

Peak oil and energy policy—a critique

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Abstract Energy policy has frequently been based upon assumptions about future oil prices. At the end of the 1970s it was assumed oil prices would continue to rise. Now a similar assumption pervades policy design. This article critiques the peak oil hypotheses which lie behind these forecasts and policy beliefs, and considers that, from a climate change perspective, the challenge is too much not too little fossil fuel reserves. The coming of shale gas, its fungibility with oil via the electrification of transport, along with technological advances in increasing the depletion rates of existing wells and new reserves, together undermine that assumption that rising oil prices will rapidly make renewable and other low-carbon technologies cost competitive without subsidies. The paper suggests indexing carbon prices to the oil price, infrastructure investment, strategic storage, and a focus on market failures provides a superior approach to energy policy rather than relying on forecasts of oil prices and picking winners.

Key words: peak oil hypothesis, energy policy, carbon prices, strategic reserves, shale gas, renewables, climate change policy, oil prices, energy security, fossil fuels

JEL classification: L980, O130, Q410, Q380, Q480, Q54

I. Introduction

Energy policy has to a considerable extent been based upon assumptions about future oil prices. In the 1970s, it became conventional wisdom to assume that oil prices would go ever upwards, in part driven by the fear that the world was running out of oil, and in part driven by the perceived success of the Organization of the Petroleum Exporting Countries (OPEC) in exerting market power. In response, the International Energy Agency was set up; strategic oil reserves were created; new, more expensive, exploration and production (E&P) was promoted in areas such as the North Sea; and a renewed dash for nuclear got under way, most spectacularly in France. These measures were justified on the assumption that oil prices would rise from what turned out to be a peak of \$39 a barrel in 1979 to \$100 (in 1979 prices) and beyond by the end of the century.

The outcome was almost the diametric opposite: oil turned out to be in abundant supply, and prices fell towards \$10 a barrel and, with the brief exception of the First Gulf War, stayed low for the subsequent two decades until 2000. Indeed, so low did they fall that in 1999 *The*

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Economist speculated that they might fall as low as \$5 a barrel. The ‘new’ conventional wisdom was now that low prices were the norm and that there would be few problems with supply. In response, developed countries embarked on a policy agenda suitable to a world of excess supply—privatization, liberalization, and competition.

The excess-supply world evaporated gradually after 2000, with oil prices rising to a peak of \$147 a barrel in early 2008 (not very different in real terms from the \$39 peak in 1979), then falling back sharply in 2009, before rising again past \$100 in 2011 in response to the Arab revolutions. It is now fashionable to get excited again about ‘peak oil’ and predict prices on an ever upwards trajectory, perhaps towards (or even beyond) \$200 a barrel. Security of supply is back on the energy policy agenda. The extra twist is that prices at this level would justify much of the low-carbon investment designed to meet the challenge of climate change. Even nuclear and offshore wind could look attractive with oil at \$200 a barrel.¹

Policy-by-oil-price-assumption has resulted in some spectacularly bad decisions, and there is little evidence of a learning process. Given the current assumptions, several questions arise. What substance is there to the current claims about peak oil and ever-rising prices of energy? How dependent are current policies on peak oil assumptions? And how robust are current energy and climate change policies to rather different outcomes? Put another way: are we running out of oil (and gas)? And hence is there no option but to switch to low carbon fuels? Or is the problem that we have too many fossil fuel reserves, and hence decarbonization will be relatively more difficult and expensive?

This paper examines these questions. Section II considers the peak oil hypotheses (there are many) with a view to establishing whether the current fossil fuel concerns are well grounded. Section III considers whether the focus on conventional oil (and gas) is appropriate and the extent to which technical progress has opened up the possibility of new fossil fuel reserves, notably more diffuse resources in shale deposits. Section IV considers whether, given the new resources, the nature of security of supply has changed, particularly in Europe with its dependency on Russian gas supplies. Section V considers the radical implications for climate change policy if fossil fuels are abundant. Finally, section VI sets out a more robust approach to policy design that takes account of oil and gas price uncertainty.

II. The peak oil hypotheses

There are many peak oil hypotheses—from claims about the physical geography of reserves, through to claims about the recovery rates and on to economic assertions about the price of oil. On the supply side, the claims are both about geology (physical constraints), about the behaviour of suppliers (insufficient investment, the exertion of monopoly power, and political instability), technology, and costs. On the demand side, the claims are about economic growth, population growth, and again about technical change (new ways of consuming energy, and energy efficiency). Peak-oilers claim that demand is going up, supply has peaked, or will do so quickly, and hence prices will rise (sharply and quickly in the populist versions).

¹ The ministers for the UK, Germany, and France advocate raising the EU target for carbon emissions reductions from 20 to 30 per cent for 2020 partly on these grounds. They state: ‘Rising oil prices would lower the costs of hitting any targets and, under some scenarios, the direct costs of hitting the 30 per cent target by 2020 actually turn positive’ (Huhne *et al.*, 2010).

Given such a diversity of claims and the complexity of fossil fuel markets (each of which has its own economic characteristics), it is hard to get a grip on the general arguments. There are lots of peak oil theories and lots of peak-oilers. Here the focus is on policy, and to give the policy context, consider the claim provided by the recent Second Report of the UK Industry Task Force on Peak Oil and Energy Security: *The Oil Crunch: A Wake-up Call for the UK Economy*, published in February 2010. It claimed that, ‘the next five years will see us face another crunch—the oil crunch . . . the era of cheap oil is behind us’, and went on to say: ‘We must plan for a world in which oil prices are likely to be both higher and more volatile and where oil price shocks have the potential to destabilize economic, political and social activity’ (UK Industry Task Force on Peak Oil and Energy Security, 2010, p. 4). The British Secretary of State for Energy and Climate Change, Chris Huhne endorses much of this as a core rationale for his energy policy. He stated that: ‘We will have a world where there may be lots of shocks, we may well have oil price rises which are similar to the ones that we had in the 1970s, a doubling’ (Huhne, 2010).

The literature on peak oil is vast and much of it is alarmist.² The aim here is to identify the main strands of the various hypotheses rather than to provide a comprehensive analysis—to identify the central building blocks and assumptions, in particular in respect of technology, substitution, and reserves. For analytical tractability, we examine supply and demand conditions separately, and then integrate to consider the dynamics of the oil and gas markets.

(i) Physical peak oil

Supply-side peak-oilers combine at least two propositions: first, that the earth’s physical supplies of conventional oils are well researched, and cannot support production beyond a ceiling (typically between the current output of less than 90m barrels per day and around 110m barrels a day—which tends to be the predicted demand for sometime before 2020); and second that the profile of a ‘typical’ field is replicated at the global level.

The starting point is geology, and this chimes with a wider environmental view that the earth is a fixed factor of production, which has (known) physical depletion limits.³ The claims are about oil; the analysis assumes oil lacks close substitutes. Oil is not part of a continuum, but a discrete commodity. There is only limited substitution between oil, conventional gas, unconventional gas, shale oils, and various types of coal. As a result, peak-oilers side-step the fact that the earth’s crust is riddled with fossil fuel resources by concentrating on only one specific conventional sort.⁴ We return to this assumption about non-fungibility below, which turns out to be critical for policy.

To get to a prediction about physical limits, peak-oilers require: geological survey evidence to estimate how much oil can be identified now; they need to make estimates as to

² There are numerous other examples of such alarmism—and associated calls for radical policy interventions. Stevens (2008) writes of the coming ‘oil crunch’, and airport bookshops are littered with titles like: *Confronting Collapse: The Crisis of Energy and Money in a Post Peak Oil World*; *The Coming Oil Crisis*; *Beyond Oil: The View from Hubbert’s Peak*. Though often dismissed in the academic literature, this sort of popularist material helps to shape expectations.

³ The Club of Rome in the 1970s set out this position and made what turned out to be a series of spectacularly erroneous predictions about the depletion of a host of minerals (Meadows et al., 1972).

⁴ See Lane (2009) on the conditions which facilitated this massive transfer of carbon from the atmosphere via photosynthesis to the earth’s crust.

what might be discovered; and they need to estimate how much of the known and estimated reserves may be recoverable. All these data are open to very considerable uncertainty.

The current ‘known’ reserves are ‘known’ to distinct and separate interests. These include the oil-producing nations and their energy agencies, the oil companies (national and independently owned), university researchers, and private consultancies. The information is of considerable strategic value. Particular difficulties are notable in hostile climatic contexts, such as the Arctic and Antarctic, in terms of reserves within existing fields, and in countries where state secrecy limits access (which happens also to be most producers).

For new reserves, the most immediately promising area is the Arctic, with the US Geological Survey recently estimating that perhaps an amount equal to a quarter of the world’s reserves may remain (US Geological Survey, 2008; Howard, 2009). For technical reasons, ice cover makes seismic testing more difficult, and it is only recently that the combination of warming, leading to ice-free periods making such offshore reserves accessible, and new sea-bed seismic technologies has encouraged greater scrutiny of potential reserves (Gautier *et al.*, 2009).

Why then is there so much ‘certainty’ about the physical ‘peak’? It is true that the technology for geological surveying is much improved. Great emphasis is placed on the (lack of) big new finds in the 1980s and 1990s. This purported to demonstrate that there would be no new Alaskas and North Seas, which had developed in the 1970s and 1980s. The implied assumption is that, even if smaller reserves may be discovered, geologists have already found the big ones (Campbell, 1997). The reply is that discoveries are endogenous to price, and the low oil prices for the 1980s and 1990s made much E&P uneconomic.

Contrary to the view of the peak-oilers, new reserves keep on being discovered (Lynch, 2002), with recent new finds in the Mexican Gulf and off Brazil. Promising findings off the Falkland Islands and new information from the Amazon basin give the chance of yet more discoveries to be added to the results of greater exploration in Russia. Even in the well-developed North Sea, new reserves are being found. The BP disaster in the Gulf of Mexico only temporarily limited offshore development. Onshore, the great success of the last decade has been in Africa, with, in particular, the emergence of Angola as a key supplier to the US and China.

A second encouragement to the ‘certainty’ of peak-oilers is provided by the work of Hubbert and his famous Hubbert Curve. He predicted the peak in US oil production, by generalizing from the depletion profiles of particular fields to the US as a whole. The calculation was relatively simple: he assumed that the US had been comprehensively surveyed, modelled particular field depletion, and then extrapolated to the US as a whole (Hubbert, 1971). Whatever the validity of his methodology, it gained traction because the prediction of the peak and the peak year turned out to be broadly correct. And if the conclusion was correct, it was natural—and, to policy-makers, seductive—to assume the methodology was robust. His followers have, indeed, extended this methodology (Campbell, 1997).

But Hubbert’s prediction is much disputed—and the shape of US production has not followed the path dictated by his curve. The ‘peak’ is only one statistical parameter—and it turns out not to be the most interesting. In particular, the tail matters.

Following Hubbert, peak-oilers take the yield from existing fields as given. It is typically assumed that a field will yield less than 50 per cent of its capacity. This, however, is only true if there is little technical progress and the costs limit extraction. Change these variables, and then the depletion level itself becomes a variable.

Put another way, at least half of all the oil extracted in the industry's history is still in the ground. Of more relevance for reserves is the depletion number—a small increase in the amount of oil extractable may have much more significance to total recoverable reserves than a new big oil-field find. As with abandoned coalmines, some combination of technology, costs, and price may make more of this recoverable. The importance of this point is that peak oil claims are ultimately economic ones—there is no relevant *physical* peak. Rather, it is argued that the *economics* of oil extraction dictates that only some (small) parts of the physical reserves are worth exploiting. Hence the claim that there is a production ceiling is based upon assumptions about costs—and these, in turn, rest on given (current) technologies.

In much of the peak oil literature, the scope for technical change in fossil fuel production is downplayed. Yet there is very little basis for this assumption: indeed, more resources have been devoted to fossil fuel technologies than renewables for some considerable time. The development of offshore oil is recent, spurred on by the OPEC price shocks in the 1970s. Much of this is not based on exogenous discoveries, but on investment. Looking ahead, it is to be expected that there will be significant results in the new areas of unconventional gas and shale oil, and in offshore E&P. Work on the Shtokman field off the northern Norwegian and Russian coasts, deep drilling off Brazil, and managing the conditions in Yamal are together likely to yield significant advances. The scale of the challenges faced by BP in the Mexican Gulf has led to a live experiment with frontier technologies. It has been a massive exercise in R&D.

The above considerations do not necessarily imply that resource depletion is unimportant or that it will not affect price. Rather, the point is to emphasize the uncertainty, and to highlight the extent to which the constraints are technical and economic, rather than about purely physical limits. There is no practical *physical* limit to the availability of carbon fuels. The policy implication is that predictions of an imminent oil Armageddon based on physical peaks in production (as suggested, for example, by the Industry Peak Oil Taskforce referred to above) should be treated with considerable scepticism by policy-makers.

(ii) Political peak oil

A second major strand of the peak oil case is that, having ruled out significant new discoveries, as depletion continues it is assumed that production will be increasingly concentrated in a small number of countries—in the Middle East and Russia. Although the latter is not a member, OPEC is assumed to become ever more powerful. So it is argued that, even if there is enough oil in reserves, politics will limit access. There will therefore be a 'political peak'.

It is implicit in this argument that OPEC is a unified organization of nation states; that it has market power; and can cooperate to exploit it. These are big assumptions: there is very considerable tension between Sunni and Shia states (notably Saudi Arabia and Iran) and the economic evidence suggests that market power lies—if anywhere—with countries with swing production. In the latter category, the only plausible candidate is Saudi Arabia (Kaufmann *et al.*, 2006; Hamilton, 2008).

Cartels are hard to run in almost any circumstances. The free-rider incentives are well known and tend to be pervasive. In the very short run, production cut-backs can have marked effects—notably the oil embargo in the 1970s and, more recently with the Libyan crisis. The corollary—quick releases from strategic reserves during the first Gulf War and after 9/11—had significant short term impacts, too.

Yet immediate political effects are often better thought of as volatility rather than trends driven by a controlling cartel. While it is true that the price of oil does not necessarily follow its production costs (and it is hard to deny OPEC has some market power), the limiting price is determined by: entry of new non-OPEC supplies; substitute technologies such as renewables; the problem of discipline for the cartel; and the internal revenue requirements of the producing countries. It takes time for new resources to be brought on stream—hence the short-run pricing power—but in the end they have been. The North Sea, for example, was rendered economic by the OPEC oil shocks of the 1970s.⁵

For members of OPEC, facing rapid population growth, budgetary constraints, revolutions, wars, and serious political challenges to most of their regimes, the temptation to cheat on output quotas is very great. Once the political and ethnic characteristics of each OPEC state (and Russia) are considered in detail, it is obvious that much divides OPEC, and that the political unity necessary to restrict oil supplies on anything other than a temporary basis is largely absent. Indeed, ironically it is OPEC's internal political conflicts—notably between Iran and its Gulf neighbours—that pose the greatest immediate threat to oil supplies. Add in the economic problems that the OPEC cartel faces—notably different costs, and lack of transparency and enforcement—and the surprise is that OPEC ever managed to act as an effective cartel. It is therefore unsurprising that the economic modelling of OPEC as a cartel has not produced clear-cut results (see *Almoguera et al.* (2011) in this issue).

Inevitably such pressures tell. In the next few years, OPEC will face the problem of accommodating the return of Iraq to world markets, a possible change of regime in Iran, the growing exports of Russia, and the growing roles of Angola, Nigeria, and Venezuela. Already Angola is a major supplier to China, and Africa ranks high as a source of US imports. Iraq is targeting a rise from 2.5m to 10m barrels by 2020—more than Saudi Arabia's current production—and Saudi Arabia has built in considerable swing capacity, in part a response to the growing political and military threat from Iran.

A quite separate argument is that from time to time there will be price shocks induced by the investment cycle—that oil price rises (and falls) are cyclical rather than structural. Since E&P takes time, it is influenced by expected demand and expected price. Departures from forecasts create gaps between actual supply and actual demand. For example, the low prices of the 1980s and 1990s led to a fall in E&P and part of the explanation of the rise in oil prices after 2000 is investment cycle mismatches. In effect, oil companies failed to predict the low prices and high Chinese growth rates and their impact on demand (*Stevens, 2008*). Now, with GDP in developed countries much lower than it would have been conventional to predict up to 2006, the 'surprise' potential may be on the downside.⁶

(iii) Demand and peak oil

Peak-oilers combine a pessimistic view about supply with an optimistic one about the growth of the demand for oil. The short-run inelasticity of demand implies that price shocks take time to dampen down demand, while the long-run demand is driven up by macroeconomic factors

⁵ Indeed, from an economic standpoint, the much less expensive reserves in the Middle East should be depleted first, rather than after the North Sea.

⁶ In the British case, GDP in 2010 is between 10 and 15 per cent below what might have been predicted in 2006—a fall of 5–6 per cent and a shortfall from the expected growth of 2–3 per cent per annum.

and population growth. Energy efficiency's contribution is argued to be insufficient to hold back the tide.

At the core of this demand optimism is China (and to a lesser extent India). Recent energy demand growth, backed by consistently high economic growth rates which double the size of China's economy every decade, is extrapolated forward. With an implicit assumption of no technical progress (other than energy efficiency trends) and little fungibility of gas and coal for oil (or significant renewables), a demand crunch is forecast. Whatever the validity of taking a more relaxed view about supply constraints, the relentless march of China's (and India's) demand for oil is argued to be overwhelmingly dominant.

China matters not just because of its size, but also because its growth is energy (and carbon) intensive, whereas developed countries have tended to see a gradual reduction in their energy intensities, breaking the link between economic growth and energy demand growth. That has been a reflection of the move from manufacturing to services as the location of energy-intensive industries has shifted to the developing countries.

To make the peak oil argument stick, China's growth has to be treated as exogenous. Yet there is some reason to think otherwise: that the growth of China has been driven by exports, as had Japan's growth in the 1960s, 1970s, and 1980s. The demand for China's exports has come overwhelmingly from the US and Europe (together comprising some 50 per cent of world GDP). Consumers, in turn, have driven that demand. In effect, US consumers have bought Chinese goods, and then China (like Japan before it) has lent the US the money to pay for them. The US has, as a result, experienced widening internal and external deficits, and consumers have not saved but borrowed. Loose US monetary and fiscal policy, and Chinese growth are linked, and Chinese growth has driven up the demand for oil, causing the increase in world oil prices, resulting in the \$147 peak. In other words, US macroeconomic policy has contributed to that oil spike.

This, however, is not a one-way process. The economic crisis from 2007 onwards has caused a sharp reversal of demand, and this only gradually followed through into the demand for oil, given the inelasticity of short-term demand. The initial demand drop in developed countries fed through into lower economic growth in China and India. But the response in both the US and China has been radical: simultaneously to use both monetary and fiscal policy on an unprecedented scale to hold up demand. Interest rates in the US and Europe have been close to zero, in the US, over 12 per cent of GDP was borrowed and spent, and in China, the government embarked on a large-scale infrastructure spend to offset the sharp falls in exports.

The consequence of these macroeconomic policies has, at least in the short term, been a return to growth of world energy demand. However, the robustness of this resumption is far from obvious. The Keynesian macroeconomic policies of boosting demand through unprecedented borrowing, combined with loose monetary policy, cannot last. Saving rates will have to rise and Keynesian expansions are already being replaced by fiscal consolidations. The impacts on demand are being felt in Europe, and in due course the US will have to rebalance. It is likely that such structural changes will have an impact on oil demand. China's energy demand growth should not be taken as a given.

A further change on the demand side has been energy efficiency. Numerous studies have identified the scope and scale of energy efficiency potential, and, indeed, many climate change policies rely heavily on this aspect of demand. Europe has a target of 20 per cent improvement in energy efficiency by 2020 (Commission of the European Communities, 2008a), and China and India both pledged in the Copenhagen Accord to make substantial progress (Commission of the European Communities, 2010).

At the global level, the scope for energy efficiency measures to reduce the growth (and level) of demand has been variously estimated (World Energy Council, 2008). In Europe, the Commission estimates that in consequence demand will be flat through to 2030 (Commission of the European Communities, 2008b). In the UK, the Department of Energy and Climate Change (DECC) has suggested that the demand for energy might actually fall, (DECC, 2009). These estimates for energy demand impact primarily on electricity and gas, and less on oil.

There is, however, one trend on the demand side which points in the other direction—towards greater demand. The world's population is forecast to rise from 6 to 9 billion by 2050, and much of this increase will be in countries with high economic growth, and high-energy demands. Of the extra 3 billion, roughly 1 billion will be in each of China, India, and Africa.

The combined heating and food requirements of all these extra people—equivalent to the entire world's population in 1950—will place considerable pressures on energy reserves. These pressures need to be placed in context. Hamilton (2008) notes that China used about 2 barrels of oil per person, while the US used 25 barrels per person. This reflects transport—in 2006, there were 3.3 passenger vehicles per 100 Chinese, compared with 77 per 100 Americans. Projecting forward Chinese vehicle demand, the IMF's 2005 *World Economic Outlook* estimates 387m vehicles by 2030. The overall impact on energy demand cannot be ignored.

(iv) Bringing supply and demand together: economic peak oil

The third strand in the peak oil case, combining the demand and supply sides of the argument, is that: *because* oil production would peak and then decline, and *because* demand for transport and therefore oil will continue to rise, (inelastic) prices will inevitably go up—and, indeed, for many peak oil advocates, the price spikes will be sharp, and some argue that there will be a sort of economic Armageddon as a result.

There are, indeed, good reasons to think that as a non-renewable resource is depleted, the price will rise and that, in the absence of substantial storage, the price may become more volatile, too. Hotelling (1931) famously set out this effect. But Hotelling's model has no substitutes, so the resource scarcity can only be reflected in the price. Supply is assumed to be finite (and competition is perfect). If oil is non-renewable, and non-substitutable as an energy source, then if the peak-oilers are right about the reserves position and the growth of demand, then they are right to predict rising prices.

But the non-substitution assumption is only appropriate in the short run (when the capital stock—and technology—is fixed), whereas Hotelling's effects in oil markets are longer term. As the oil price rises, peak-oilers conveniently forget the dynamics: a rising price of oil incentivizes R&D and E&P. The history of the discovery of reserves and greater extraction from existing reserves has been driven by price—as, indeed, has the development of unconventional gas and shale oil. The current major R&D programmes in renewables reflect this, too—with the added incentives of a carbon price and subsidies.

As the incentive to develop substitutes gathers momentum, there is a balance between conventional oil and gas and unconventional oil and gas, and between both and low-carbon technologies. If the substitution happens fast, then the demand for oil and gas falls, and price falls back, too—rendering the new technologies less economically attractive. If, on the other hand, the oil price is driven up fast, then the search for substitutes accelerates. The equilibrium price of oil is, therefore, one that balances these two countervailing forces. What

fatally undermines the peak-oilers' case is fungibility and substitution on the supply and demand sides. Relax Hotelling's assumptions, and the oil price will not necessarily rise in the long run (when technology changes). And it happens that technology has changed—with radical results which comprehensively undermine the peak oil concept.

III. Fungibility, substitution, gas, and coal

The peak oil argument rests on limited supply and expanding demand, all based on existing technologies. The next step in unpacking the peak oil argument is to relax the technological constraints—in particular, allowing for substitution between fossil fuels to satisfy the assumed growth in demand. As gas reserves have multiplied, and as the prospect of the electrification of transport has grown, the underlying assumptions about both supply and demand are gradually being turned on their heads. Abundant gas may increasingly provide the fuel for electricity generation, which in turn may displace oil in transport.

(i) Shale gas and the other fossil fuels

While peak oil advocates have concentrated on conventional oil, there has in the background been a quiet but profound revolution going on in gas. The importance of gas has grown slowly. Up to 1990 it was regarded as a premium fuel, to be conserved for use primarily in the industrial sector, notably in petrochemicals. In Europe, it had been effectively illegal to burn gas in power stations. But with the coming of North Sea gas and the development of Russian natural gas supplies, gas stepped up to become the fuel of choice for new power stations. Liquefied natural gas (LNG) gradually developed, too, but its higher costs initially limited its role to those countries isolated by geography from pipeline supplies. Elsewhere, competing pipeline supplies constrained its development.

Shale gas has been known about for a long time: what is new are the technological breakthroughs which enable it to be extracted at relatively low costs in considerable volumes—perhaps costs even lower than those of natural gas in the US.

The technological developments have been threefold: the ability to drill horizontally at considerable depths; the IT capacity to model and direct the drilling at depth to seek out pockets of gas; and the ability to fracture the rocks so that the gas can flow. The first two developments have been around for some time, notably in conventional oil and gas. It is the third which has been the breakthrough.

Technology now makes the very considerable shale gas reserves accessible. These are very widely distributed and, importantly, are to be found in the US, China, and Europe in considerable volumes. Deposits are expected to be found wherever there is natural gas and conventional oil—and many additional locations, too. The US has been first to exploit these opportunities commercially—already the US produces a significant amount of its total gas from shale deposits. The impacts have been remarkable: reserves in the US are now estimated to be sufficient to produce gas for 100 years at current consumption rates. World gas reserves have doubled in the last year. Companies have been quick to react: more than £100 billion has been spent on shale gas options in the first half of 2010 in the US and Europe—as much as the estimated total cost of the UK's offshore wind developments through to 2020.

The implications for prices are already being felt: the US is, in effect, ceasing to be a gas importer, so that LNG capacity built with US demand in mind is now effectively redundant. The excess LNG capacity that results at the global level, therefore, has to find other markets—including Europe. Europe no longer faces US competition to attract LNG tankers—and the short- and medium-term price is therefore weakened.

The impact of shale gas does not, therefore, depend upon European resources being developed. Europe appears to have abundant deposits of shale gas, but the environmental and political constraints are likely to slow its development. The deposits stretch from Poland through the north European plain to the North Sea and Britain. Shale gas's demands for water and concerns about water tables will require detailed environmental assessments. More constraining will be access to land and planning issues in respect of the multiple drilling that shale gas necessitates.

For Poland, these constraints are likely to be weaker than in the west. Poland's current electricity industry is over 95 per cent dependent on coal, and it is very exposed to climate change policy measures. The obvious strategy would be to switch to natural gas, but that requires reliance on Russia in a context within which the Nord Stream pipeline has been deliberately built outside its borders, between Russia and Germany. Given Poland's terrible historical experiences with its neighbours, energy independence has a much greater resonance than for most other EU members. Its potentially very large shale gas deposits therefore represent an alternative, which has attracted international oil and gas companies, and which is likely to be developed over the coming decade. Other European countries are likely to follow at a somewhat slower pace.

Though shale gas has gained the most attention, it is not the only unconventional gas affected by technical change. Coal-based methane has historically been used in a number of limited applications. It has been difficult to extract in volume and to transport. However, as with shale gas, new technologies are beginning to transform its prospects. Liquefying coal-bed methane offers an alternative source of LNG, with Australia the leading country in developing the technology commercially (Arrow Energy, 2010). Up until now, such a project would have been almost inconceivable. Tight gas—gas in sandstone—adds to the supply picture.

Finally there is unconventional oil—not only tar sands, but shale oil. The scale of tar sand deposits is well known, and its costs are such that an oil price of around \$70 a barrel is typically assumed to be necessary for its economic exploitation. If the peak-oilers are right about price spikes and trends, large quantities would become economic. Shale oil is only now being developed on a large scale in the US. Bartis *et al.* (2005) suggest that US resources of shale oil may be capable of meeting a quarter of US current consumption for 400 years.

(ii) The growth of coal

Alongside the growth of gas, coal not only continues to play a major role in electricity generation, but has been growing in terms of its share of world energy demand. This growth has been driven in large measure by China and India, though coal remains a major fuel source in the US. It is widely distributed, its costs are known, and coal-based power station technology is well understood.

The growth of coal has continued during the period of the Kyoto Protocol, and it accounts, too, for much of the growth of emissions. As energy-intensive industries have moved to China from the US and Europe, the coal-based electricity industrial production has more than offset the slower emissions growth in the developed world. China's plans for around 1,000

GWs of new coal by 2030 have hardly been affected by the economic crisis. The carbon intensity of world GDP continues to rise.

(iii) The continued growth in the importance of electricity

The link between the abundant supplies of gas and coal, and the demand for oil is via electricity. Electricity's importance has been a growing trend in world energy markets. Electricity concentrates power in a targeted way to applications which increasingly require precision. New IT-based technologies, in particular, reflect this trend. There is no reason to expect this comparative advantage for consuming energy as electricity is going to abate—indeed, it is likely to grow.

The march of electricity has been going on for a century. In heating, electricity displaced open coal fires, oil, and town gas, only itself to be challenged by natural gas at the end of the twentieth century. The coming of electrical appliances gave electricity a boost in households and offices, followed by the new IT. Industry processes, such as steel, coal mining, cement, aluminium, and chemicals, switched in significant measure from coal to electricity, again with competition from natural gas. The competition for heat is now turning back in electricity's favour. Heat pumps and air conditioning are liable to dominate household demand and office space. But it is in transport that the competition—and fungibility—with oil is likely to be most important.

(iv) Transport and oil demand

The development of the oil industry has been closely linked with transport, which has become the most oil-specific application. Cars, lorries, aviation, shipping, and, to a considerable extent, trains have been almost exclusively reliant on oil. Hence, as long as this relationship remains, and transport is an essential infrastructure in inelastic demand, oil could be treated as a discrete demand.

Peak-oilers point to the trends in transport—and, in particular, to the growth of the car in China—as evidence that demand for oil will continue to expand. The numbers are, indeed, stunning. Projections of car ownership in China through the next few decades are dependent on the continuation of the fast economic growth rate. As noted above in section II(ii), estimates by the IMF suggest that 387m cars will be added to China's roads by 2030 (IMF, 2005). If these cars are assumed to be conventionally fuelled, then the translation into oil demand is straightforward, with the result that within quite wide ranges of estimates of conventional oil supplies, demand outstrips supply, with inevitable sharp price rises.

This relationship is, however, not one bounded by science and technology—it is a response to abundant and cheap oil. Any fossil fuel can, in principle, provide energy for transport, and the electrification of cars is likely fundamentally to change the arithmetic.

Electric cars are not new: the ability to apply electric power to wheels has been known since the very origins of electricity generation. The changes have come in designing electric cars which can achieve high speeds, batteries which increase the range of car mobility, and hybrids which combine electric mobility with conventional petrol engines.

There are two main challenges to greater market penetration of electric cars: batteries and infrastructure for charging them. The problems of batteries are: weight; range; sources of the core components; and cost. Regarding weight and range, these problems mirror those with the development of mobile phones and portable computers. Neither the mass market for

mobiles or for laptops would have been feasible without a revolution in battery technology. For cars, these issues are the focus of major R&D. The core components—notably lithium—are not scarce, though some easy and cheaper sources may have limitations. Other sorts of batteries may—or may not—displace lithium-based batteries (King, 2007).

In terms of infrastructure, existing electricity networks help a lot. In addition, electric cars bring a major benefit to the electricity systems—they provide storage. Particularly in the context of intermittent electricity generation—for example, from wind farms—this storage has considerable value, and in turn needs to be set against the costs of electric transport. Extensions of networks will also have benefits on core electricity applications beyond transport, notably in a context in which electricity networks are moving from a passive to a smart mode. Smart meters combined with electric cars will have considerable synergies.

Hybrids provide a transitional (or even permanent) way of applying electricity to transport. The advantage of hybrids is that they can be deployed before a comprehensive network is in place, and before batteries can solve the range problem. Indeed, for more remote areas and in developing countries, hybrids may be essential to facilitate any application of electricity. The use of hybrids also impacts on fuel efficiency, which in turn reduces oil demand growth.

(v) The implications for peak oil

Given that there is no physical shortage of fossil fuels, peak-oilers have to rely on demands for energy which rely overwhelmingly on oil. For practical purposes, that means transport. Peak-oilers assume that oil is essential to transport, and will not be substituted by other fossil fuels (or indeed other non-fossil fuels). The prospect of the electrification of transport undermines this claim. The electricity can be produced by abundant gas (and coal), and shale gas pushes aside any serious notion of ‘peak gas’.

The implication is not just that the peak oil claims should be largely dismissed, but rather a very different perspective. It is wrong to assert that we do not have enough oil—or fossil fuels. On the contrary, we are awash with fossil fuels; we have too much, not too little. On oil, we may eventually leave quite a lot of it in the ground as electricity gradually takes over, generated in large measure by gas in the coming decade. The chances of running out before the predicted dangerous climate change occurs are quite low. The policy implications—for security of supply and for climate change policy—are considerable.

IV. Energy security policies without peak oil

For much of the 1980s and 1990s, cheap energy and abundant supplies were not only the norm, but were increasingly assumed to be a permanent fixture in the energy landscape. In the 1970s and in the mid-2000s, the opposite case prevailed, and the conventional wisdom assumed it would be permanent.

Unsurprisingly then, in the 1980s and 1990s, energy security simply did not much matter. And when it did—for example in the Iraqi invasion of Kuwait—the world’s only superpower (following the implosion of the Soviet Union) could be relied upon to deal with the fall-out.

From 2000, the energy paradigm did, indeed, begin to change (Helm, 2007), in large measure as a result of policies that neglected energy security, and as a result of the collapse in E&P by the oil companies, which shared the common assumption that oil prices would stay low. This cyclical investment effect, combined with the impact of loose monetary and fiscal

policies in the US inducing the growth of Chinese demand, created a mismatch between supply and demand.

The gradual rise towards \$147 caught oil companies and governments on the hop. Only when the price climbed more steeply, creating an element of crisis, did governments begin to react. Supplying countries flexed their muscles in the short term as their revenues kept improving, and as customers courted their attention (notably with the arrival of China). Russia played its oil card with Belarus and Lithuania, and its gas card with Ukraine. Suddenly energy security moved from a fringe interest to a main concern. Governments began to issue papers on security (e.g. Wicks, 2009) and the EU got in on the act (Commission of the European Communities, 2006, 2008b).

Concerns about oil and oil prices were compounded in Europe by its growing gas dependency. For Europe, Gazprom's monopoly was particularly problematic: dependency on Russian supplies grew, pipeline bottlenecks (notably in the Ukraine) created specific vulnerabilities, and the rapid depletion of the British North Sea reserves created first a boom and then a market tightening. In 2006 and then again in 2009, the Russians interrupted supplies through Ukraine, while, as noted above, the Germans and the Russians got together to build the Nord Stream pipeline round the outside of Poland, and German, Italian, and French companies supported Russia's South Stream pipeline. Meanwhile Europe dithered over its rival to South Stream, the Nabucco pipeline, which would have provided supplies from the Caspian independent of Russia. The dependency was further exacerbated when the North African gas suppliers entered into discussions with Russia with a view to creating what some called a 'gas OPEC'.

Understandably, there was some alarm at the prospect of the Russian 'bear hug' on European supplies and its willingness to exploit market power via Ukraine. But for the economic crisis, gas prices might have moved sharply upwards, and Europe's drive for an element of energy independency (or rather less dependency) through a combination of new coal generation, nuclear, and renewables would have been justified in the face of monopoly power. Gas might not be 'peaking', but it appeared to be politically constrained.

Broadly, this remains the European policy position. It is the view expressed by the leading energy and environment ministers and by the European Commission (Huhne *et al.*, 2010). However, the facts have changed. The economic crisis has lowered demand and the projections for future demand. Gas prices have fallen. The gas-oil price link has weakened. Ukraine has become much more Russia-friendly, with the Orange Revolution a distant memory and aspirations to NATO membership abandoned. Near-term fears on both prices and quantities have dissipated.

But the bigger changes have been medium to longer term. Dependency on Russian gas has been radically changed by the coming of shale gas in the US and prospectively in Europe, too. This does not mean that security of supply no longer matters, but it does change the context and hence the design of policy.

Security of supply is about both price and quantity: as capacity margins tighten, the price tends to rise, and insecure markets display considerable volatility. For most economic activities, the cost implications of energy security are asymmetric: if the market is undersupplied, the costs to the economy tend to be large; but in conditions of oversupply, the costs of the capacity margin are spread more generally across the economy.

It is, however, beyond the scope of any single consuming country to have much impact on the overall market price of oil, gas, and coal. The price is given. It is also hard to predict—the history of energy price forecasting suggests that error even in the short run can be

considerable. Trying to manage the oil price explicitly does not enhance security of supply. However the scope for policy to influence the *volatility* of the market, and to ensure against physical interruptions of supply, is considerable. Governments can also help to shape the energy networks and set their taxes in a way that does not exacerbate price volatility.

So what can governments do about security of supply? There are four broad options: holding strategic reserves and storage; influencing the physical infrastructure; diversifying the sources of supply and the energy mix; and adjusting taxes inversely to the oil price. Only the latter depends upon the oil price and, as we shall see, it is reactive and does not require a forecast.

(i) Strategic reserves and storage

Security of supply is a public, not a private, good. It has two dimensions: price and quantity. Typically, as supply conditions tighten, the price rises and thereby rations off demand. It is only at the limit that quantity constraints apply—and almost always as a political rather than a market constraint. Thus an aim of security policy is not only to hold stocks and reserves for emergencies when there is a physical interruption, but also to hold sufficient supplies in order to maintain a margin—to keep supply ahead of demand.

The requirement to hold strategic reserves of oil, brought in with the creation of the International Energy Agency (IEA) in the 1970s, has had three effects: the very presence of the reserves provides a constraint on OPEC, in that embargoes take time to have their full impact (in a context in which the international pressures are brought to bear quickly in the context of a crisis); the reserves can be released in the event of a physical interruption; and they can be used to head off or ameliorate price spikes. Gas storage and reserves have similar effects: in the 2006 and 2009 Russian interruptions of supplies through Ukraine (another politically driven shock), the presence of large reserves in Ukraine enabled that country to survive for a considerable time, but the absence of much storage in the UK led to considerable price volatility.

Strategic reserves do, however, create an overhang in the market, and because security requires an element of excess supply, in the absence of a payment for providing this service, the effect will be to drive prices down so that the marginal cost is below the average cost. As a result, strategic reserve requirements may be counter-productive, reducing investment. In the gas case, this matters particularly, given the price is determined by regional pipeline suppliers, capped off by the LNG price. In oil, the effects may be somewhat weaker, in part because the marginal costs vary very greatly, and the price is typically above these costs. Taxes also play a significant role.

Therefore a strategic reserves requirement needs to be paid for. It is, in effect, a compulsory insurance policy provided by companies on behalf of customers, and a security or capacity payment is the appropriate mechanism. But because it is a public good, with a zero marginal cost to the customer, some form of averaging is required. In a security/capacity market, the options to shed demand on notice in the form of interruptible contracts, and variants of demand-side management can also contribute to the security cushion.

Ameliorating price by releasing reserves is the most controversial aspect of these sorts of measures. It is unavoidable, since rising prices is one of the ways in which insecurity is manifest, but it is also open to political and regulatory market manipulation. As a consequence, a rules-based procedure, backed up by independent institutions, is a requirement of a well-functioning mechanism. Unsurprisingly, countries are unwilling to cede much control over the release (or more importantly, restraining the release) of reserves

and this remains a significant weakness in the IEA oil system and is one of the reasons the EU has found it difficult to develop a strategic gas reserves regime.

Defining the reserves margin is crucial to the design of the mechanism. In particular, a key requirement is that the margin is independent of the price—and the price forecast. Low prices indicate that the security concerns are weak, but they also point to a low stock-holding cost. Furthermore, low prices may indicate that investment and E&P are correspondingly low, too (as at the end of the 1990s), and hence they may be predictors of problems to come.

The trigger for the release of stocks includes obvious shocks. In the oil case, examples include wars (the first Gulf War), terrorist attacks (9/11), and natural disasters (Hurricane Katrina). In the gas case, supply interruptions (Ukraine 2006 and 2009), pipeline failures, and extreme weather would qualify. The difficult case comes when there is no explicit event or shock, but prices rise sharply. This might include speculative bubbles (as argued by some in respect of the last stages of the rise of the oil price to \$147), or simply temporary supply/demand imbalances.

Creating rules and enforcing them for responses to non-shock induced price volatility has many of the features that would be displayed in long-term contracts and translated through into implicitly or explicitly regulated supply tariffs. In principle, it could be achieved through a requirement in respect of the contract durations in the market, but in practice the very existence of the reserves would have a role to play. It is here that the rules and institutions matter greatly.

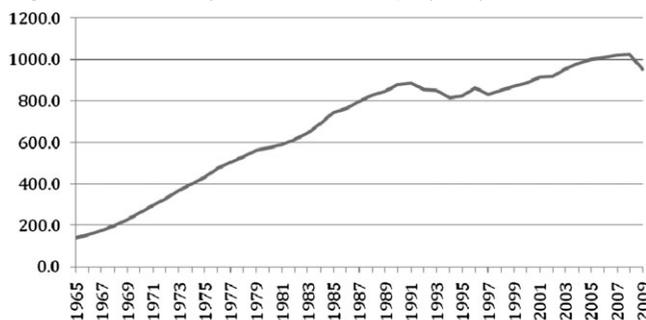
Security of supply, however, has costs, and these will vary according to the availability of reserve assets—empty gas fields, salt caverns, and storage tanks. By reflecting system security in a market for this insurance, the price is revealed, and this provides a basis for evaluating it against the costs of interruptions and price spikes. These sorts of calculations have to be done by governments and public institutions, and they will always be very approximate. Transparency, however, allows debate and evidence to be brought to bear.

(ii) Infrastructure

The second security measure independent of price forecasts is the infrastructure. Oil and gas require pipelines, terminals, refineries, distribution networks, and shipping. Some of this is defined in specific assets, but much of it is in networks. Markets tend to under-supply these networks, in order to extract monopoly rents and because they are public goods. Interconnection brings competition and third-party access—threats to monopoly—and the excess capacity in networks encourages marginal cost pricing for transit, undermining the recovery of the sunk and fixed costs. Pipelines typically have high fixed costs and low marginal costs.

The network characteristics are especially important in pipeline gas. Almost all national natural gas networks are heavily regulated in terms of access and charges, and most have been built with at least implicit government involvement. Long-distance pipelines between countries are inherently political. Examples include the monopolization of Gazprom's Russian pipeline system and its attempts to buy control of downstream pipelines in Europe, the problems for Europe in developing the Nabucco pipeline, and the overt politics of the Nord Stream pipeline between Russia and Germany.

In both oil and gas, ensuring that the market provides the appropriate infrastructure is an important element of energy policy and, as with the strategic reserves, it should be

Figure 1: Growth of gas demand in Europe (Mtoe)

Note: Mtoe is million tonnes of oil equivalent.

Source: © BP Statistical Review of World Energy, 2010.

independent of price forecasts. Indeed, since energy infrastructure tends to last for decades, price forecasts are largely irrelevant. From the private perspective, the risks are that it will not be used—overtaken by shifts in demand or by technical progress. Hence there is a reluctance to build, for example, new oil refineries if transport might be electrified, or if demand might be lower for macroeconomic reasons (a growth rate of 1 per cent per annum GDP over three decades is very different from, say, 3 per cent). In consequence, it is perhaps not surprising that it is governments in China and the Middle East which are building new refineries, not private oil companies in the US and Europe. The result is an obvious gap which the US and Europe will need to address.

(iii) Diversifying the sources of supply and the energy mix

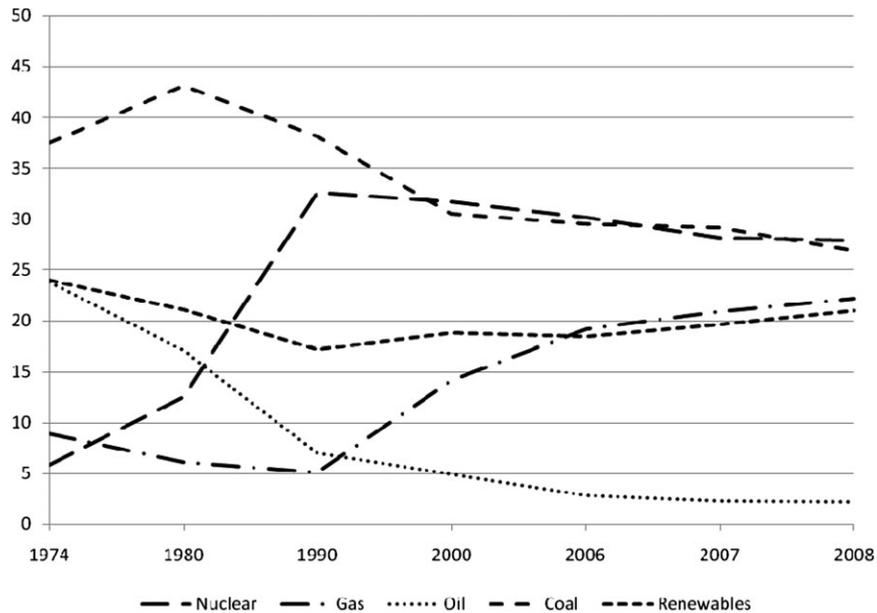
The individual decisions of energy companies are unlikely to deliver the optimal diversity of supply. This—as with the capacity margin—is a system public good. Thus there is a role for energy policy—irrespective again of the price level—to encourage diversification at times when the market becomes dependent on a single fuel or course of supply.

Diversification policies are, however, fraught with difficulties and open to lobbying and capture. Often they result in governments’ ‘picking winners’ in technology terms—such as renewables. In terms of oil and gas supplies governments do rule out some options (such as Iran) and encourage others (such as Nord Stream). In these circumstances, oil and gas supplies become part of foreign policy.

(iv) Taxes and prices

The fourth element in security of supply which is independent of price forecasts (but, in this case, not price) is the design of oil and gas taxes. Energy taxation is pervasive: the inelastic demand for petrol is, in particular, a major revenue target for governments.

The setting of such taxes tends to follow two objectives: upstream it is designed to manipulate E&P; and downstream it is about the revenue requirements within the public finances. In neither case is the market price taken into account *ex ante* (though there may be *ex post* adjustments). The result is that taxes set as a percentage of the price tend to exacerbate price fluctuations, on both the upstream and downstream sides. This, in turn, reduces the

Figure 2: Share of gas and other fuels in electricity generation in Europe (percentage of total)

Source: IEA (2010b).

efficiency of the price signal in these energy markets, and it can also destabilize the public finances.

These impacts matter in the normal course of energy markets' behaviour, but they become even more important when it comes to consideration of climate change and carbon taxes, where the aim is to incentivize a switch from high- to low-carbon technologies, to which we turn in the next section. The general point is that security of supply is enhanced if energy taxes are set by some rule inversely to the oil (and gas) price, providing a cushion to price spikes, a floor to price collapses, and a more stable revenue flow.

The various peak oil hypotheses have no impact on the rationale or design of any of the first three of these security-of-supply policy measures. Each is independent of price forecasts, and each relies on the market price (whether on the peak oil upwards path or not) to signal the underlying scarcity of resources. Energy security policy is appropriate to address the public-good aspects—storage, infrastructure, and diversity. On taxation, the peak oil hypotheses point to very high prices and, hence, for any revenue requirement, to lower tax rates.

Where the peak oil forecasts do, however, matter—and where belief in them is potentially most damaging—is in respect of climate change policy and the interventions necessary to encourage a switch from high- to low-carbon technologies. It is to this we now turn.

V. Climate change policy with abundant cheap fossil fuels

The peak oil narrative describes a future in which oil runs out and, in the process, prices rise sharply. It is a world of high and rising prices, and because the market is ever tighter, price volatility is high, too.

Figure 3: United States shale gas plays

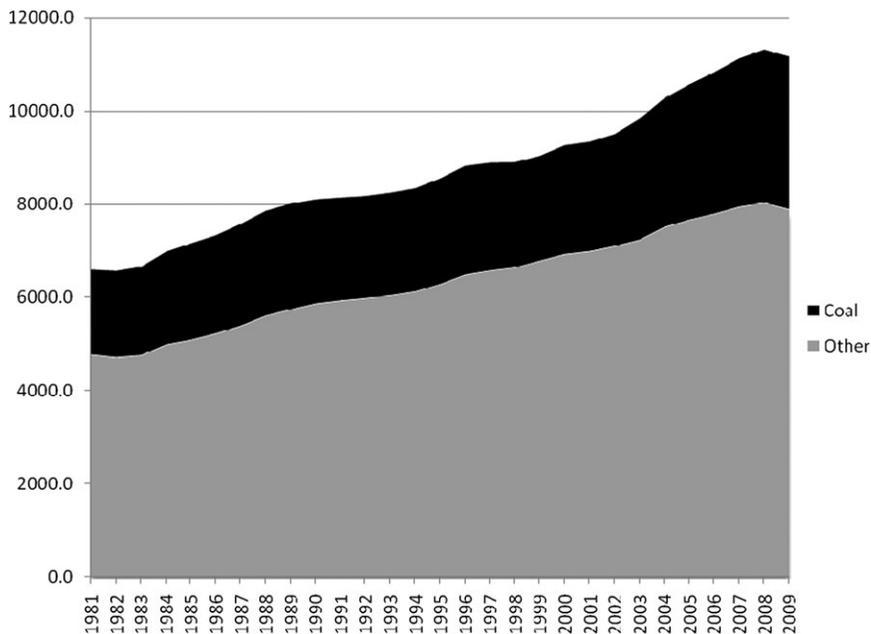
Source: US Department of Energy, *Modern Shale Gas Development in the United States*.

The narrative has been enormously helpful to non-governmental organizations and vested interests intent on capturing public policy. If we face an energy Armageddon in the future, we have to switch away very rapidly from oil and gas towards, for example, renewables and nuclear. Given, too, the imminent realization of the consequences of peak oil, governments should intervene directly and radically, setting targets for non-fossil fuels and the associated investments.

Politicians might understandably balk at the costs that this radical switch might involve, but here the peak oil narrative helps, too. If the oil and gas prices are going to be high and rising, then the relative price of renewables and nuclear will be correspondingly lower. Indeed, on some peak oil price forecasts, the non-fossil fuel technologies would be economic in their own right. It follows that the voters can be told that the costs of the transition from fossil fuels are low.

This is, indeed, what has happened. The advocates of renewables and nuclear have typically used a high oil—and, importantly, gas—price forecast to estimate the costs of the transition (together with a host of other, often optimistic, assumptions about cost levels and trends for particular preferred technologies). The Stern Review (Stern, 2007) relies on such assumptions to support its claim that decarbonization can be achieved at a cost as low as 1 per cent GDP per annum—the number from the Review most widely quoted by politicians across Europe (Helm, 2009). It helped greatly to gain political acceptance for the 2008 EU climate change package—with its catchy 20-20-20 targets. In particular, member governments accepted the 20 per cent renewables targets on the basis of cost estimates which are already questionable (especially in the UK).

In the British context, DECC has taken this line. In the DECC Annual Energy Report in 2010, explicit reference is made to the predicted rising and volatile oil prices: ‘With the UK’s own oil and gas resources declining, unless we act now, we will become more vulnerable to high and volatile oil and gas prices’ (DECC, 2010).

Figure 4: Growth of coal in world energy demand

Source: © BP Statistical Review of World Energy, 2010.

Contrast this with the more difficult politics and policy implications if the peak-oilers turn out to be wrong, as has been argued in section II. Suppose for a moment that we are about to enter an age of cheap gas and the electrification of transport, backed up by the continuing upward trend in the share of coal in world energy demand (based on practically limitless supplies). The gas price would decouple from the oil price, and unconventional gas would provide a price ceiling. The oil price would ease back as gas competition intensified for chemicals, electricity generation, and industrial uses, while the gradual electrification of transport would eat away at oil's premium market. Coupled with increased supplies from Iraq in the short to medium term, limited by the availability of tar sands, and undermined in the medium to long term by the abundance of Arctic and other new supplies, the oil price might remain weak, perhaps even falling away in a couple of decades or so. Current conventional oil and gas forecasts, like those made by the famous peak coaler, Jevons, in the nineteenth century about the prospect of running out of coal, may turn out to be very wrong (Jevons, 1865).

The impacts on climate change policies would be radical. The relative cost of renewables and nuclear would be (much) higher, and the short- to medium-term emissions reductions might come from the switch from coal and oil to gas. Without policy intervention, the share of fossil fuels would remain high, especially in developing countries.

(i) Cost implications of low-carbon transition from low oil and gas prices

Though politicians—and the Stern Review—have made a point of stressing the low costs of decarbonization, it is important to realize that these estimates are based upon forecasts not

just of the (falling) costs of low-carbon technologies, but also the costs of fossil fuels. Indeed, alongside the cost of capital for what are typically long-lived sunk- and fixed-cost dominated projects, the oil, gas, and coal prices are the key determinants. In particular, cost estimates are relative, not absolute.

To see how important the fossil fuel price is, consider a wind farm project. It has high fixed and sunk costs, and produces intermittent power at a low marginal cost. A nuclear power station has similar characteristics but also has a long construction period. By contrast, a gas power station is quick to build with a less stark ratio of fixed to variable costs. The price of the fuel—gas—is clearly much more important to its overall cost structure than is the cost of wind to the wind farm. The cost of capital determines how quickly the price of electricity relative to the low marginal costs in the nuclear and wind farm examples has to recover the fixed and sunk costs.

It is currently estimated that a new combined-cycle gas turbine (CCGT) is significantly cheaper than either of these non-carbon technologies. Now consider two cases: the gas price doubles and the gas price halves. In the first case, offshore wind would still need a subsidy, but nuclear begins to become cost competitive. In the second case, both technologies need considerable subsidies. Furthermore, uncertainty about the future price of gas increases the cost of capital more than proportionately to the wind farm and nuclear power station. For, if the gas price increases, the CCGT can reduce its running time, whereas the wind farm and nuclear plant cannot. The CCGT is flexible, and given that the ratio of fixed to variable costs for the CCGT is more benign, the overall consequences to the economics of the project are more limited.

This dependency on the price of fossil fuels has very important implications for the design of support mechanisms for low-carbon technologies—but only if there is a risk that the price will be low, and hence the peak-oilers are wrong. If they are right, then there is only a limited need for intervention, and as the peak is reached and prices rise, supports can drop away. In particular, in a peak oil world, any support for low-carbon technologies should be time limited, and the longer term (including R&D) should largely take care of itself. The key incentive mechanism in this context is the price of carbon.

(ii) Policy instruments and low prices—the carbon tax

The general case for a carbon price is well known: carbon is an externality and unless it is priced it will be over-produced. Using regulation requires much greater information for regulators, and is much more open to rent capture (Helm, 2010). The choice between price and quantity measures is complex and much debated. In theory, the issue turns on the relative slopes of the cost and damage functions; in practice, the permit schemes tend to be much more open to capture.

In both cases, the price of carbon comes in two parts: the explicit price of the tax or the permits; and the implicit carbon component incorporated into oil, gas, and coal prices. In the latter case, part of this is just the price of carbon fuels (not the additional externality component), part is the premium which results from market power, and part is taxation for revenue-raising reasons. The ‘correct’ price of oil would be the marginal cost of production, plus the Hotelling depletion cost (to the extent it is relevant), plus the social cost of carbon. The current price is the marginal cost, plus the market power premium, plus taxation.

The addition of a price of carbon therefore needs to be *net* of the other distortions, not *gross*. One implication is that the carbon tax or permit price should not be calculated on the

basis of a simple read across of the estimates of the social cost of carbon. This will almost certainly be the wrong answer. A second implication is that the 'correct' carbon tax or permit price will vary with the oil (and gas and coal) price, insofar as it varies for reasons other than a change in the marginal costs. The first has implications for the level; the second for the instrument design.

In the case of the design of the carbon tax, the impact of the changes in the price of oil points towards indexation. So if the peak oil hypotheses turn out to have substance, then as the oil price rises, so the price of carbon can fall away for a given carbon target. This falling away might reflect an increase in market power (as supplies concentrate in fewer Middle Eastern and Russian hands), or it might reflect the depletion premium. From the perspective of policy design, it does not matter which: in either case, the relative price of carbon versus non-carbon technologies is changed by the oil price movement.

With permits, in theory the indexation is already implicit: if the oil price rises, for a given number of carbon permits, the relative price change accelerates decarbonization, and hence the equilibrium price of the permits should fall. However, here the problems of rent seeking and capture come into play: the vested interests may bear down on the number of permits and the exemptions. In practice, the EU Emissions Trading Scheme has proved particularly prone to such capture.

There remains a further complication that emerges from the discussion above about the abundance of gas, and unconventional supplies. Inverse indexing to oil prices may speed up the electrification of transport, but a very low gas price might slow down the decarbonization of electricity generation. There is, therefore, a case for at least considering a basket of fossil fuels, weighted by carbon content as the index, or even a gas price index.

Setting taxes on the basis of indices tends to raise practical questions. Which index? How frequent is the indexing? The answers need to be pragmatic: almost any indexing rule improves on the current situation, where the oil price is taken into account from time to time in the implicit process of tax or permit setting. Making it explicit improves transparency and predictability, thereby reducing uncertainty and the cost of capital. In addition, there are a series of indices to choose from: the oil price is one of the most published and understood commodity prices. As to frequency, this is pragmatic, too: it could be daily, monthly, or yearly. Since oil price volatility is often very short term, the closer to real time the better from an efficiency perspective.

Indeed, dampening the volatility is one of the additional efficiency benefits of an indexed carbon tax. The volatility is not determined generally by short-term movements of marginal costs, but rather from the production decisions and fluctuations in demand. While the latter should inform the price, the oil price often moves more than proportionately to what are, at the global level, small demand shifts—in part due to speculation, in part inventories, and in part the feedback to production decisions.

The advantage of this approach to setting a main policy instrument to address climate change in this way is that it strips out the need for governments to take a view about the future oil price: indeed, it makes it largely irrelevant to the setting of policy (although the revenue yield remains uncertain). Therefore, in an important sense, it does not matter whether the peak oil hypotheses are valid.

Governments might nevertheless want to protect themselves from the downside risk of a fall of the price of oil and gas in the short to medium term: the possibility that the peak oil hypotheses are wrong. For if they are, and fossil fuel prices (especially gas) fall away, then the substitution effect will be all the harder to achieve (and at much higher subsidy levels).

Locking in an oil price of around \$70–90 now, through a carbon tax indexed to that level, means that consumers will have to plan ahead on the basis that their final energy price is not going down. This expectation then feeds straight through to investment decisions—from the domestic level, in terms of energy efficiency measures and smart meters, through to the choice of technology for power generation. In the latter case, it matters greatly that the gas price figures in the index selected.

VI. Conclusions: designing robust energy and climate change policies

The determination of the price of oil and the uncertainty surrounding its future level is of profound importance to the design of energy security and climate change policies. To date, policy-makers have tended to take a view, and pick winning technologies. At the end of the 1970s, the oil price was assumed to go ever upwards, and now that assumption is again central to much public policy design. Too little thought has been given to the opposite possibility that, just as in the 1980s and 1990s the price turned out to be very low, so too the future might be less like the one the peak-oilers assume, and prices might as a result be more subdued.

There are, indeed, very good reasons for doubting the claims of the peak-oilers. The reserves may be much greater than currently assumed (especially in the Arctic), technology is likely to enhance both recovery rates and reduce the costs of currently marginal supplies, transport is increasingly likely to be electrified, and with the coming of unconventional gas, gas supplies look like joining coal in their abundance. The danger is now that we have far too much oil, gas, and coal, not too little, for the climate to tolerate.

Any energy or climate change policy that rests on a bet on the future price of oil is inherently risky. Rather than assuming that the future and its technologies are known, policy should start from the assumption of uncertainty, and look for robust corrections of market failures (and to limit government failures).

In the case of energy security, the key mechanisms are: strategic reserves and storage; infrastructure; diversification; and the design of taxes and subsidies, especially in respect of E&P. The first two elements are robust to high or low prices: strategic reserves are designed to inject stability and limit the impact of stocks, and infrastructure is in the main a public system good, which increases competition, reduces security margin requirements, and provides the physical linkages to address shocks. Diversification has obvious portfolio benefits, and in the case of taxes, these should be set with an eye to the stable medium- and longer-term development of new resources and supplies.

In the case of climate change policy, a core argument of this paper has been that too little attention has been paid to the implications of the peak oil hypotheses proving wrong. If fossil fuel prices (especially gas) stay low, then the relative prices of low carbon technologies will rise. The already highly questionable cost assumptions in, for example, the Stern Review will turn out to be even more erroneous. Instead of renewables and nuclear becoming cost competitive in their own right as the oil price rises, they could remain well out of the market. And when the gas price is included in this calculation, gas CCGTs may command a very large competitive advantage.

Policy is best designed independently of the forecast for future oil (and gas) prices. The obvious way to embed this is to index the carbon price inversely to the oil (and gas) price.

This maintains (and gradually increases) the relative price effect on substitution, and if done now would embed the existing oil price.

There is urgency to these policy considerations. The coming of unconventional gas is a potential game-changer, and the economic crisis has had an impact on demand as well as on investment as capital has been rationed. Carrying on in the belief that the oil price will go ever upwards may prove one of the most costly mistakes yet for climate change policy, and while, in the short run, the easier market conditions may slacken the pressure on security of supply, not to take the appropriate policy actions on strategic reserves and storage and on infrastructure and diversity now may store up further trouble later. Price matters and is inherently uncertain, and technical change is also inherently uncertain. These are the facts upon which energy policy should rest—and not the assumption that governments know both future prices and technologies. The peak oil hypotheses are just that—hypotheses—and there is little compelling evidence to support them.

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