responds to the price ratio and the effect of the global economy and environment (a link we return to shortly). As the price ratio goes up, intended demand goes down. The price ratio itself combines factual and behavioural information. It depends directly on the market oil price, thereby completing loop B3 representing consumer price response. The ratio also depends on the benchmark price, which is the price consumers are used to. This benchmark adapts with a time lag to the market oil price to form loop R1 that captures price drift in consumer behaviour. The combination of feedback loops B3 and R1 is very common in business and social systems. The structure is known as an eroding goal archetype (Senge, 1990: Appendix 2) and represents the tendency in any goal-seeking, purposive enterprise for the goal itself to adapt to current conditions. In this case, consumers facing high oil prices eventually get used to them and carry on consuming – they are hooked on oil.

The effect of the global economy and environment is a scenario parameter. It sits on the edge of the feedback structure representing pressures on demand that are not directly attributable to price. It is an enormously versatile parameter. It is a single number (confined in the range −0.1 to 0.1), yet it can portray scenarios as different as a green world or an Asian boom and bust. When the parameter is set to its neutral value of 0, then price alone drives intended demand. Market forces prevail on the demand side. When the parameter is set to a value less than 0 there is continual pressure from consumers to reduce demand, independent of market forces (though market forces are of course still at work). Such downward pressure might correspond to environmental awareness (a green mindset), the effects of an economic recession or steady increase in the efficiency of energy-consuming devices from technological progress. The exact cause need not be modelled in detail. Whether driven by the global economy or the environment, the effect is to suppress demand below what it would otherwise be on the basis of price alone. Conversely, when the parameter is set to a value greater than 0, there is continual pressure on consumers to increase demand, due to boom times and general optimism about the future.

The Visible Hand of OPEC

Loops B4 and R2 complete Figure 8.16 and show OPEC's control of oil price exercised by the swing producer. OPEC production in the bottom right of the figure is the sum of swing producer production and opportunists' production. When the member states are in harmony they produce to quota, so in each case production depends on negotiated quota. Two circumstances can cause the swing producer to depart from negotiated quota. One is punitive action, but this is quite rare and occurs only when the swing producer's share of production is too small (see next section on 'webs of intrigue'). The most common circumstance is a short-term tactical adjustment of production to manage price – a legitimate and important role for the swing producer. In Figure 8.16, swing producer production is influenced by the price gap, which is the difference between intended marker price and market oil price. This connection to market oil price closes a balancing feedback loop B4 that passes back through production shortfall and OPEC production before reconnecting with swing producer production. This fast-acting balancing loop represents OPEC's price control and is capable of creating prolonged periods of price stability, as seen in the 1960s. When market price falls below the intended marker price, due to a temporary supply glut, the swing producer quickly cuts production below negotiated quota to bring price back in line with the target or marker. The loop acts quickly because the swing producer is willing to make capacity idle – a process that takes only a month or two. Similarly, when market price rises above the intended marker price, due to a temporary demand surge, the swing producer quickly re-activates idle capacity to increase supply and bring price down. Despite the popular bad-guy image of Saudi Arabia, the swing producer is in fact a benign and calming influence in global oil markets, boosting or curtailing production in order to maintain stable prices. As we shall see, this benign role only becomes sinister and threatening when OPEC as a whole agrees quotas that deliberately undersupply or oversupply the global oil market, or when the swing producer is provoked into punitive mode.

The intended marker price itself changes over time. It depends on the recent history of market oil price. This adaptive connection from the market price to the marker price completes a reinforcing loop R2 (OPEC price drift) that combines with loop B4 to form another eroding goal archetype.

Webs of Intrigue – Inside OPEC's Opulent Bargaining Rooms

Figure 8.17 shows feedback loops within OPEC's quota agreements and quota negotiations. The starting point is the call on OPEC, which is the difference between demand for oil and independents' production.

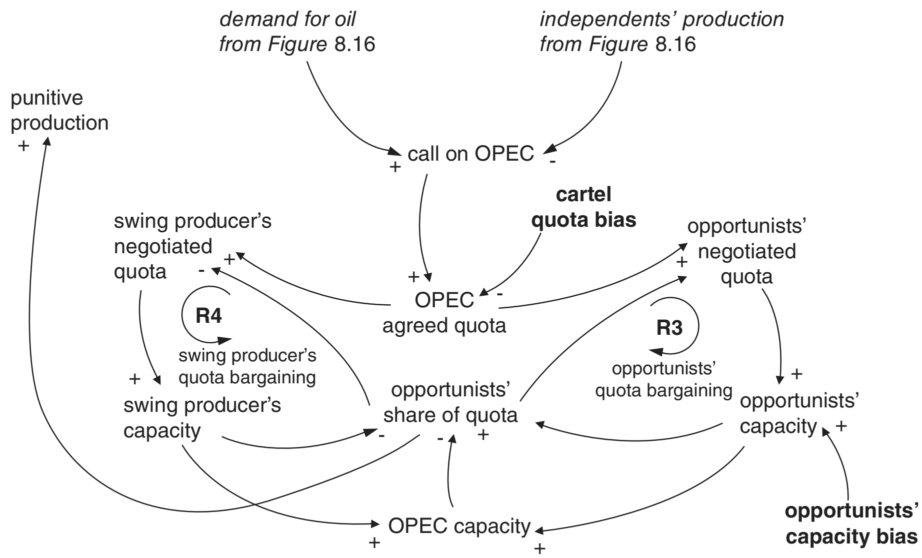


Figure 8.17 More feedback loops

OPEC member states use the call as a first-cut guide to their agreed quota. This approach makes sense because when quota equals call then OPEC is exactly filling the supply gap between global demand and independents' production. But OPEC can manipulate quota above or below the call depending on political and social motives reflected in the cartel quota bias. Quota bias is a scenario parameter that can be set to represent an OPEC supply squeeze or even political turmoil in OPEC. When the parameter is set to its neutral value of 0, then agreed quota is equal to the call. When the parameter is negative, say −0.1, then agreed quota is 10% less than the call and there is a sustained supply shortage or squeeze (as happened in the 1970s). When the parameter is positive, say +0.1, then agreed quota is 10% greater than the call and there is a supply glut (as happened in the late 1990s).

Agreed quota is allocated between the swing producer and the opportunists through negotiation and hard bargaining. Opportunists' negotiated quota depends on agreed quota and opportunists' share of quota. Negotiated quota then drives opportunists' production and also justifies expansion (or contraction) of opportunists' capacity. Capacity is a surrogate for bargaining power. The more capacity OPEC members bring to the bargaining table, the stronger is their case for a bigger share of quota. This bargaining logic is captured in opportunists' share of quota that depends on opportunists' capacity relative to OPEC capacity as a whole and completes reinforcing loop R3 in which successful quota negotiations lead to more capacity, more bargaining power and so on. OPEC capacity is simply the sum of opportunists' capacity and swing producer's capacity, where capacity is defined (for the purposes of bargaining) as operating capacity excluding any idle capacity. Loop R4 is the mirror image bargaining process of the swing producer. Here, negotiated quota depends on OPEC agreed quota and the complement of opportunists' share of quota. As before, quota drives capacity, which affects bargaining power and share of quota.

The combination of loops R3 and R4 is a common feedback structure known as the success-to-the-successful archetype (Senge, 1990: Appendix 2). This archetype occurs repeatedly in business and social systems where rivalry is at play. A successful player reinforces its competitive position at the expense of rivals. The phenomenon is well-known in battles between competing industry standards such as Betamax versus VHS in videos, or Google versus Yahoo in search engines. The dominant standard attracts more followers, which increases its dominance. Similarly, in quota bargaining, the actions of the successful negotiator strengthen future bargaining position while the rival becomes ever weaker.

Opportunists are easily tempted to boost their bargaining power by covert additions to capacity. For some member states of OPEC, the temptation is huge. They are developing economies with large populations, inadequate infrastructure and endless possibilities for revenue-consuming development such as social investment programmes in education, health, housing, road building and so on. In the model covert capacity comes from opportunists' capacity bias.

Capacity bias is the last of the scenario parameters in the model. It is used to invoke scenarios such as political turmoil in OPEC and quota busting. When the parameter is set to its neutral value of 0, then opportunists adjust capacity to match negotiated quota. When the parameter is positive, say +0.1, then opportunists covertly add 10% capacity more than quota alone could justify in the expectation that the extra capacity will bring them more bargaining power. This covert investment provides the opportunists with surplus capacity above quota.

If opportunists' share of quota becomes too large then the swing producer takes punitive action by greatly expanding production and abandoning quota. The result is a temporary supply surplus which drives market price down. If market price falls significantly below the intended marker price then this price gap is a clear signal for opportunists to stop using their surplus capacity and to fall back in line with quota.

The scatter list of 37 phrases in Figure 8.15 has become a network of more than 50 interconnections and eight dynamically significant feedback loops in Figures 8.16 and 8.17. This web embodies a slice of dynamic complexity from our modern industrial society with its intricate membrane of stakeholder interdependence. The best way to investigate this complexity is through simulation. Before presenting simulations, however, first imagine how the web might work by conducting a thought experiment.

A Simple Thought Experiment: Green Mindset and Global Recession

What if consumers were gripped by a collective green mindset (leading to a reduction in the use of fossil fuels) and, at the same time, there was a global economic recession? Intuitively one might expect this combination of forces to damage the industry. What does the industry web tell us? Demand would fall due to strong downward pressure from the effect of the global economy and environment. A supply surplus would appear and simultaneously a fall in the call on OPEC. From this starting condition numerous alternative futures can unfold depending on OPEC solidarity, the cost of commercial reserves and the psychology of consumers. If OPEC is disciplined, and its members in harmony, then the quota system absorbs the full impact of a downturn in global oil demand with little or no disturbance to the market oil price – the managed tranquillity of the 1960s. We can trace the effect in Figures 8.16 and 8.17. As the call on OPEC declines then OPEC agreed quota falls leading to a prompt reduction of output which removes the original supply surplus and restores the balance of supply and demand. Oil price remains stable and the independent producers carry on investing as though nothing had changed. OPEC absorbs the revenue loss for the industry as a whole.

However, a more complex chain reaction is possible leading to a different, less tranquil future. If OPEC's revenue loss is significant and sustained (for example, it eats into budgets for social programmes funded by oil), then cracks can appear in OPEC's solidarity. Opportunists begin to cheat, expanding output and revenue at the expense of the swing producer (loops R3 and R4). For a time the swing producer absorbs the additional loss. But dwindling quota share, idle capacity and diminishing power will eventually provoke the swing producer to punish the industry. Output rises dramatically and oil price plummets. Now the market is in turmoil. Price is low and volatile. OPEC member states suffer chronically low revenues and commercial producers report low or negative profits. Many green-minded consumers question the need for conservation in the face of an oil glut. Turmoil continues until discipline returns to OPEC or until independent producers reduce output by depleting existing fields (a 10-year wait!).

Using the Model to Generate Scenarios

Having described the conceptual building blocks and feedback loops of the oil producers' model we are now ready to simulate scenarios. The key to effective scenario modelling is to unfold several alternative futures (each an internally consistent story, but with a different plot and a different ending) in order to challenge conventional wisdom and to encourage users to think how they would act if this future were to unfold. It is important to remember that such simulated futures are not predictions of oil price, supply or demand, nor do they represent official company forecasts. Two archive simulations are presented below. Each covers a 25-year period from 1988 to 2012 using the version of the model without Russian oil, developed before the fall of the Soviet empire. The model, called 'Oil World 1988' can be found in the learning support folder for Chapter 8. I have deliberately chosen to include these archive scenarios in order to show simulations exactly as they were originally presented to the project team. However, it is also instructive to repeat the simulations under the same scenario conditions in 'Oil World 1995'. This model runs over a 25-year period from 1996 to 2020 and shows the profound effect of Russian oil reserves on the global oil market and long-term price dynamics.

Archive Scenario 1: 10-Year Supply Squeeze Followed by Supply Glut

Imagine that in 1988 OPEC had followed a policy in which quotas were set 10% lower than the call on OPEC (the difference between total demand for crude oil and the independents' production). The policy is successfully enforced for 10 years until 1998, and then reversed. Hence, in the remaining 15 years of the simulation, from 1998 to 2012, quotas are set 10% higher than the call. The result is a 10-year supply squeeze followed by a supply glut. Assume that OPEC maintains quota discipline throughout the squeeze and glut, so there is no cheating on quota by any member of OPEC. Also assume that non-price pressures on crude oil demand from the global economy and the environment are neutral so that, in the absence of price changes, demand would stay constant at 50 million barrels per day.

To run this scenario for yourself, open 'Oil World 1988'. The initial screen displays a blank time chart and the simulator controls for creating scenarios, as shown in Figure 8.18. Set 'cartel quota bias' to −0.1 by moving the slider to the left. This change brings about an OPEC supply squeeze. All the other controls should remain in their default positions.

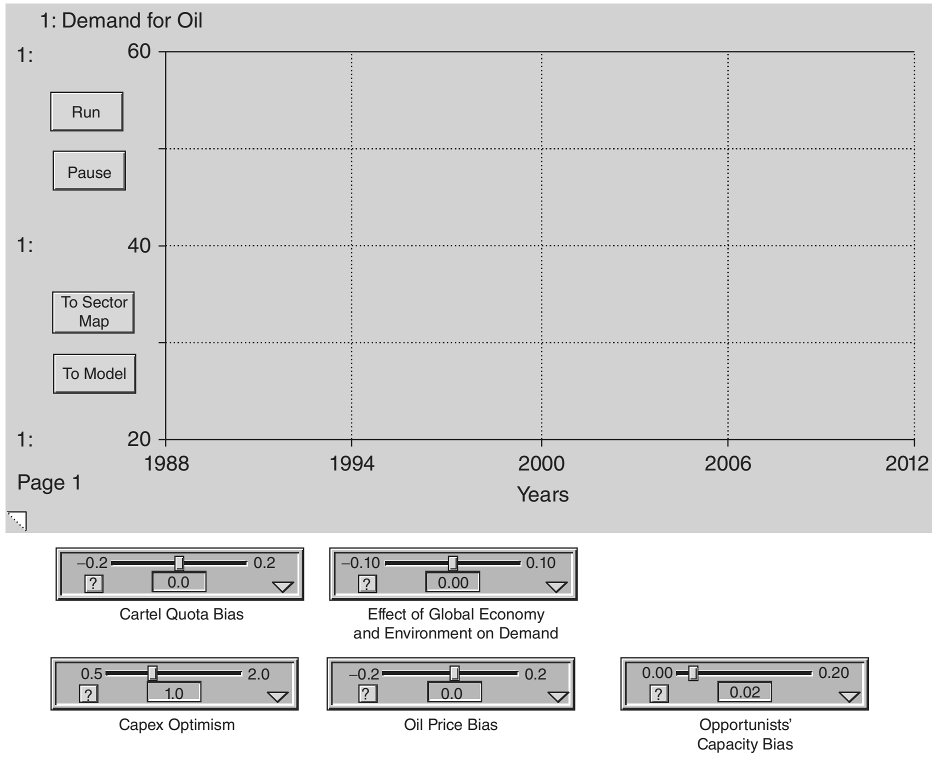


Figure 8.18 Opening screen of Oil World 1988 showing simulator controls for scenarios

Press the 'Run' button and simulate for five years and then press the 'Run' button once more to simulate for a further five years to 1998. At this point, reset the 'cartel quota bias' to +0.1 by moving the slider to the right in order to bring about an OPEC supply glut. Run the simulation out to 2012 and inspect the time charts. There are four pages available to view by selecting the 'page' tab symbol at the bottom left of the graph pad. The time charts are described below.

Figure 8.19 shows profiles of demand and production for the squeeze-then-glut scenario. Demand in the top chart begins at 50 million barrels per day in 1988 and falls gradually to about 45 million barrels per day during the decade of supply squeeze. As OPEC switches policy from squeeze to glut in 1998, demand begins to rise and maintains a steady growth to about 52 million barrels per day by the end of the simulation in 2012. The lower half of the figure shows how demand is shared among the different producers. In 1988, the independents are producing 26 million barrels per day (line 1), the opportunists 17 million barrels per day (line 2), and the swing producer 7 million barrels per day (line 3).

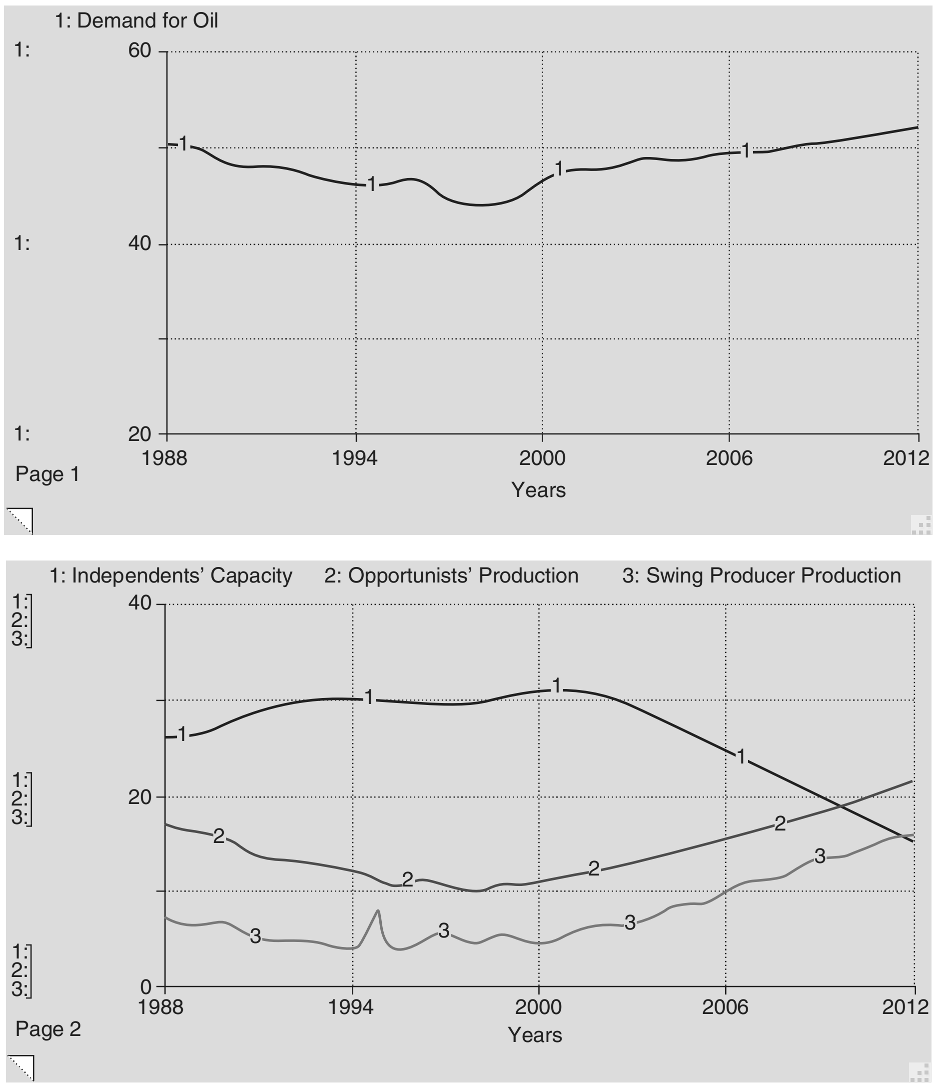


Figure 8.19 Demand and oil production in an archive scenario: OPEC squeeze then glut without Russian oil

As the supply squeeze begins to bite OPEC's output gradually falls. By 1993 the opportunists have cut production by 5 million barrels to 12 million barrels per day, while the swing producer's output has fallen to 4 million barrels per day. Meanwhile the independents' production has risen to compensate.

In 1994 and 1995 there is a temporary surge in production as the swing producer switches to punitive mode to prevent further loss of market share. At this point, the policy of supply squeeze is almost exhausted because the swing producer is unwilling to sacrifice further market share. The burden of any additional OPEC supply reductions is carried mainly by the opportunists. In 1997, there is another small burst of punitive production by the swing producer. Then in 1998, OPEC reverses policy, changing a supply squeeze into a supply glut. Gradually OPEC's output begins to rise. Opportunists' production increases from a low of 10 million barrels per day in 1998 to 21 million barrels per day in 2012. Meanwhile, the swing producer's output rises from 4 million barrels per day to 16 million barrels per day in 2012. It is interesting to note that OPEC's policy change from squeeze to glut has no immediate impact on independents' production. At the time of the policy change in 1998, the independents are producing 30 million barrels per day. Their combined output then rises to 31 million barrels per day by the year 2001. By 2003, five years after the policy change, independents' output is still 29 million barrels per day. Thereafter it declines steadily to 15 million barrels per day by the end of the simulation in 2012.

The impact of OPEC's policy on market oil price is shown in the top half of Figure 8.20. Oil price (line 1) begins at $15 per barrel in 1988. Broadly speaking, during the supply squeeze price rises to a peak of $30 per barrel in 1998, then falls during the supply glut back to about $15 per barrel. Within the rising and falling trend there is much interesting detail in the movement of price that arises from the interplay of feedback loops that balance supply and demand. The reader can view the state of supply and demand by comparing the trajectory of demand minus production (line 2) with the horizontal grid line denoting equilibrium. When line 2 is above the grid line, demand exceeds supply. When line 2 is below the grid line there is a supply surplus and supply exceeds demand.

From 1988 to 1990, price rises sharply to $20 per barrel as the supply squeeze takes hold. Demand exceeds supply as shown by line 2. Price then declines slightly between 1990 and 1991 as falling demand creates a temporary supply surplus (despite OPEC's policy). Then as the supply squeeze bites once more, price rises steadily to the next peak of $25 per barrel during 1994. Price dips sharply in 1995 as the swing producer switches into punitive mode and rapidly expands production, creating a supply surplus. After the pulse of punitive production OPEC sharply curtails production which causes price to rise sharply during 1996 to a peak of $33 per barrel. The oil price is maintained around $30 per barrel for a period of three years. The era of moderately high price ends during 1998 as the swing producer once more switches into punitive mode and price falls rapidly to $20 per barrel. Over the next two years, the price level recovers slightly to a peak of about $24 per barrel in 2001 before settling into a slow and gently fluctuating decline to its final value of $15 per barrel as OPEC's new policy of excess supply takes effect.

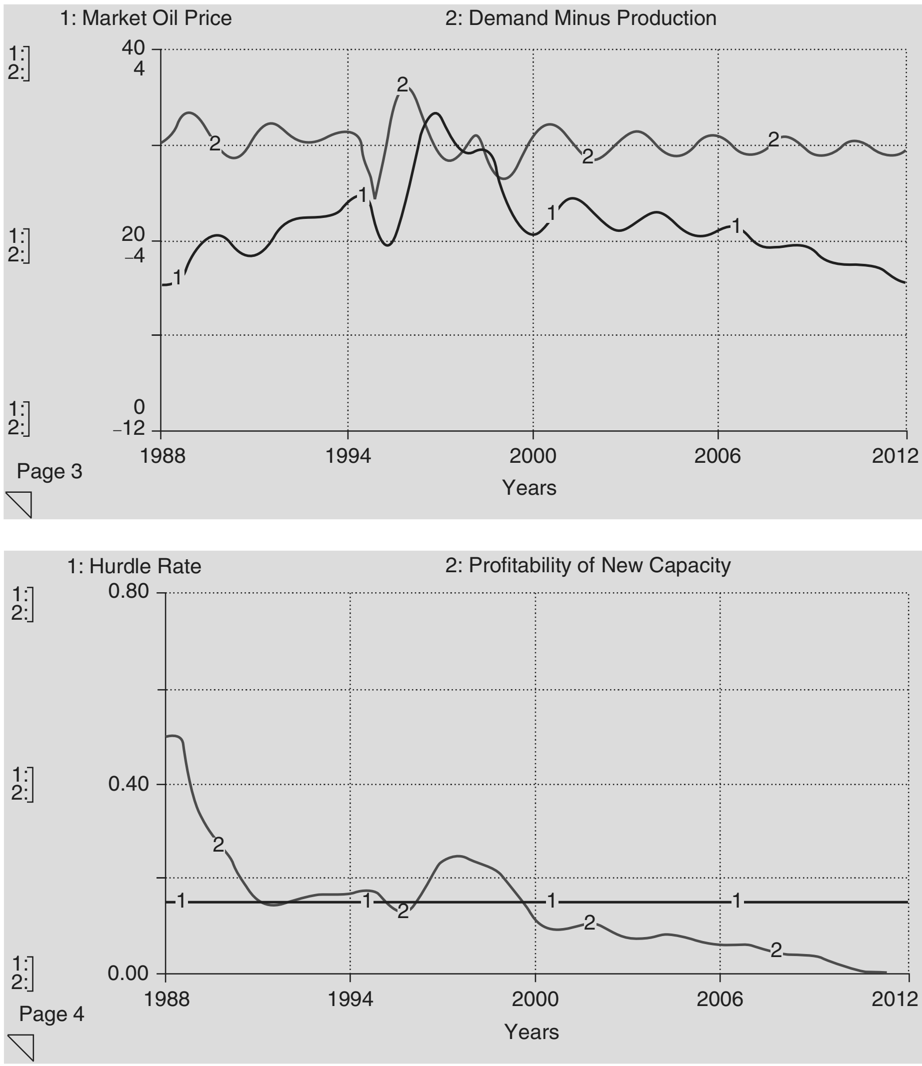


Figure 8.20 Oil price and profitability of independents' capacity in an archive scenario: OPEC squeeze then glut without Russian oil

The lower half of Figure 8.20 shows the changing investment incentives for independent producers that helps explain the rise and fall of independents' production. The hurdle rate for upstream investment projects (line 1) is assumed to remain constant at 15% (0.15). At the start of the simulation, when the oil price is $15 per barrel, the profitability of new capacity (line 2) is 50% (0.5), reflecting the initial low cost of reserves. It is financially very attractive to add new capacity, but over the three-year interval to 1991, profitability falls sharply to equal the hurdle rate. This fall in profitability occurs despite the rise in oil price from $15 to $20 per barrel, because the development cost of new reserves is rising even faster (the independents are operating on the steep shoulder of the cost profile). As price rises to its second peak of $25 per barrel in 1994, the profitability of new capacity increases slightly above the hurdle rate. The price plateau of $30 per barrel between 1996 and 1998 creates an attractive era for investment in which the profitability of new capacity rises to 25%, well above the hurdle rate. Then, as the swing producer generates a pulse of punitive production, and as OPEC changes policy, profitability falls quickly to only 10% in the year 2000. The investment climate continues to deteriorate throughout the remainder of the simulation. By the year 2011, the profitability of upstream investment has fallen to zero, meaning that the price of oil is now equal to independents' development costs. In the final year of the simulation, profitability actually goes negative.

Changing profitability drives independents' capacity as shown in Figure 8.19, but only after a lag that represents the time to develop a new field. The lag effect is most obvious following the attractive investment era between 1996 and 1998.

Independents' capacity is static at 30 million barrels per day (actually declining slightly) during the high price plateau. Then as profitability declines sharply between 1998 and 2000, independents' capacity rises gradually to 32 million barrels per day as new fields, approved earlier, begin to come on stream.

Archive Scenario 2: Quota Busting in a Green World

Imagine a world in which there are environmental pressures to reduce oil consumption – a green world. In the absence of price changes, these pressures are assumed to be sufficient to cut consumption by 10% per year. Imagine too that the opportunist producers in OPEC are inclined to cheat on quota. They deliberately plan to build capacity 10% greater than quota, and secretly use the excess capacity to produce more than quota whenever the opportunity arises. Assume that OPEC adopts a neutral quota policy, setting quotas that exactly match its estimate of the market call on OPEC. To create these scenario conditions set the effect of 'global economy and environment on demand' to −0.1 and the 'opportunists' capacity bias' to +0.1. Also, make sure to reset the 'cartel quota bias' to its default value of zero. The other sliders should remain at their default values.

Figure 8.21 shows profiles of demand and production for this scenario of quota busting in a green world. In the top half of the figure, demand begins at 50 million barrels per day in 1988 and falls gradually to a final value of 44 million barrels per day by 2012. The decline is due to the assumption of a green world. Despite the *ceteris paribus* green assumption of a 10% cut in consumption per year, demand falls by only 6 million barrels per day over 25 years due (as we will see) to the compensating effect of lower price resulting from conservation and quota busting.

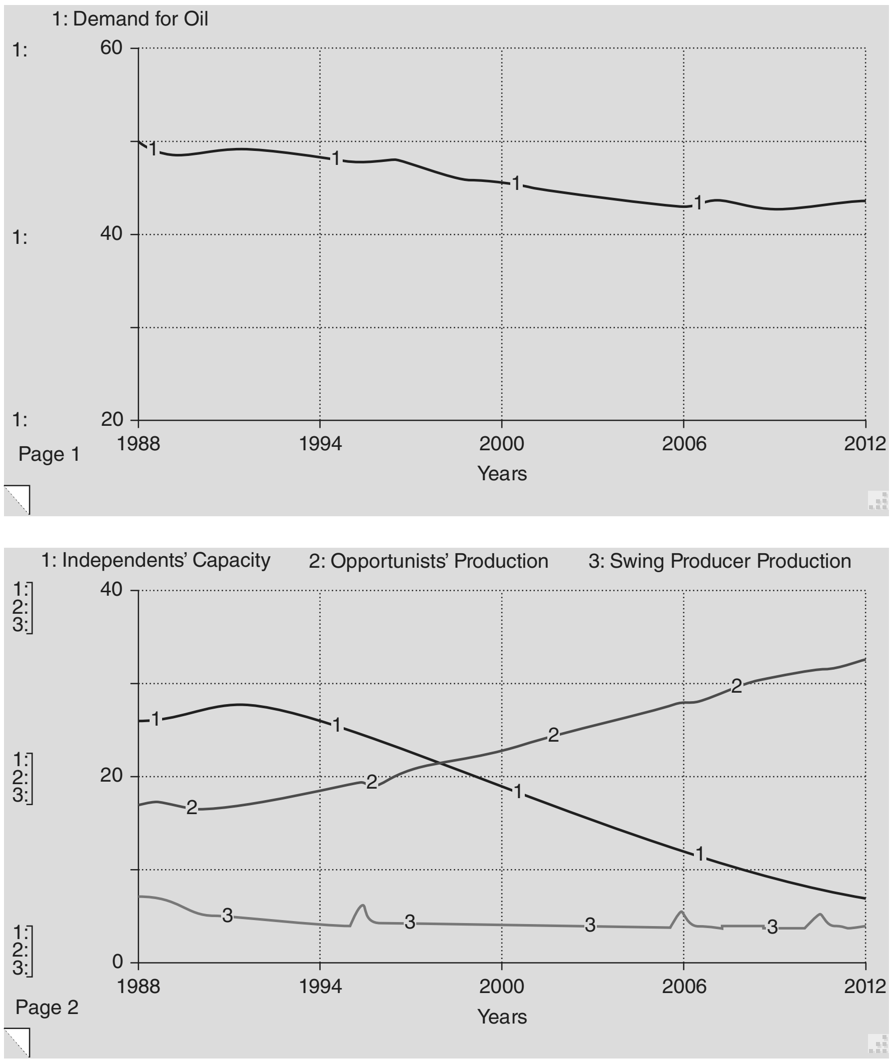


Figure 8.21 Demand and oil production in an archive scenario: Quota busting in a green world without Russian oil

In the bottom half of the figure, the opportunists' propensity to cheat pays off as they expand capacity and increase their bargaining strength in quota negotiations. Their production rises steadily from a starting value of 17 million barrels per day to a final value of 33 million barrels per day. Most of this expansion comes at the expense of the independent producers who see their output fall from a starting value of 26 million barrels per day to only 7 million barrels per day at the end of the simulation. The swing producer too is squeezed by the opportunists at the start of the simulation, as output falls from 7 million barrels per day in 1988 to 4 million barrels per day in 1994. However, beyond 1994, and for the rest of the simulation, the swing producer uses mild pulses of punitive production to maintain market share and hold production at 4 million barrels per day. The first pulse occurs in 1995. The next pulse of punitive production occurs in 2006 and again in 2011.

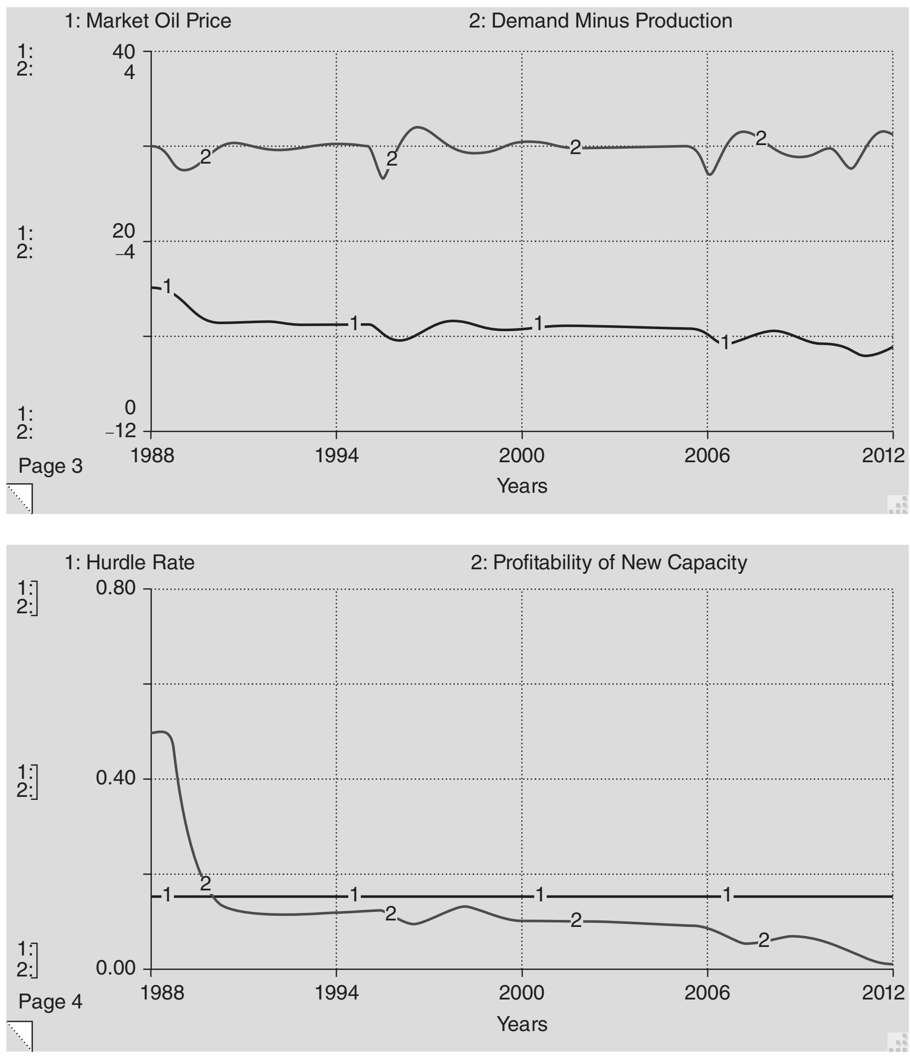


Figure 8.22 Oil price and profitability of independents' capacity in an archive scenario: Quota busting in a green world without Russian oil

The top half of Figure 8.22 shows market oil price (line 1). Price drops quickly from its starting value of $15 per barrel in 1988 to $11 per barrel in 1990 as demand falls in response to green conservation pressures. After this initial sharp drop, price falls very gradually during the rest of the simulation (with minor fluctuations caused by the swing producer's bursts of punitive production) to a final value of $8 per barrel by the end of the simulation. Needless to say, the sustained run of low oil price generates a bleak environment for independents' upstream investment. In the lower half of Figure 8.22, the profitability of new capacity quickly falls below the hurdle rate of 15%. By 1991, profitability is at 11%, and continues to fall throughout the simulation to a final value of about 1% in 2012.

With no financial incentive for new investment, the independents' capacity (lower half of Figure 8.21) gradually declines as existing fields are depleted. Quota busting in a green world leads to a rapid demise of the independent producers. They end the simulation with no new capacity in the pipeline, a gloomy investment climate, and a market share of only 16% (down from 52% at the start of the simulation, and still declining).

Scenario from the Mid-1990s to 2020: Asian Boom with Quota Busting, Cautious Upstream Investment and Russian Oil

The previous simulations were archive scenarios created before the fall of Communism in an era when the expectation among industry experts was that Russian oil would never be globally traded. Circumstances then changed. The next scenario runs from 1996 to 2020 and includes Russian oil. The scenario assumes steady upward pressure on oil demand arising from a sustained Asian boom in the giant developing economies of China and India. In this climate of growth, opportunist producers within OPEC are assumed to engage in quota busting while independent producers take a cautious approach to upstream investment, approving development of only the most profitable new fields.

To run this scenario for yourself, open 'Oil World 1995'. The initial screen is identical to Oil World 1988 in Figure 8.18 except that the time chart spans the period 1996 to 2020. There is also one extra control called 'time to build trust in Russia' that determines the rate at which commercial confidence builds to develop Russian reserves. To mimic demand pressure from an Asian boom, move the slider 'effect of global economy and environment on demand' to the far right so it takes a value of 0.1. This setting means that consumers collectively want to use more oil. To activate quota busting within the OPEC cartel move the slider 'opportunists' capacity bias' to the right so it takes a value of 0.1. Also set the 'cartel quota bias' to a value of −0.05 to enact a deliberate policy of moderate undersupply by OPEC. Finally, to represent cautious upstream investment by independents reset 'capex optimism' to 0.6.

This setting has the effect of authorising only the most profitable 60% of the upstream development projects whose estimated financial return exceeds the hurdle rate. The remaining two sliders ('time to build trust in Russia' and 'oil price bias') can remain at their default settings.

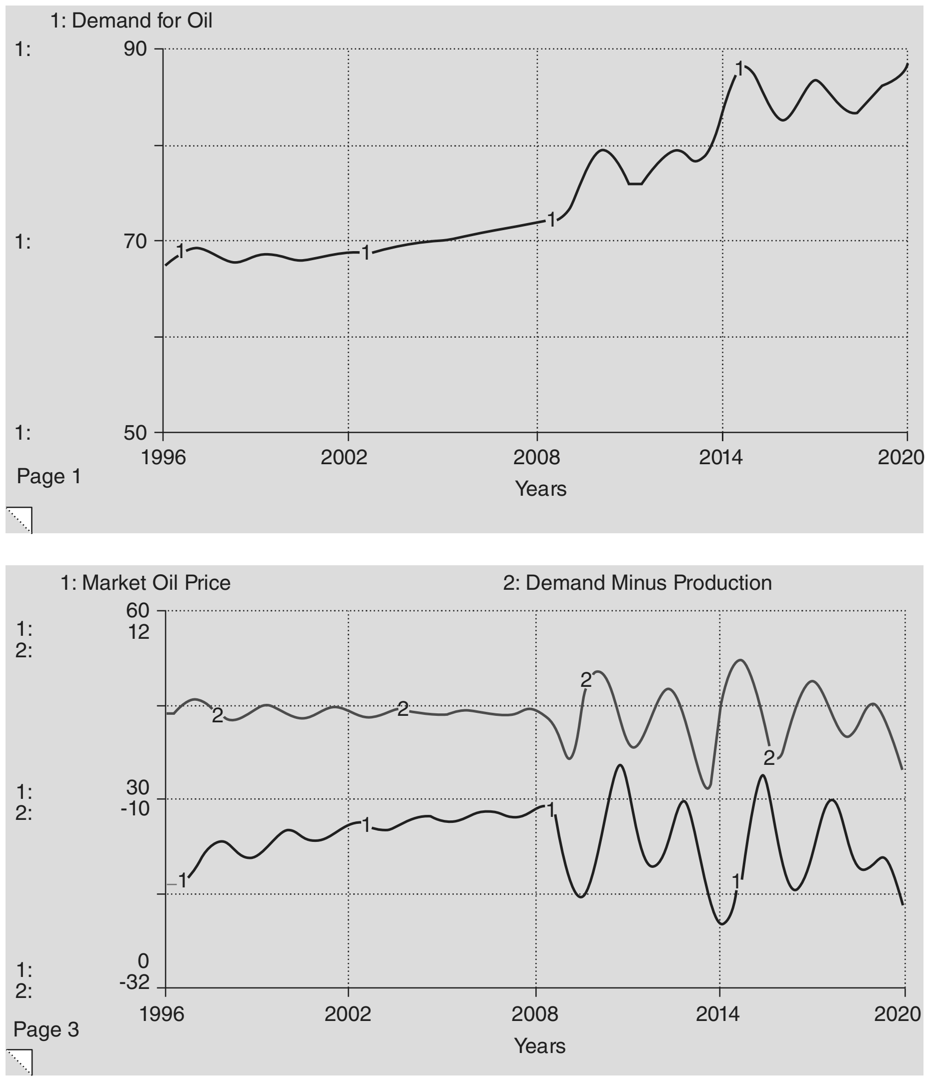
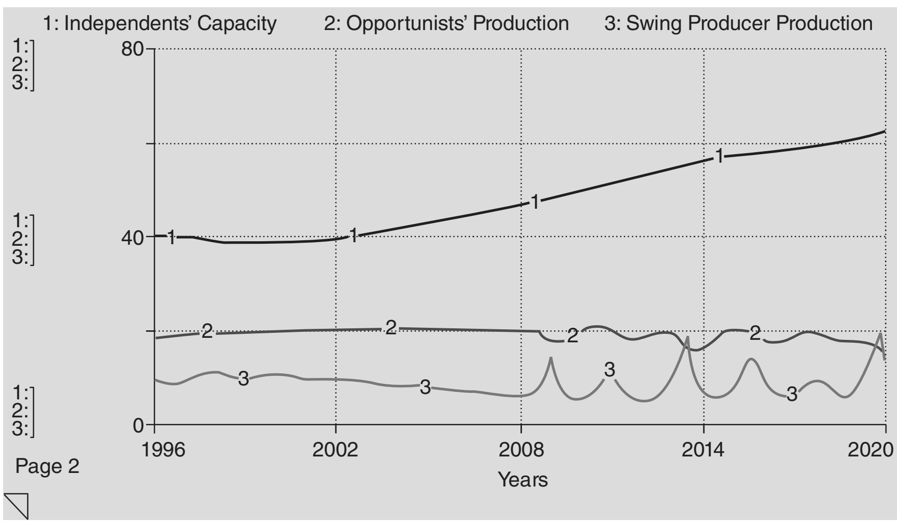


Figure 8.23 Demand and oil price in a scenario from the mid-1990s to 2020: Asian boom with quota busting, cautious upstream investment and Russian oil

Press the 'Run' button to see this scenario play out in five-year intervals resulting in the time charts shown in Figures 8.23, 8.24 and 8.25. Remember that any scenario shows time paths that are internally consistent with the assumptions about conditions in the industry. These time paths do not necessarily fit history or point-predict the future. In Figure 8.23, demand for oil starts at 68 million barrels per day in 1996 and over the decade to 2006 rises gradually to 71 million barrels per day. The increase in demand is modest, only 4% over 10 years despite steady upward pressure on demand from the assumed growth in Asian economies. The reason that demand does not grow more quickly is that oil price (shown in the bottom half of Figure 8.23) rises from $16 per barrel to almost $30 per barrel – practically doubling over the simulated decade. Such a large price increase evokes greater fuel efficiency in the global economy.



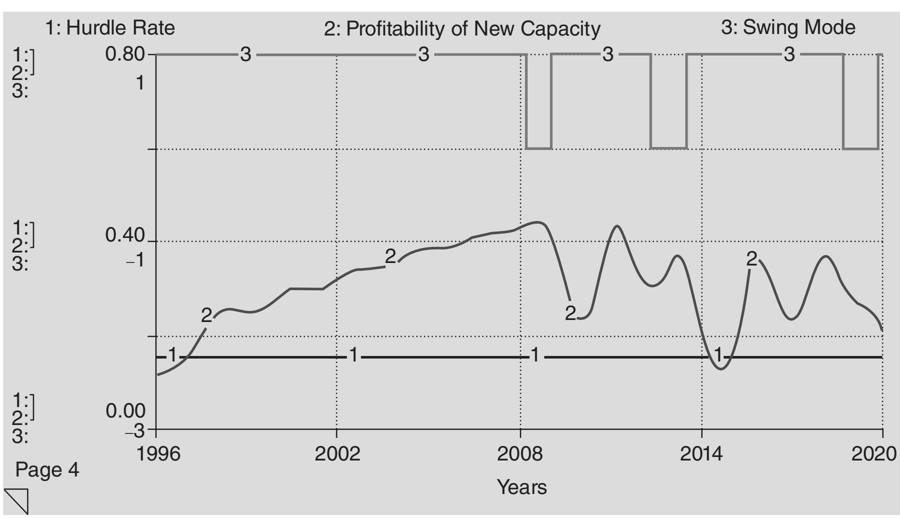


Figure 8.24 Production profiles and profitability of independents' capacity in a scenario from the mid-1990s to 2020: Asian boom with quota busting, cautious upstream investment and Russian oil

In the remainder of the simulation, from 2006 to 2020, demand grows swiftly and is also far more volatile. In only two years, from 2008 to 2010, demand surges from 72 to 79 million barrels per day, a 10% increase, as global economic growth combines with a dramatic drop in oil price (from $30 to $15 per barrel) to unleash vast additional consumption. As we will see later the price drop is caused by a temporary burst of punitive production by the swing producer that floods the market with oil. When punitive production ends the oil price rapidly rises to $35 per barrel by late 2010 leading to a slight reduction of demand, despite the continued pressure of economic growth. Thereafter, demand continues on an upward trajectory with intermittent upturns and downturns, reaching almost 90 million barrels per day by 2020. The ups and downs stem from volatility in oil price as the oil industry enters an era of OPEC-induced supply instability between 2008 and 2020.

The supply story can be seen in Figure 8.24. The top chart shows the production profiles of the three main producer groups – the independents (line 1), the opportunists (line 2) and the swing producer (line 3). In the interval between 1996 and 2002, independents' capacity (and therefore production) is steady at almost 40 million barrels per day. Over the same six years, opportunists' production increases gently from 18 to 20 million barrels per day as opportunists take advantage of demand pressure and stable oil price to engage in limited quota busting. Meanwhile, the swing producer's production fluctuates gently and then settles into a downward trend resulting from the deliberate policy of undersupply and the need to compensate for quota busting by opportunists. The overall picture in the early years of the scenario is restrained production by the industry as a whole that leads to the near doubling of oil price already seen in Figure 8.23. High price creates a favourable environment for commercial upstream investment as shown by the trajectory for the profitability of new capacity in the bottom half of Figure 8.24. Profitability (line 2) begins at 12% (0.12), just below the hurdle rate (line 1) of 15% (0.15) in 1996 and rises steadily to 43% (0.43) by 2008. As a result, more and more upstream projects are approved and independents' capacity (line 1 in the top chart begins to rise) reaches 47 million barrels per day by 2008 and 56 million barrels per day by 2014. Independents take an increasingly large share of demand and this relative growth puts pressure on the OPEC cartel. The swing producer is increasingly marginalised and finds production falling to only six million barrels per day by 2008 despite growth in demand.

This unsatisfactory condition of chronic low output provokes the swing producer into punitive production starting in early 2008. The indicator for swing mode (line 3 in the bottom chart) moves from one to zero and swing producer production surges upward reaching 14 million barrels per day in 2009. As we saw previously, oil price plummets, unleashing latent growth in demand. Meanwhile, the opportunists cease quota busting and their production takes a temporary dip between 2009 and 2010. By 2010, the swing producer ceases punitive production having regained market share. Opportunists resume quota busting under the cover of rising oil price and booming demand. Notice that independents' capacity continues to grow over the interval 2008 to 2010 and beyond despite a steep decline in profitability of new capacity from 44% (0.44) to 23% (0.23) in 2010. Even so, the financial return from new upstream projects comfortably exceeds the hurdle rate and there is lots of new capacity in the pipeline from the previous decade of investment.

In the remaining years of the simulation to 2020 the relentless expansion of independents' capacity creates periodic crises within OPEC, leading the swing producer to renewed bouts of punitive production that induce volatility in oil price and demand. This instability of supply in the period 2008 to 2020 restricts oil price to a range between $10 and $35 per barrel. Moderate, though volatile, oil price is conducive to greater consumption in a growing global economy and consequently demand rises. The resulting upstream investment climate remains mostly favourable (with the exception of a notable downturn in profitability in 2014) and so the independent producers continue to expand capacity and to grab most of the extra global demand.

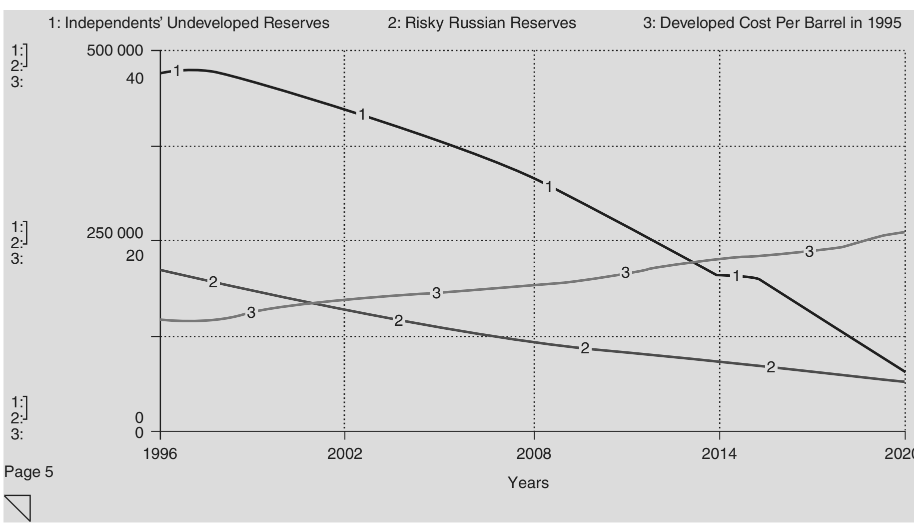


Figure 8.25 Commercial reserves and development cost in a scenario from the mid-1990s to 2020: Asian boom with quota busting, cautious upstream investment and Russian oil

Figure 8.25 shows the effect on commercial reserves of the Asian boom scenario with quota busting. Independents' undeveloped reserves (line 1) begin at 471 billion barrels in 1996 (471 000 million on the vertical scale), while risky Russian reserves (line 2), known to exist but not yet adopted by any major commercial producer, begin at 210 billion barrels (210 000 million on the vertical scale). Over time, risky Russian reserves steadily fall as confidence builds among commercial producers to exploit more and more Russian oil. These risky reserves are essentially transferred into independents' undeveloped reserves. The rate of transfer is governed by the parameter 'time to build confidence in Russia' which is set at 20 years in the scenario. By 2008 risky reserves are down to 115 billion barrels and by 2020 to 63 billion barrels, barely a quarter of the initial amount. The transfer of almost 150 billion barrels of Russian oil replenishes independents' undeveloped reserves and extends their lifetime. Nevertheless, independents' reserves decline steadily throughout the simulation because the rate of development of new commercial oil fields exceeds replenishment. Reserves fall to 329 billion barrels by 2008 and to 202 billion barrels by 2014. Notice that in the period 2014 to 2015 independents' reserves are virtually stable at 200 billion barrels despite production of 56 million barrels per day. This plateau corresponds to a brief period in which replenishment of reserves (through adoption of risky Russian oil) exactly balances new development in the wake of a dip in new upstream projects caused by low oil price. Thereafter, reserves continue to fall, declining to 75 billion barrels by 2020.

Figure 8.25 also shows development cost per barrel. This trajectory merits close investigation. Development cost starts quite low at $12 per barrel in 1996. It rises steadily over the 25-year simulation to $21 per barrel in 2020. This increase is modest considering that total non-OPEC reserves have fallen from 681 billion barrels in 1996 (the sum of independents' undeveloped reserves and risky Russian reserves) to 138 billion barrels in 2020. Almost 80% of known commercial reserves are used over this period. Surely such extensive depletion means that remaining recoverable reserves will be much more expensive to extract. However, escalation of development cost is curtailed by two factors. First, known Russian reserves, available at modest cost, are steadily replenishing commercial reserves as independent producers build confidence in Russian oil. Second, recovery technology is advancing throughout the quarter-century scenario period, as reflected in the downward sloping technology cost curve shown on the right of Figure 8.6. If this particular technology assumption is broadly correct, then it means that recovery costs in 2020 for a given oil field are only 55% of their 1996 value. So far, technology has delivered on this efficiency assumption.

A High Price Scenario from the Mid-1990s to 2020: How to Push Oil Price Over $60 per Barrel

In 2006, oil price was almost $70 per barrel and the pump price of petrol in the UK was very nearly £1.00 per litre. This price level is much higher than achieved in the simulated scenario above. So what scenario conditions are needed to push oil price into this realm? Apparently buoyant demand alone is not enough, although it is certainly an important scenario ingredient. The model suggests that it is difficult to invoke high oil price because OPEC oil is cheap and even non-OPEC oil can be extracted for less than $25 per barrel under quite aggressive assumptions about growth in global demand. If oil price exceeds $40 per barrel then commercial production is highly profitable and, sooner or later, adequate supply will be forthcoming. Conditions that would cause chronic undersupply are an Asian boom coinciding with restricted supply from OPEC; but is OPEC undersupply plausible in light of quota busting by opportunist producers? The answer is yes if a combination of political uncertainty, economic sanctions and military conflict in the Middle East conspire to reduce OPEC output so much that opportunist quota busting is cancelled out.

The scenario parameters in Oil World 1995 can be adjusted to capture the political uncertainty that would curb OPEC output. Two changes are required relative to the previous scenario. Opportunists' capacity bias is reduced to zero meaning that collectively opportunist producers are unable to engage in quota busting because oil exports for some are curtailed through sanctions or war. In addition, capex optimism is reduced to its minimum value of 0.5 to represent extreme caution in the investment decision of independent producers because of assumed political volatility and conflict in the Middle East. Otherwise, all the other scenario parameters remain at the same settings as in the previous scenario, including of course the assumption of an Asian boom driving global economic growth.

Figure 8.26 shows a simulation of this modified scenario. Only two time charts are displayed, but additional charts can be inspected by running Oil World 1995 with the parameter settings described. Oil price (line 1, bottom chart) rises steeply from $16 per barrel in 1996 to $40 per barrel in 2008, increasing still further to $63 per barrel in 2016 and $68 per barrel in 2020. There is also considerable volatility in price, with peaks of more than $60 per barrel and troughs of $30 per barrel. This volatility is caused by an interaction between the swing producer (as price regulator) and consumers. Demand growth is curtailed by high price despite the assumption of an Asian boom. Demand for oil rises from 68 million barrels per day in 1996 to 74 million barrels per day in 2020.

The simulation shows that it is possible for oil price to rise very high even when development costs remain at less than $20 per barrel (as they do in this particular scenario). High price is sustained by a combination of demand pressure and politically induced restriction in OPEC supply. Even so, the simulator cannot fully match the price peak of 2006.

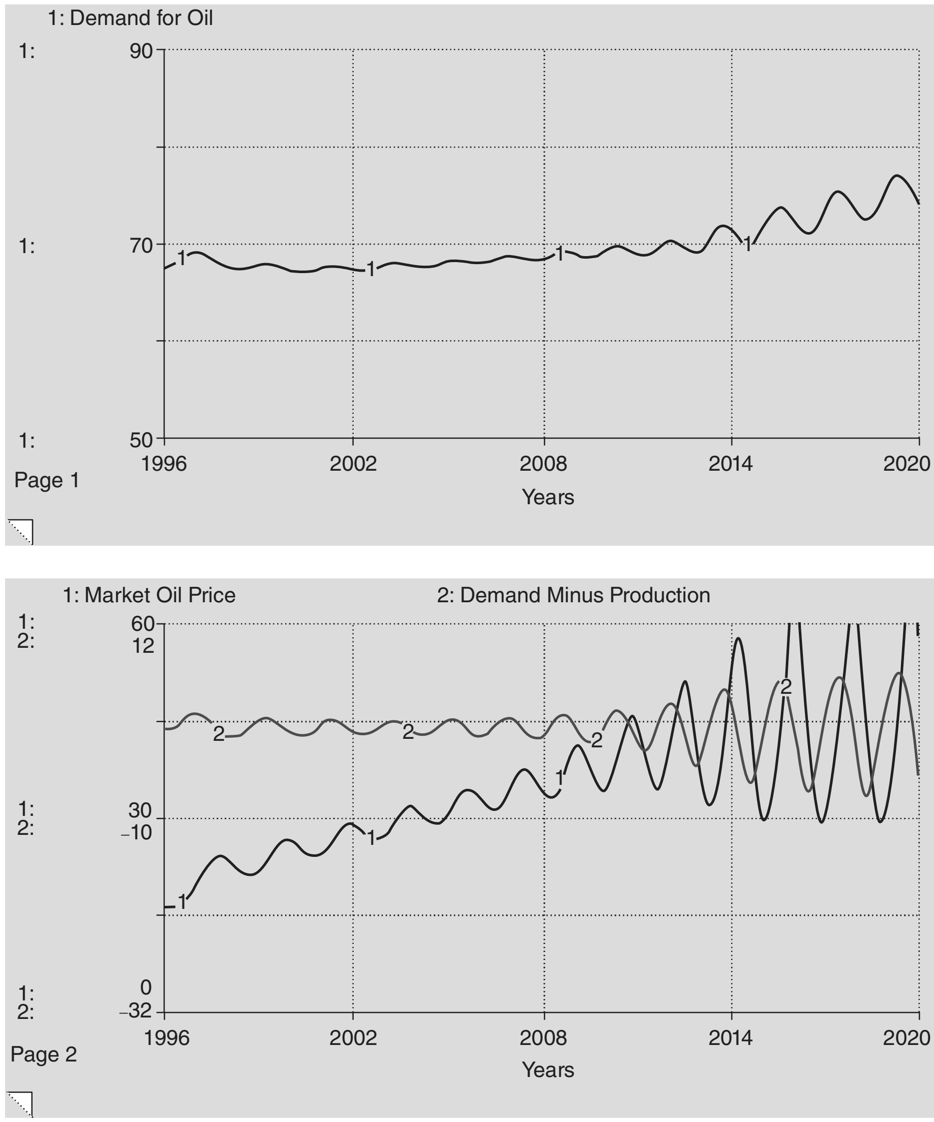


Figure 8.26 Demand and oil price in a high price scenario from the mid-1990s to 2020: Asian boom with OPEC undersupply, very cautious upstream investment and Russian oil

Most likely, this shortcoming is because the model does not fully represent oil stocks, hoarding and speculation in oil markets; short-term factors that make oil price particularly sensitive to political uncertainty in the Middle East. Nevertheless, the simulator clarifies the enduring economic and political forces driving long-term supply, demand and price in the oil industry.

A 2010–2034 Scenario: Subdued Global Oil Economy with Shale Gale and OPEC Supply Boost

By 2010 conditions in the oil industry had changed significantly by comparison with the mid-1990s. Global oil demand had surged to almost 90 million barrels per day in the wake of an Asian economic boom and oil price was more than $100 per barrel. Meanwhile Russia had become the world's biggest oil producer and output of shale oil was rising in the US. The updated model 'Oil World 2010' captures these changes.

Imagine now a scenario, starting in 2010, in which the Asian boom has ended, global economic growth is moderate, and there is increasing environmental pressure to curtail the use of fossil fuels. The result is a subdued global oil economy in which the world's growing appetite for oil is curbed, though not eliminated. Let's also assume that shale oil is rapidly exploited and that OPEC expands production through a combination of quota busting and deliberate oversupply. To explore this scenario open 'Oil World 2010'. The initial screen shows a blank time chart for the period 2010 to 2034 with a vertical axis set up to show Demand for Oil. The scenario controls are below the time chart, just as they were in 'Oil World 1995'.

The settings and parameters to generate the three main features of the intended 2010–2034 scenario are as follows:

1 The assumption of a subdued global oil economy is captured in the default value of 0 for the slider labelled 'effect of global economy and environment on demand'. This setting means that for 25 years, from 2010 to 3024, there is no upward pressure whatsoever on oil demand, unless it comes from falling oil price. In other words, in the absence of price change, oil demand remains constant. If there is economic growth, as seems likely, then its upward effect on oil demand is presumed to be cancelled by oil substitution from non-fossil fuel sources (such as pure electric vehicles for transportation or nuclear power/solar for home heating) and from improvements in energy efficiency (such as hybrid vehicles for transportation or improved insulation for home heating).

2 A shale gale happens without the need to make any slider adjustments. The effect plays out through a variety of parameter assumptions that boost the capacity and output of the independents' sector. These assumptions were described earlier in the chapter. They include extra reserves, a high initial oil price, and an attractive commercial investment climate.

3 An OPEC supply boost is created by moving the sliders for 'cartel quota bias' and 'opportunists' capacity bias'. First set 'cartel quota bias' to +0.05 by moving the slider to the right. This change causes OPEC to deliberately oversupply the market by agreeing a collective quota for member states that is 5% higher than the call on OPEC. Then set the slider f or 'opportunists' capacity bias' to 0.1. This change activates quota busting within OPEC as individual member states attempt to boost vital oil exports and revenues.

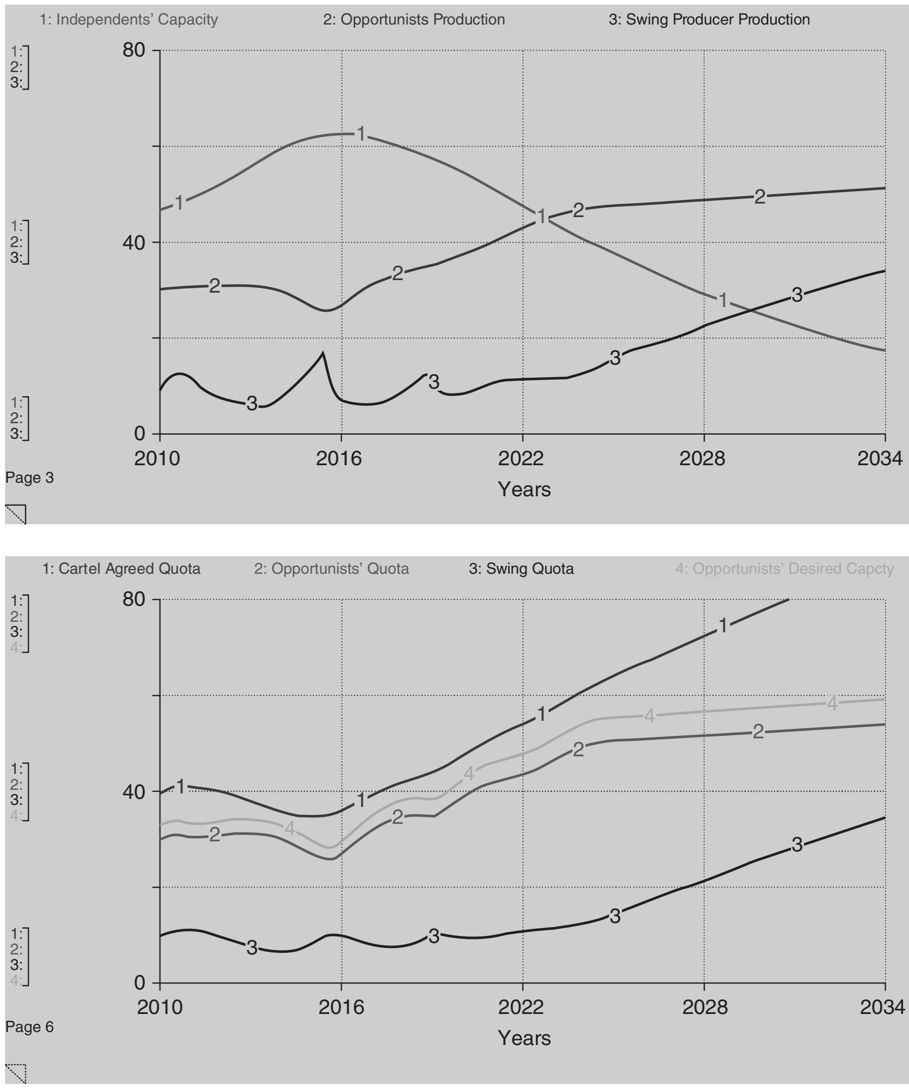


Figure 8.27 Production and OPEC quotas in a 2010–2034 scenario: subdued global oil economy with shale gale and OPEC supply boost

All the other sliders remain in their default positions.

Press the 'Run' button to generate the time charts shown in Figure 8.27. The shale gale is evident in the trajectory for independents' capacity (line 1, top chart) which grows rapidly in the period between 2010 and 2016 from 47 million barrels per day to 63 million barrels per day; a huge increase of more than 30%. This expansion puts a severe squeeze on OPEC, forcing a decline in the cartel's agreed quota (line 1, bottom chart) from 41 million barrels per day in 2010 to only 34 million barrels per day in 2015. As a result the swing producers' production (line 3, top chart) falls by 50% between 2010 and 2013 while opportunists' production (line 2, top chart) remains level at 31 million barrels per day – despite opportunists' quota busting.

The squeeze on OPEC invokes retaliation within the cartel. Starting in late 2013 the swing producer temporarily abandons the quota system and increases production far above quota in order to regain lost market share and to punish other producers for pumping too much oil. By early 2015 the swing producer's production (line 3, top chart) peaks at 17 million barrels per day. By comparison the swing quota peaks at only 9 million barrels per day (line 3, bottom chart). This surge of punitive production fails to quell the shale gale. Independents' capacity (line 1, top chart) remains above 60 million barrels per day from early 2014 to late 2017, reaching a peak of 63 million barrels per day in 2016 – one year later than the peak in swing production. The market is flooded with oil. Only the opportunists reduce production (line 2, top chart) from 30 million barrels per day in late 2013 to 25 million barrels per day in mid-2015. This modest reduction is too small to offset the supply glut.

After 2016, and over the next two decades, the oil world changes almost beyond recognition. There is a gradual long-term decline in independents' capacity (line 1, top chart) from its peak value of 63 million barrels per day in 2016 to only 18 million barrels per day in 2034. The shale gale is over and conditions are now ripe for expansion of OPEC. The cartel's agreed quota (line 1, bottom chart) rises almost linearly from 34 million barrels per day in 2015 to 80 million barrels per day in 2030, partly to fill the supply gap left in the wake of the shale gale and partly as a result of sustained quota busting by opportunists overlaid on OPEC's deliberate policy of oversupply. Opportunists' quota (line 2, bottom chart) doubles from 25 million barrels per day in 2015 to 54 million barrels per day in 2034 while the swing quota (line 3, bottom chart) more than trebles in the same period.

If this future were to unfold the upstream businesses of big commercial producers like ExxonMobil and Shell would be reduced by two-thirds (just a shadow of their former selves) and the world would be more reliant than ever on oil from the Middle East.

How could such radical change happen? The answer lies in the geology and economics of the oil industry with its vast low-cost reserves concentrated mainly in the Middle East and its modest high-cost reserves spread around the globe, trapped in awkward-to-reach places at the bottom of deep oceans, or in shale rocks and tar sands. If, as assumed in the 2010 scenario, global oil demand is subdued for more than two decades then OPEC may be tempted to compete on price and use its reserves to drive commercial producers out of business or at least curtail their market power.

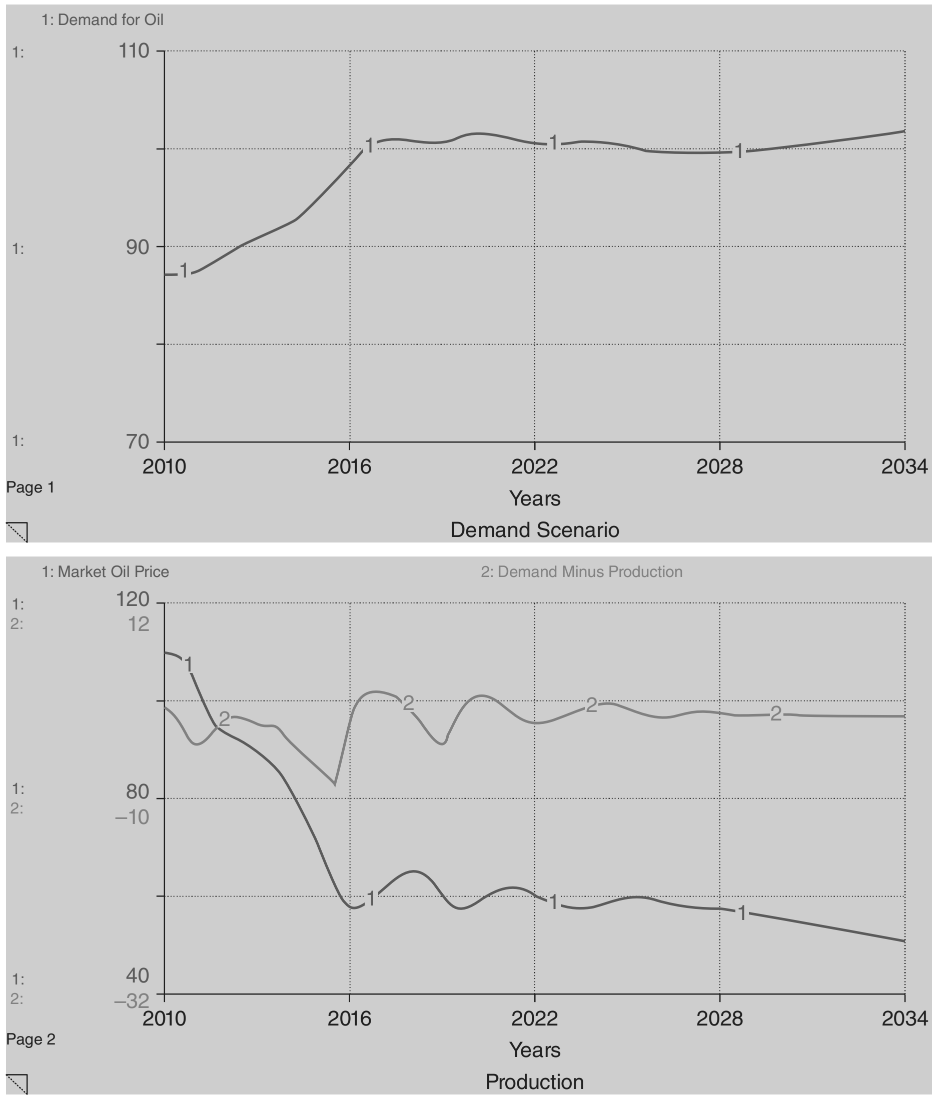


Figure 8.28 Demand and oil price in a 2010–2034 scenario: subdued global oil economy with shale gale and OPEC supply boost

The resulting demand and price story can be seen in Figure 8.28. Demand (line 1, top chart) starts at 87 million barrels per day in 2010 and rises to 101 million barrels per day in 2017. Thereafter demand remains steady, hovering around 100 million barrels per day for the rest of the simulation out to 2034. An increase in demand may seem surprising given the scenario assumption of a subdued global-oil economy. However there is a glut of oil during the first seven years of the scenario which causes a rapid decline in market oil price (line 1, bottom chart). As oil price falls from $110 per barrel to just under $60 per barrel then oil consumption is stimulated, despite environmental pressure to use less fossil fuel. For example, new hybrids or pure electric vehicles will be much more difficult to sell if the pump price of gasoline plummets and stays low.

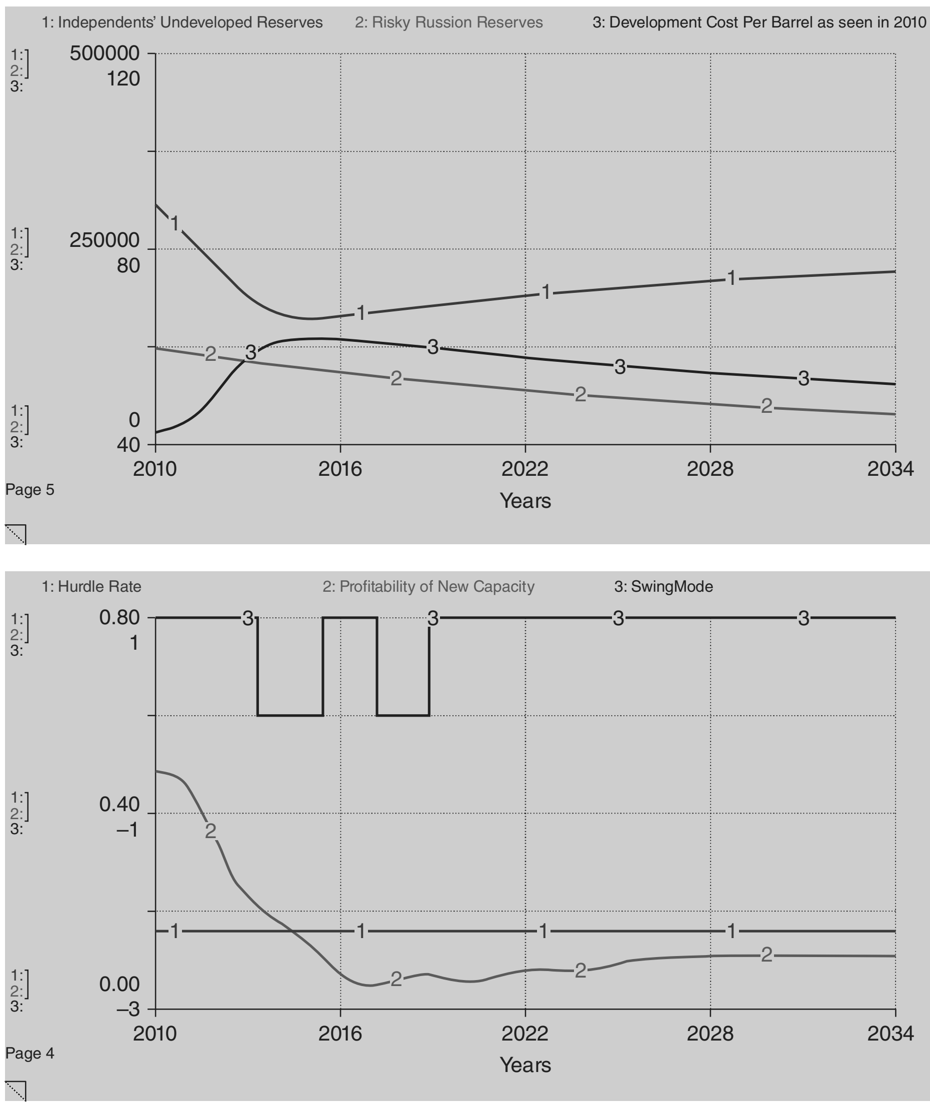


Figure 8.29 Independents' reserves, development cost and profitability in a 2010 scenario: subdued global oil economy with shale gale and OPEC supply boost

Figure 8.29 shows just how unfavourable upstream oil economics can become if OPEC adopts a hostile stance toward commercial producers in the wake of the shale gale. Independents' undeveloped reserves (line 1, top chart) fall swiftly in the period 2010 to 2015 as already-approved commercial oil fields are developed and come onstream. Meanwhile the profitability of new upstream capacity (line 2, bottom chart) declines sharply and by late 2014 has fallen below the hurdle rate (line 1, bottom chart) due to the pincer movement of oil price and development cost per barrel (line 3, top chart). Projects to develop new oil fields that would previously have been profitable are now rejected. Upstream investment is halted and remains unprofitable all the way out to 2034. For 20 years no new capacity is added by upstream commercial producers. Commercial output dwindles and OPEC fills the supply gap. It is cold comfort for the independents that their undeveloped reserves (line 1, top chart) rebuilt gradually between 2016 and 2034 as risky Russian reserves are deemed suitable for future development – if and when there is a financial incentive to do so.

Modified 2010–2034 Scenario: Subdued Global Oil Economy with Shale Gale and Punitive Saudi Supply Control

A subdued global oil economy leaves no room for long-term growth of the West's commercial upstream oil industry. So a sustained OPEC supply boost as described above, lasting 25 years, is not necessarily a wise policy for OPEC to adopt. It shifts too much market power to OPEC and emaciates the independents. Instead imagine a more pragmatic policy in which the cartel agrees quotas sufficient to meet, but not exceed, the call on OPEC (the difference between global demand and independents' production). Also imagine that Saudi Arabia exerts punitive control over supply by deploying its surplus capacity to pump extra oil, above the swing quota. The result of such Saudi intervention is a deliberately lower oil price intended to punish excess production by the other producers.

To examine this modified scenario reset the sliders for cartel quota bias and opportunists' capacity bias to their default values. Also confirm that all other sliders are set at their default values. Then press the 'Run' button to obtain the two time charts shown in Figure 8.30. For brevity I have chosen to exhibit only two pages (3 and 6) from the full set of simulated time charts. Readers can view all the other pages and trajectories (including oil demand and oil price) by using the 'page' tabs at the bottom left of the charts.

Once again, independents' capacity (line 1, top chart) surges upward between 2010 and 2017 as new capacity, including shale, comes onstream, justified by high oil price. In response the cartel pragmatically lowers its agreed quota (line 1, bottom chart). However by 2013, after three years of quota accommodation, the swing producer switches into punitive mode, in an

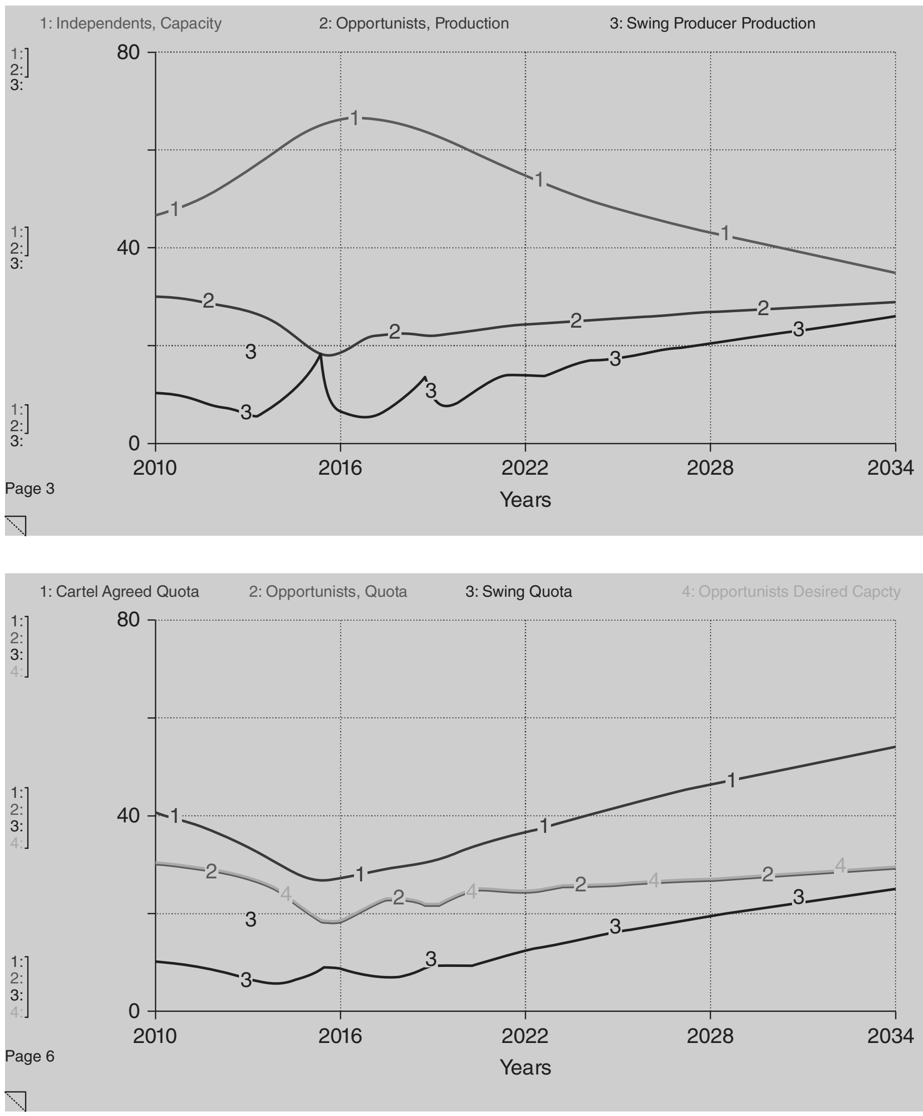


Figure 8.30 Production and OPEC quotas in a modified 2010–2034 scenario: subdued global oil economy with shale gale and punitive Saudi supply control

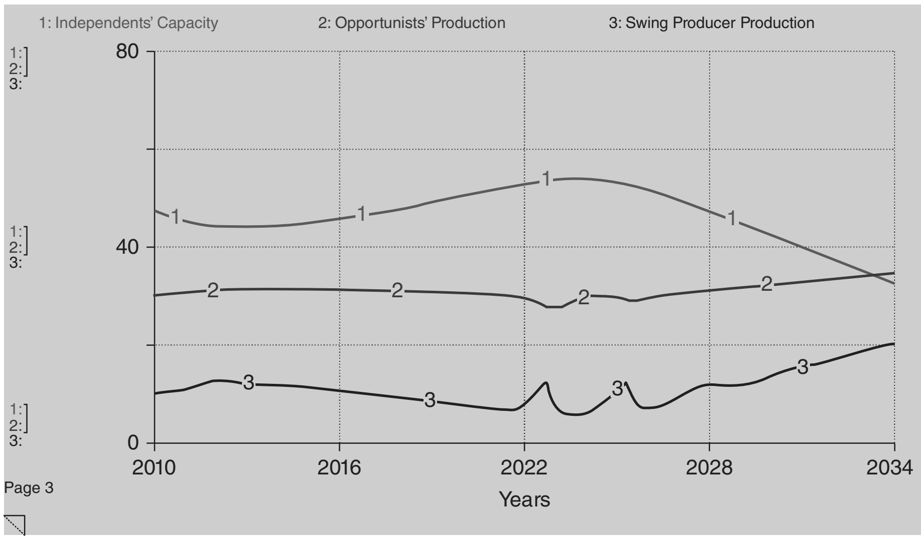
attempt to quell the shale gale. Swing production (line 3, top chart) rises sharply and greatly exceeds swing quota (line 3, bottom chart), to reach a peak of 18 million barrels per day in 2015, before subsiding close to swing quota of 8 million barrels per day in 2016. This burst of punitive production, followed by another brief burst in 2018, lowers oil price enough to discourage further investment by the independents (see pages 2 and 5 of the simulated time charts for price and profitability trajectories). As a result, capacity (line 1, top chart) gradually declines throughout the rest of the simulation to year 2034.

However, unlike the previous scenario, OPEC no longer attempts to drive the independents out of business. The cartel's agreed quota (line 1, bottom chart) rises only gradually to fill the supply gap left by the independents; ending in 2034 at 54 million barrels per day and split almost equally between opportunists' quota (line 2, bottom chart) and swing quota (line 3, bottom chart). Note that during OPEC's long period of gentle growth there is no need for further punitive production by the swing producer. From 2018 onwards the cartel works harmoniously within the framework of the quota system.

2010–2034 Thought Experiment: Subdued Global Oil Economy with a Shale Gale and Mooted US Supply Control – The 'Saudi America' Hypothesis

The final simulation experiment tests an intriguing hypothesis advanced by some oil economists and reported in *The Economist* magazine (February 2014). A reprint of the original article can be found in the learning support folder for Chapter 8. The argument is that shale oil production is much more responsive to world prices than conventional oil due to the short lifetime of tight oil wells. Oil flows sluggishly through impermeable shale rock by comparison with the much freer movement of oil through porous rocks that make up conventional reservoirs. As a result the area that can be tapped with a shale well is much smaller than the area for a conventional well and, as pumping commences, production declines quite rapidly for the first few years (typically by 30% a year by comparison with only 6% a year for a conventional well). So when oil price rises, tight oil producers quickly drill more holes and ramp up supply. When price falls they simply stop drilling and production soon declines. From this geological difference arises the 'Saudi America' hypothesis which suggests that as US shale production expands, and the US becomes one of the world's largest producers, then America will replace Saudi Arabia as the swing producer.

To test the hypothesis it is first necessary to manually adjust the model parameter called 'Average Lifetime of Field Wells' in Oil World 2010. Re-open Oil World 2010 and press the button labelled 'To Model' in the bottom left of the time chart on the opening screen. A diagram of the Independents sector appears. (Note: If the 'Map' tab is selected on the left of the diagram then, before proceeding, be sure to select the 'Model' tab instead.) Double select the icon for the 'Average Lifetime of Field Wells' in the top right of the diagram. Change the parameter value from 10 years to 5 years. Then press the button labelled 'To Charts' and rerun the simulator with all the sliders set at their default positions, just as they were for the modified 2010–2034 scenario above.



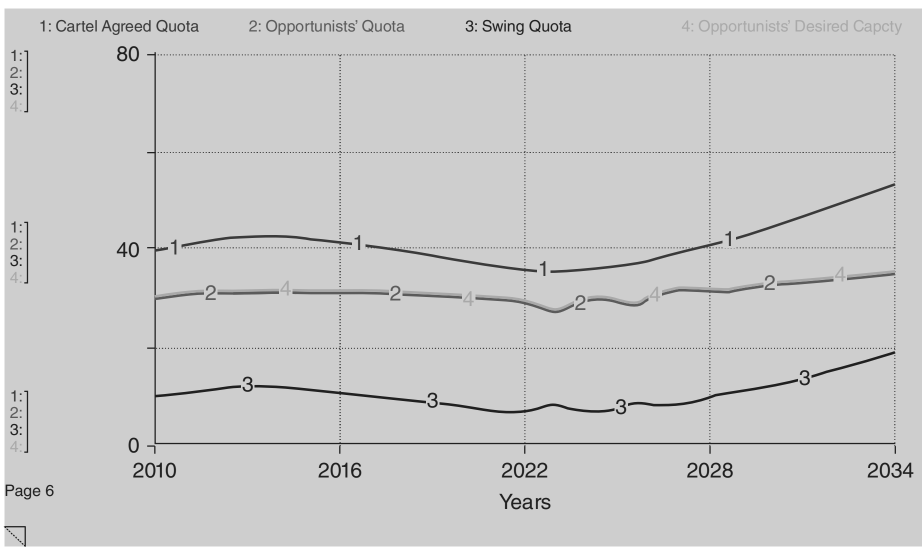


Figure 8.31 Production and OPEC quotas in a 2010 thought experiment: subdued global oil economy with shale gale and mooted US supply control; the 'Saudi America' hypothesis

Locate the two time charts shown in Figure 8.31 and compare the trajectories with those shown in Figure 8.30.

There is a noticeable change in dynamics. Independents' capacity (line 1, top chart) remains quite flat all the way to 2028 and only then begins to decline gradually. The distinctive capacity hump of the shale gale, clearly visible in

Figure 8.30, has disappeared. Meanwhile swing producer production (line 3, top chart) closely matches the swing quota (line 3, bottom chart) meaning that Saudi Arabia no longer needs to exert supply control through bursts of punitive production. Moreover, the cartel's agreed quota (line 1, bottom chart) remains relatively stable for almost two decades, from 2010 to 2028, suggesting the cartel's influence on supply (or need to influence supply) is diminished, consistent with the 'Saudi America' hypothesis. Meanwhile oil price (shown on page 2 of the graph pad) remains above $100 per barrel for most of the simulation. This high and relatively steady price stabilises demand for oil (shown on page 1 of the graph pad), which settles at or just below 90 million barrels per day; a pattern that now fits well with the scenario assumption of a subdued global oil economy. Also, the profitability of new capacity (shown on page 4 of the graph pad) remains above the hurdle rate all the way out to 2034 (despite shrinking reserves and rising costs). So, unlike previous shale gale scenarios, there is always a financial incentive, albeit diminishing, for independents to invest in new capacity.

So perhaps the Saudi America hypothesis is true and the locus of power in the oil world will shift from Saudi Arabia and OPEC to the US in coming decades. However the simulator suggests there is only a grain of truth in the hypothesis. The main reason is that only a small fraction of independents' overall capacity is in shale oil, which is anyway relatively expensive to develop. There is lots of conventional oil capacity too in Russia's medium-cost oil fields, and in conventional deep-sea fields rendered profitable by high oil price. With all this commercially viable non-shale output already in the industry it is extremely unlikely that shale producers in the US can, by themselves, enforce production cuts big enough to stabilise price in the way the hypothesis suggests. It would take remarkable discipline by entrepreneurial frackers in the biggest US tight-oil production basins (such as Bakken and Eagle Ford) to withhold production for months on end, or even years, in the hope that the oil price will rise. Meanwhile, conventional oil producers will continue to pump oil from their long-life wells, unable to match the production cuts in nimble tight-oil fields. Moreover, some shale oil producers will surely behave opportunistically, drilling new wells to sustain their output even as other shale producers cut back – rather like the opportunist producers in OPEC. So the most likely outcome for independents' output as a whole is a partial production cut, much shallower than imagined in the Saudi America hypothesis.

The true aggregate situation can be represented in the simulator by a smaller reduction in the average lifetime of field wells from (say) 10 years to 7 years (rather than 5 years). When this more realistic assumption is used then the main dynamic features of the modified 2010 scenario reappear. The capacity hump of the shale gale returns, prompting bursts of punitive Saudi production that in turn causes a significant drop in oil price. Of course it is important to bear in mind, as with all scenarios, that the trajectories are internally consistent stories, not accurate point predictions of future oil price and production. Nevertheless there is a strong message in the 2010 simulations. Unless there is another global economic boom, then we are entering an era of lower oil price, ushered in by a shale gale that re-ignites the smouldering power of OPEC.

Devising New Scenarios

You can devise new scenarios by varying the slider settings in any of the three versions of the oil producers' model: 'Oil World 1988', 'Oil World 1995', or 'Oil World 2010'. The sliders, which can be seen in Figure 8.18, correspond to the parameters marked in bold in Figures 8.16 and 8.17. The default settings represent a benign oil industry in which demand is stable and OPEC cooperates with independents to fully supply the market. The meaning of each slider is explained below. By understanding the sliders it is possible to create a very wide range of plausible scenarios from low-price to high-price, from stable to volatile, and from OPEC-dominated to independent-dominated.

Effect of Global Economy and Environment on Demand

The effect of global economy and environment is a parameter representing pressure on oil demand from the global economy or from environmental policy to limit carbon emissions. The effect can vary from −0.1 to 0.1 with a default value of zero. When the effect is zero long-term demand is normally stable. Moving the slider to the right results in growing oil consumption because, at constant price, intended demand (in Figure 8.16) exceeds demand. Conversely, moving the slider to the left results in falling oil consumption. With this versatile slider an Asian boom is portrayed by setting the slider to its maximum value of 0.1, whereas a green world (committed to reducing carbon emissions and using fewer fossil fuels) is portrayed by setting the slider to its minimum value of −0.1.

Cartel Quota Bias

Cartel quota bias captures the tendency of OPEC to deliberately oversupply or undersupply the market by setting a collective quota that differs from the call on OPEC (the difference between demand and independents' production). The effect can vary from −0.2 to 0.2, with a default value of zero. When the effect is zero OPEC agrees a quota exactly equal to the call. Moving the slider to the left causes an OPEC supply squeeze, a deliberate undersupply of oil that can be as much as 20% of the call. Moving the slider to the right causes an OPEC supply glut, a deliberate oversupply of oil.

Opportunists' Capacity Bias

Opportunists' capacity bias represents the propensity of some OPEC member states to over-expand capacity and exceed their allocated quota. There is always a temptation for OPEC producers to cheat on quota, particularly oil nations with underdeveloped economies and large populations that desperately need oil revenues to support social welfare and infrastructure projects. Capacity bias is defined on a scale from zero to 0.2 where zero means no quota busting. The default value is assumed to be 0.02 on the presumption that, no matter how hard OPEC strives for quota discipline, there is naturally some propensity to cheat and over-expand capacity. Moving the slider to the right amplifies this natural propensity up to a maximum where opportunists strive for capacity at a level 20% (0.2) above allocated quota.

Oil Price Bias

The oil price bias is a parameter that captures any inclination of OPEC to intentionally increase oil price by setting a target (marker) price higher than the current oil price. The default value is zero and the parameter can be moved in the range −0.2 to 0.2. Moving the slider to the right creates a condition in which OPEC's target price exceeds the current oil price by up to 20%. There is no presumption, however, that OPEC will always pursue a policy of price escalation. Moving the slider to the left creates a condition in which OPEC's target price undercuts the current oil price. Incidentally, the oil price bias does not (and cannot) directly influence oil price. It acts indirectly to restrict or to boost the swing producer's production.

Capex Optimism

Capex optimism represents the collective investment optimism of senior management in commercial oil companies. It is defined on a scale of 0.5–2 and has a default value of 1. Capex optimism influences the amount of upstream investment undertaken by the independents. When optimism is set to 1, senior managers approve all recommended investment projects, in other words all those that satisfy the hurdle rate. Moving the slider to the left makes management more cautious and they approve fewer investment projects than recommended, as little as 50% fewer (0.5 or half the recommended). Moving the slider to the right makes managers more optimistic and less cautious and they approve more investment projects than recommended.

Time to Build Trust in Russia (in Oil World 1995 and 2010)

As mentioned earlier, Russian reserves are huge, with an initial value of 225 billion barrels in Oil World 1995 and 137 billion barrels in Oil World 2010 (after 15 years of commercial exploitation). They amount to almost 50% of total non-OPEC reserves. Time to build trust in Russia controls the rate at which commercial oil companies adopt risky Russian reserves into their undeveloped reserve portfolio. The parameter is defined on a scale of 5–40 years. When the time to build trust is at its default value of 20 years commercial companies are assumed to adopt 1/20 (5%) of risky Russian reserves per year. In other words, the value of the slider setting (20 years) defines the denominator (1/20) in the adoption rate. Moving the slider to the right captures the effect of a less trusting climate for exploration and production. Adoption of risky Russian reserves slows to as little as 1/40 (2.5%) per year at the slider's maximum setting of 40 years. Moving the slider to the left increases adoption to as much as 1/5 (20%) per year at the slider's minimum setting of five years.

Endnote: A Brief History of the Oil Producers' Project

There have been five phases in the life of the oil producers' project. The first phase was the original model development, which happened in the period 1988–1989 as an input to Shell's 1989 scenario round (Shell Group Planning, 1989). This work took place under the guidance of Kees van der Heijden who was then head of the scenario team at Shell International, London, within a department known (at the time) as Group Planning. Model conceptualisation was led by John Morecroft and the model development team included Kees van der Heijden, Ged Davis (a member of the 1989 scenario team) and Andrew Davis (who had been seconded to the team from the business consultancy department of Shell UK).

The second phase was translation of the model into a microworld for internal Shell management training programmes, in the period 1990–1992. The original interface design was carried out by Linda Morecroft in a language called Microworld Creator (Diehl, 1992). The integration of the microworld into the training programmes was carried out by John Morecroft in collaboration with Brian Marsh, a senior member of Group Planning. Samples of the interface and experiences from the training programmes are reported in Morecroft and Marsh (1997).

The third phase was the use of the oil producers' model in Paul Langley's PhD dissertation at London Business School, in the period 1993–1995. The purpose of the thesis was to study user learning in gaming simulators (Langley, 1995). The research required a completely new graphical interface suitable for controlled experiments on user learning. Paul Langley collaborated closely with Erik Larsen (then a research fellow at London Business School) to develop the interface in Visual Basic before going on to design and execute his experiments. He also simplified the user controls. Originally there were the five sliders depicted in Figure 8.18. The thesis microworld had just one control – the capacity approval decision.

The fourth phase, in the period 1995–1997, involved revisions to the original oil producers' model to take account of structural changes in the oil industry since 1988. The most dramatic and significant change, as mentioned earlier in the chapter, was the opening up of Russian oil fields to global markets, stemming from the break-up of the Soviet Union and the fall of Communism. It was fortunate that Ged Davis, a member of the original model development team, was by then back at Shell Centre and able to offer expert advice on how best to incorporate Russian oil into the model. The result was a new model (called Oil World 1995 to distinguish it from the original Oil World 1988) that captured Russia's vast oil reserves as an extension of the commercial reserves available to independent (non-OPEC) producers. Though Russian oil was treated in the model as commercial oil, there were nevertheless political strings attached to the timing of its exploitation. Ged Davis' conceptualisation of Russian oil fields fit very well within the model's existing architecture. The necessary changes required the addition of only six new equations to the existing 100 equations portraying industry structure.

The fifth model development phase took place in 2014 as I prepared the second edition of the book. Although by this time more than a quarter century had passed since the creation of the original model, it nevertheless seemed that key feedback structures from the 1988 model were still present in the new oil world of the 21st century. Indeed I was intrigued by the idea that the model contained a practical example of 'enduring feedback structure', thereby illustrating a principle central to the modelling philosophy of system dynamics. In particular, the OPEC cartel was intact with a swing producer and opportunists following much the same operating policies as in the 1980s and 1990s for quota setting, price control and punitive production. It remained to add the changes brought about by the exploitation of shale oil which were mostly concentrated in the Independents sector. These changes were introduced by adjusting parameter assumptions for reserves and development costs, using data available from public sources such as BP's Statistical Review of World Energy and articles in the business press of the time, such as the report on 'cheaper oil' in *The Economist* (2014b). I also updated the initial oil price numbers in the model to match the real world price of $110 per barrel in 2010.

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