Oil Shortages, Climate Change and Collective Action

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Abstract Concerns over future oil scarcity might not be so worrying but for the high carbon content of substitutes, and the limited capacity of the atmosphere to absorb additional CO_2 from burning fuel. The paper argues that the tools of economics are helpful in understanding some of the key issues in pricing fossil fuels, the extent to which pricing can be left to markets, the need for, and design of, international agreements on corrective carbon pricing, and the potential prisoners' dilemma in reaching such agreements, partly mitigated in the case of oil by current taxes and the likely incidence of carbon taxes on the oil price. The 'Green Paradox' in which carbon pricing exacerbates climate change is theoretically possible, but empirically unlikely.

Keywords exhaustible resources, climate change, carbon prices, prisoners' dilemma, international agreement, Green Paradox

JEL Classification Q32, Q54, H23, L71

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EPRG WORKING PAPER

Oil Shortages, Climate Change and Collective Action[1]

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1. Introduction

Growing affluence and population are putting increasing stress on the planet's resources, particularly fresh water, agricultural land, forests, biodiversity, key minerals including oil, and the capacity of the oceans and atmosphere to absorb greenhouse gases (GHGs). Two such resources are in direct conflict – fossil fuel and the atmosphere. Burning all of the current estimates of fossil fuel reserves without carbon capture releases CO_2 that would more than double pre-industrial atmospheric CO_2 concentrations. With high probability that would result in global warming of considerably more than 2^0 C, with damaging climate changes, as well as ocean acidification. Conventional oil reserves alone do not appear to contain enough carbon to exceed the current target of limiting global warming to 2^0 C, but there are growing concerns that conventional oil will soon experience shortages that will not only be disruptive, but may lead to the more rapid exploitation of even more carbon-intensive alternatives. This paper asks what economics can say about oil shortages and their possible consequences, and about the larger question of agreeing collective action to mitigate climate change. In particular, it asks what are the key obstacles to such action, whether they would avoid or delay damaging climate change, or whether they might have perverse effects.

Any commodity or service that carries a positive price is by definition scarce – the lack of scarcity would cause the price to fall to zero - but a shortage suggests something more serious than mere scarcity. An economist would interpret shortage as excess demand, or a situation in which the demand, given the terms of access including the price, exceed the amount supplied under those terms. Under ideal conditions (competition, full information, well-established property rights and no externalities) markets will so price resources that there is only scarcity, and no shortage. Shortages may be caused by either a temporary and unexpected disruption, or the suspension of market pricing, often for distributional reasons, as in wartime rationing. Oil markets are global, and can certainly respond to the possibility of increased scarcity, but national policies can also turn those market signals into situations of shortage. This paper considers well-designed policies that use market prices to minimise, rather than amplify, the costs of scarcity and climate change, and so ignores disruptions and shortages.

[1] This paper was presented at a Royal Society Discussion on the *Sustainable Planet* at the Kavli Royal Society International Centre at Chicheley Hall, Bucks, under the title 'The economics of strategic resource shortages and climate change'. I am indebted to Joel Cohen, Eirik Amundsen and EPRG referees for assistance in refocusing the paper more tightly.

2. Oil: exhaustible resource theory and practice

Projections made in successive editions of IEA's *World Energy Outlook* (WEO) reference scenario for 2030 oil demand were 119.9 million barrels/day (mb/d, 5759 Mtoe) in 2002, 116.1mb/d in 2006, 106.4mb/d in 2008, and 105mb/d in WEO 2009. Significantly, only 26mb/d or 25% of that is projected to come from existing fields, while 50% is to come from fields yet to be developed or found, with the balance coming from natural gas liquids (double the 2000 level) and unconventional oil (7mb/d). Differences in the reference scenario reflect different price and economic growth projections, as well as different policies in place at successive dates. UKERC (2009) examines the evidence for "peak (conventional) oil" which it estimates to lie between 2009 and 2031, after which conventional oil production will decline, although demand at unchanged prices would continue to rise. Clearly, scarcity pricing should lead to rising oil prices, until prices are sufficiently high to elicit adequate supplies of unconventional oil, [2] including liquids from gas and coal. USGS (2000) estimates conventional oil reserves in the range 2,000-4,300 billion barrels (Gb) compared to cumulative production to 2007 of 1,128 Gb.

The economic theory of pricing exhaustible resources like oil goes back to Hotelling (1931), who considered a world of perfect certainty, with a known total stock of oil that could be extracted at known costs at unlimited rates at any moment, to be sold on competitive markets. His insight was to note that the value of oil in the ground at any date was the sales price *less* the extraction cost. This value, termed the rent, measures the scarcity value of that oil *in situ*. With perfect capital markets, the equilibrium rent now should be the same as the present discounted value (PDV) of its future rent whenever the well is producing. If the rent were less than the PDV of future rent it would be better to keep it in the ground and wait until the price and rent rose enough, while if the rent were greater than any future PDV, it should be immediately extracted and sold in the market to give the highest (present valued) profit.

In the simplest case if the extraction cost is very low compared to the oil price and is taken as zero (a good approximation for the supergiant mid-East oil fields), then the competitive price of oil will rise at the rate of interest. If the price now is p_0 then its price at date t will be $p_t=p_0e^{rt}$, where r is the rate of interest at which future rent is discounted. If we know the demand as a function of price and time (acting as a proxy for future income), $D_t = D(p_t, t)$, then cumulative consumption can be determined, and the current stock of oil, S_0, will be depleted at date T when cumulative demand, $\int_0^T D(p_t, t)dt = S_0$. If at that date oil is to be replaced by some substitute that is available at price p^*, then the price now will be p^*e^{-rT}, where T has been determined by the depletion condition. The price at any subsequent date will be $p^*e^{r(t-T)}$.

This model can be readily modified to accommodate positive production costs, and if they are constant at m per barrel, the price at date t will be just $p_t=m+(p^*-m)e^{r(t-T)}$. Models that take account of a range of more complex cost and market conditions can be found in Dasgupta and Heal (1979), Newbery (1984) and Karp and Newbery (1993). Figure 1 shows the equilibrium price and demand when there is a sequence of oil fields of increasing cost.

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[2] Unconventional oil is any resource that requires processing to produce the equivalent of conventional oil. Deep offshore oil is treated as conventional, if expensive to extract.

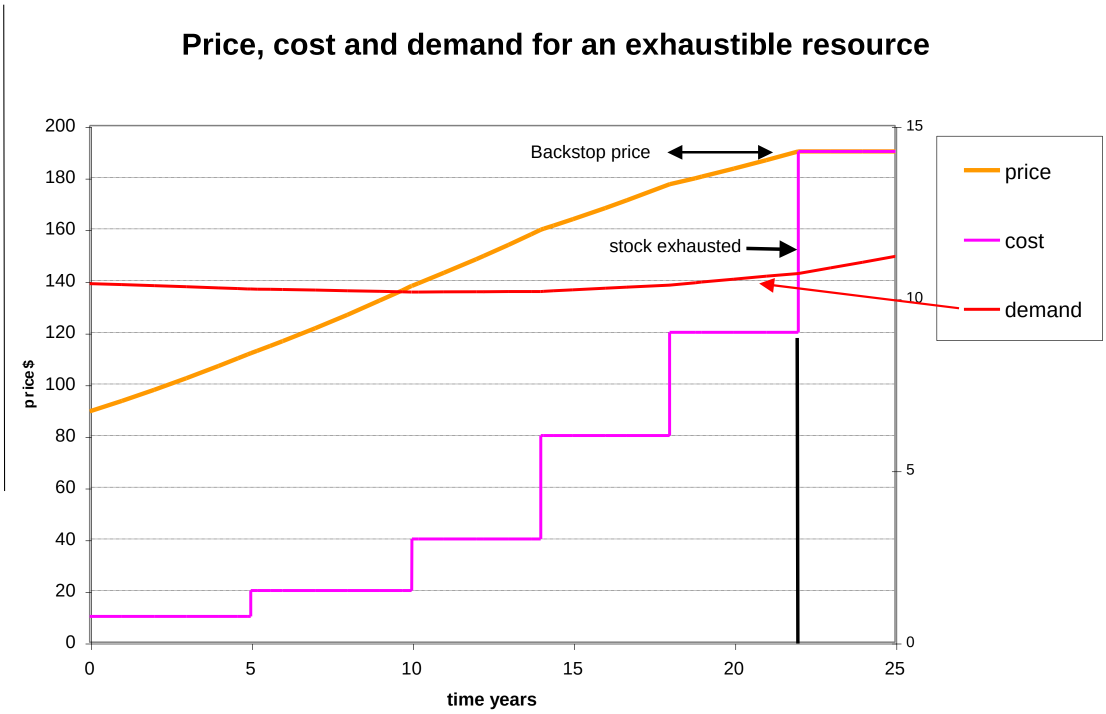

Figure 1 Price (discount rate 5%, demand growth 1.5%, elasticity of demand -0.5)

How well does this model predict oil prices? Figure 2 shows that real oil prices dramatically jumped in 1974 and again in 1979, in the period in which the US was moving from near self-sufficiency to a quadrupling of oil imports, tightening the world oil market, encouraging resource nationalism and consequential political tensions. Prices then collapsed, first as OPEC cartel members were tempted to cheat and increase supplies, to which Saudi Arabia responded and reasserted its swing position in OPEC by flooding the market to support its preferred price.

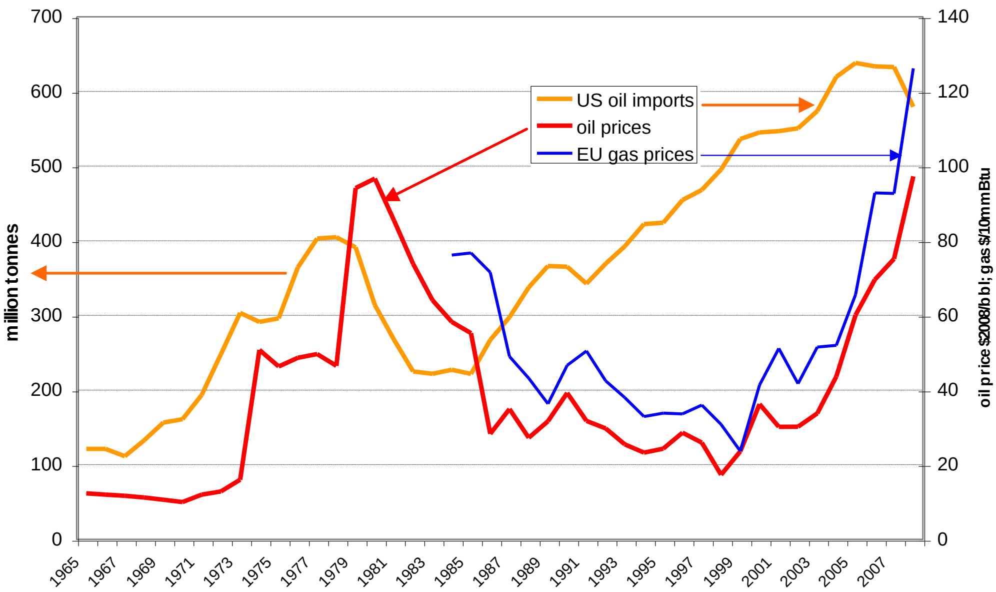

Figure 2 World oil prices, EU gas prices and US oil imports, 1965-2008
Source: BP (2009)

Nevertheless, at each date after the initial price rise, analysts were tempted to use the Hotelling theory to predict that future prices would rise at something like the rate of interest from then on. Graphs of projected prices against the subsequent actual prices look like a spiny porcupine with forecasts rising at 3% (real) while prices drifted down for the rest of the century. Clearly the model fails to capture important aspects of reality – such as market power and the difficulty of sustaining a cartel by national quota allocations, supply constraints, ambiguities over ownership, the changing balance within OPEC between hawks and doves, surges in exploration and rapid technical improvements in off-shore drilling, the oil-induced recession and inflation of the 1980s, to mention but some. To return to the original model, we should not be surprised at the volatility of the spot oil price as it should depend on estimates of future reserves, their cost, the cost of substitutes, and the discount rate, all of which are uncertain and subject to periodic major revision. Nevertheless, the economic argument is clear – oil prices today depend on future developments and particularly the transition from conventional to unconventional oil or other alternatives, as well as being heavily influenced by market structure, and tax policy (which affects demand).

3. Climate Change

Greenhouse gas (GHG) emissions are, to use economic language, a global stock public bad – emissions anywhere impact climate for everyone everywhere, and GHGs are persistent, so that there is little difference in the damage done from emissions today and next year. To quote the Stern Review "Climate change presents a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen" (Stern, 2006, p i). Given that it is the stock of GHG that sets climate change in motion, the question to ask is how the absorptive capacity of the atmosphere relates to the stock of unextracted carbon in the form of fossil fuels (while recognizing the importance of other sources and sinks of GHGs, notably land use change, livestock and changes in forest cover). Current modeling suggests that to have a 50% change of preventing global warming of 2^0C from pre-industrial levels we can only release another 500 Gt carbon, compared to past emissions of 500 GtC – we are half way to exhausting our trillion tonne global carbon budget, as figure 3 illustrates (Allen et al, 2009).

Figure 3 also shows the amount of carbon locked up in fuel reserves, showing that the low estimate of conventional oil, gas, and coal reserves are larger than the 2^0C absorptive capacity of the atmosphere, while exploiting that and unconventional oil and gas would likely take us to 4^0C. If we add the very uncertain estimates of the potential resources the bar goes outside the range considered.[3] Clearly if we are to avoid damaging climate change we need to ensure that either we do not exploit all current fossil reserves, or that we capture the CO_2 and store it securely in geological reservoirs. That explains the urgency in demonstrating carbon capture and storage (CCS) technology, as well as discouraging excessive fossil fuel use. The economics of mitigating climate change are thus relatively straightforward in theory – we need to limit the cumulative emissions of GHGs.

[3] Source: Meinshausen et al (2009), BP (2009), NPC (2007)

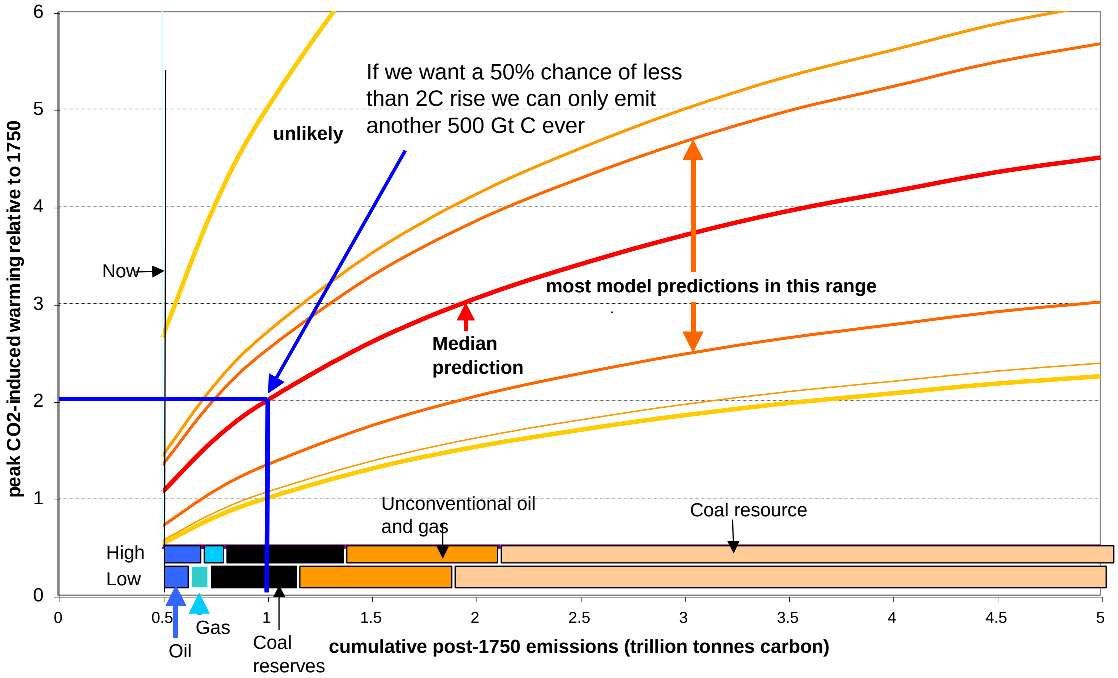

Figure 3 Illustrative peak global warming vs cumulative emissions 1750-2500
Source: after MR Allen *et al* (2009)[4]

The approach to date, starting with the Kyoto Protocol, is to agree country-specific emission targets, initially for Annex I countries, and typically specified as average emission rates relative to 1990. Figure 4 shows that although Annex I countries accounted for only a quarter of the population they account for 70% of emissions. (The areas of each bar measure population times emissions per hear, thus total country emissions.)

The EU has addressed its emissions targets through the EU Emissions Trading System (ETS) under which member states are allocated an annual quota of emission allowances (EUAs) based on (unsurprisingly inflated) estimates of what they considered they needed. These EUAs are freely tradable and can be banked from year to year. Phase I ran from Jan 1 2005 to 31 Dec 2007 and EUAs could not be banked beyond that date. Phase II runs until 31 Dec 2012 and second period EUAs can be carried over to Phase III.

There are two main reasons for creating a tradable emissions permit. The fundamental reason is that it puts a price on CO_2 with the intention that all installations covered by the ETS (roughly half of total EU CO_2 emissions) face the same charge for emissions. Installations that can reduce emissions cheaply will do so and sell (or not buy) EUAs, while those for whom reduction is more costly will prefer to buy EUAs, until the marginal cost of abatement is the same everywhere and the total cost of abating the required amount (the cap) is minimised. In contrast, regulations specifying limits for

[4] The median line approximates the best fit for simple climate models, other lines are of equal but different probabilities. The range indicated corresponds to the majority of model predictions, and the outer lines indicate the tails of the probability distributions; with suitable caution about increasing lack of understanding of more extreme variations. The horizontal bar indicates high and low estimates of proven reserves, rough estimates of unconventional oil and (mainly) gas, and estimates of possible coal resources.

each installation are likely to deliver any given amount of abatement at higher, and perhaps much higher, total cost, as there is no guarantee that it will be equally costly to abate the final tonne in each installation.

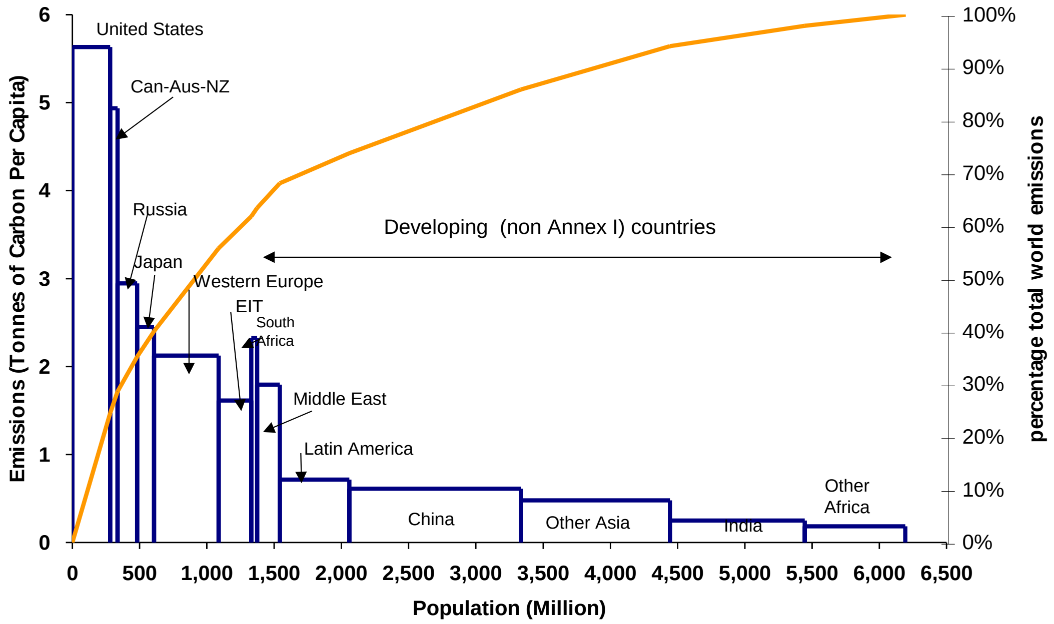

Figure 4 CO_2 Emissions per head against population IN 2000 (areas represent emissions)
Source: Energy Information Administration, International Energy Agency

The second reason is political – it is much easier to agree a target future level of emissions and to allocate quotas to each country on the basis of past levels of emissions than it is to agree a price for CO_2. In addition, existing installations can be allocated EUAs, which they are free to use or sell, and hence they are typically better off as a result. Imposing a carbon tax would make all emitters worse off, unless the government were to hand back the revenue in proportion to base-year emissions. Of course, consumers are worse off under the free allocation scheme, but they almost certainly do not realise this until it is too late. The electricity industry provides an excellent example of this political economy, as the European Commission required all member states to freely allocate at least 95% of base year entitlements to generating companies, who were then free to sell them, at a price that in 2005 reached over €30/EUA, or €25 /MWh for coal-fired generation. Politicians might naively have thought that as they were compensated for the cost of CO_2 they would not need to raise electricity prices, but in liberalised markets the price of electricity immediately reflects the carbon cost of generating the most expensive electricity (where cost includes fuel and CO_2). Had the electricity companies been required to bid for EUAs in an auction or buy them in the ETS market, the most expensive plant would have broken even, if, as was likely, it had the highest emission rate, and more carbon efficient plant (e.g. gas-fired) would have made more profit (equal to the difference in carbon intensity times the EUA price – or 0.4 EUAs/MWh for CCGT). As they had all been given free allocations, they experienced a windfall of billions of Euros.[5]

[5] Point Carbon (2008) estimated that for the five countries it studied the windfall profits in the second phase could be between €23-71 billion – see http://assets.panda.org/downloads/point_carbon_wwf_windfall_profits_mar08_final_report_1.pdf

Fortunately this is now recognised and generators will have to buy all their required EUAs in Phase III. The experience of the ETS is well known and points to its key failure. Prices rose steeply to March 2006, when the actual emissions data were released, showing, unsurprisingly, that countries and firms had exaggerated their future emissions to secure more free allocations. The EUA price dropped sharply, falling to zero in late 2007, as these EUAs could not be carried over to Phase II. The second period price started promisingly and rose to €30/EUA in mid 2008 before steadily falling to less than half that value as a result of the increased target for EU renewable energy by 2020 and then the global recession (CCC, 2009). The ETS thus failed to give clear and stable price signals for investors choosing the carbon-intensity of generating plant with an expected life of 25-60 years.

That brings us to another economic insight – whether it is better to stabilize the quantity of emissions or the price. If there is complete information and no uncertainty, the efficient level could be achieved either by issuing the correct number of quotas or setting the pollution tax at the marginal damage cost at the efficient level. This equality of outcome breaks down under uncertainty or with asymmetric information (e.g. if the policy maker does not know the true cost of abatement but producers do). Weitzman (1974) started a lengthy debate by observing that in the presence of uncertainty, taxes are only superior to quotas if the marginal benefit from abatement schedule (i.e. the marginal damage of emissions) is less steep than the marginal cost of abatement schedule. But as observed earlier, emissions today contribute to the total stock of CO_2 as do emissions next year, and one more tonne today can be offset by one less tonne next year, so that at any moment the marginal damage of emissions is almost independent of the instantaneous amount, making the marginal benefit of abatement effectively flat, and giving a clear preference for stabilising the price, not the cap on total emissions.

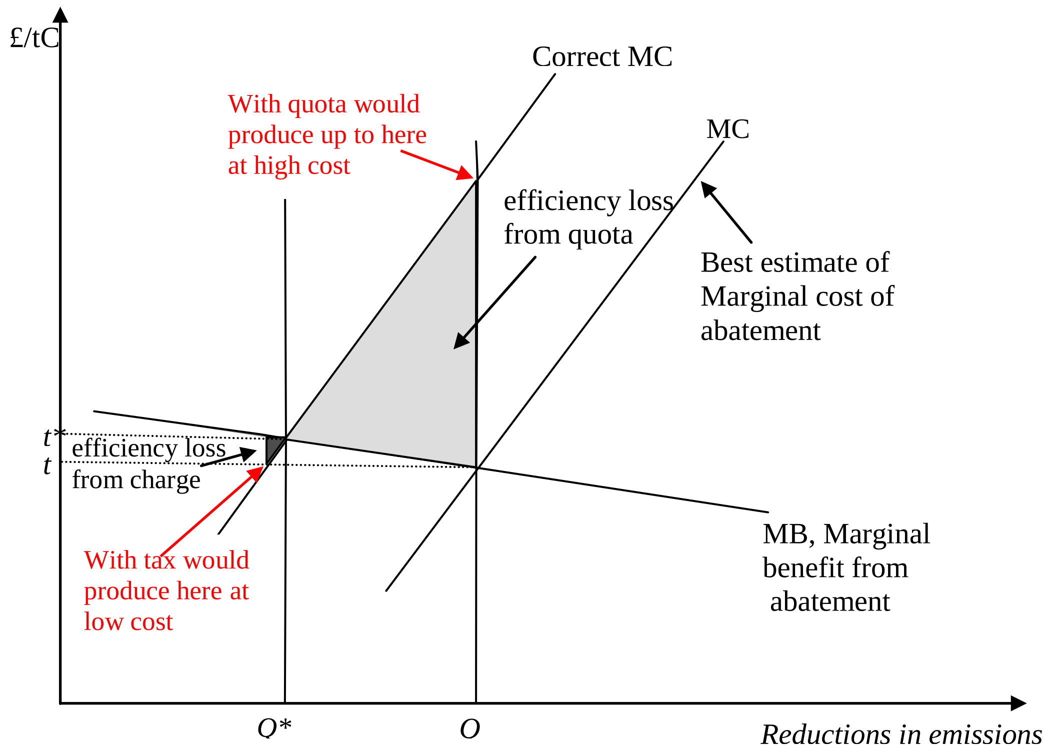

Figure 5 Costs of errors in setting prices or quantities

Figure 5 shows that the correct emissions level is Q^* and price t^*. If the marginal cost schedule is incorrectly located and the quota set at Q, the error resulting will be the large lighter shaded area, whereas setting the charge (incorrectly) at t would lead to the small costs of error (shaded dark).

What investors need if they are to make rational low-carbon investment decisions is a credible time path for future CO_2 prices. The appendix shows that the price of CO_2 should rise at close to the rate of interest in equilibrium. As new information arrives and reduces uncertainties about the absorptive capacity of the atmosphere, the technologies and their costs for abatement, so we shall be better placed to adjust the time path of CO_2 prices required to guide us to long-run equilibrium. One might expect that new information is as likely to raise as lower the required carbon price, so that at any moment the current price should be the best estimate of the required price. If governments (or the European Commission, the CEC) are to credibly reassure investors making risky durable investments, it would be desirable to issue contracts for differences (CfDs) on the projected future carbon price, thus reassuring investors that subsequent changes caused by new information or other circumstances would not needlessly increase their investment risk.[6]

The ETS could make the transition to a price rather than quantity system in various ways, of which the most simple would be to move first to 100% auctioning of all EUAs (as proposed for electricity after 2012), and for the CEC to retain sufficient allowances to sell more if the price rises above the desired level, and to sell fewer if the price threatens to fall, acting rather like a central bank in stabilizing its currency. An attractive alternative would be to replace the ETS by a requirement that member states impose carbon taxes on the carbon content of fuels burned, thus extending the ETS to the entire economy and greatly simplifying the management and monitoring of emissions.

In the past carbon taxes have been notably unsuccessful in the EU (except for the Nordic countries, and even these exempted trade exposed sectors). The gradual evolution from grandfathered emissions rights to full auctioning, then stabilizing prices, and finally replacing them with carbon taxes, might be more politically palatable. Indeed, in the UK the Committee on Climate Change (2009) has recommended that the government put a floor on the CO_2 price, either by persuading the CEC to reform the ETS, or failing which, by some other means – advice accepted in the Conservative-Liberal coalition agreement. One fiscally attractive UK solution would be to transform the current Climate Change Levy into a Carbon Correction Levy imposed on the carbon content of all fuel, with rebates equal to the EUA price for the covered sector.

4. Reaching global agreement

It is one of the more impressive achievements of the EU that it has managed to reach agreement on more stringent emissions limits than were accepted under the Kyoto Protocol, and is willing to tighten them (from a 20% reduction relative to 1990 to a 30% reduction) if non-Annex I countries agree to satisfactory limits. It has accepted the need for an 80% reduction by 2050 and the UK has written this into a legally binding limit in the Climate Act. But the EU only accounts for about 15% of global emissions and

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[6] A carbon CfD would have a strike price, c_t, at date t for one EUA in each year for some specified number of years (e.g. 25). If the actual carbon price in year t were C_t the holder would be entitled to receive (c_t - C_t) per CfD, if $c_t > C_t$ and would be required to pay (C_t - c_t) per CfD, if $c_t < C_t$. One-sided CfDs would entitle the holder to receive compensation if the actual price were below the strike price, but would allow the holder to benefit from any upside risk.

without tighter limits for the Annex I countries than under Kyoto, extended to include non Annex I countries, the likelihood of remaining within the one trillion tonne carbon limit looks small to vanishing.

Again economic theory can explain why this is so and what might be needed to avoid the tragedy of the global commons. In its simplest form there are two countries, 1 and 2, who must decide whether to Abate (A) or not abate (N). The pay-offs are as described in the table below – (pay-off to Country 1, pay-off to Country 2). There is no external means of enforcement, so that any agreement must be individually rational, that is, each player (country) will make a choice based on her own interests, given the predicted choice of the other player.

		Country 2	
		A	N
Country 1	A	(10, 10)	(-50, 110)
	N	(110, -50)	(5, 5)

If this game is played once, then we have the classic Prisoners' Dilemma:[7] each would prefer that they both play A, in which case they each receive 10, but as they cannot sign enforceable binding agreements, each will play N, which is a dominant strategy, meaning that it is the best for each to play regardless of what choice the other makes. The outcome is the inferior Nash Equilibrium (N, N), and each receives only 5. However, if the game is played repeatedly, there is the potential for agreement on the superior outcome (A, A), provided that it is in each player's interest to continue to cooperate. Suppose each discounts future returns at rate r, then we can ask what is the highest value for r, r^*, that allows continued cooperation. This will require the greatest cost to not cooperating, which in the game specified here is to refuse to cooperate ever again (the so-called grim strategy). This strategy is clearly a (sub-game perfect) Nash equilibrium, since if either player stops cooperating and plays N it is in the best interest of the other to play N.

The value of r^* will make deviating in the first period for a net gain of 100 no more attractive than the consequence of accepting 5 less in each subsequent period for ever, so $r^* = 5\%$. Any higher discount rate will make deviation more attractive, while a lower rate will allow less severe punishments for deviation to support cooperation. Another insight that recurs repeatedly is that low discount rates are an essential element in addressing climate change, as high rates of discount make the future benefits of mitigation smaller, and raise the cost of the very capital-intensive low-carbon technologies (wind, nuclear power, CCS, etc). The discount rate turns out to be a critical determinant of the incentives to cooperate, the estimated future damage of global warming, and the cost of capital-intensive low-carbon mitigation strategies.

To return to the case of climate change agreements between sovereign states, the benefits of individual abatement are a small contribution to reducing cumulative emissions and hence a small reduction in the equilibrium temperature rise. The costs are the higher costs of abatement rather than not, but in addition there are further

7 In the original form, the prisoners are separated and told that if they implicate their colleague, they will go free and the other will be severely punished, and if both testify, each will receive a reduced sentence, but if neither testify, they will both be charged with a lesser offence (which would be their best joint outcome).

opportunity costs. If all other countries agree to abate by agreeing measures that raise the effective price of CO_2 (either by a cap and trade system, regulations or a carbon tax), then the demand for fossil fuels will decrease, and so will the price at each date (although the tax-inclusive fuel price will be higher). Countries that drop out of the international agreement will benefit from cheaper fossil fuel, and, if there is free trade, will be able to produce carbon-intensive manufactures and products (steel, cement) for export to other countries (like China today), where the cost of producing these goods will be higher.[8] So the cost of joining the international agreement includes the foregone opportunity of access to cheap fuel and high export demand.

The impact of carbon taxes on fossil fuel prices can be examined in the Hotelling model of exhaustible resources, with some surprising results. Much depends on the carbon-intensity of the backstop technology and the cost structure of conventional fuels. The appendix shows that if the backstop is zero carbon (e.g. nuclear or solar power with biofuels and hydrogen), if fuel extraction costs are zero and in instantaneous elastic supply, then a global carbon tax that rises at the rate of interest (as it should) will merely depress the pre-tax price of fuel by the amount of the tax, leaving the post-tax price and the date of exhaustion unchanged. The price will not increase, demand will not fall, and emissions (from oil) would not be reduced. Countries opting out of the climate agreement will enjoy cheaper oil than they do at present, and will thus increase their consumption, so the total level of emissions would increase and the oil would be depleted faster than with no intervention, worsening global warming. This is Sinn's 'Green Paradox' in which a poorly designed carbon tax can accelerate global warming rather than having its intended effect (Sinn, 2008).[9]

Of course, this is an extreme assumption, and figure 6 illustrates the effect of positive extraction costs and a backstop for oil that is more carbon-intensive than conventional oil (as would be the case with oil sands, liquids from coal, etc). The case with no climate agreement shows the oil price rising to the backstop price, while demand initially declines as price rises, but then increases as income grows.

With a global carbon tax that has the effect (as far as consumers are concerned) of raising the cost of extraction by the amount of the embedded carbon (extraction, processing, transport) and which in this case raises the cost of the backstop, the price now rises to reach the tax-inclusive backstop cost (the highest line at the right), demand is depressed, and the date of exhaustion is delayed. The price for a single small country that refuses to join the agreement is shown at the line indicated "price not paying C tax" and is not far below the price with no agreement at all. In this case the carbon tax mainly falls on consumers, not producers, and the fuel price rise is almost as great as the tax. The green paradox is avoided.

Mejean and Hope (2010) have explored the impact of carbon taxes on conventional and unconventional oil, paying attention to the uncertainties surrounding estimates of future costs, learning rates that drive down costs, demand elasticities, the carbon price and discount rate, and find that between 81-99% of the carbon tax will feed through into the final (tax-inclusive) price of oil, with a consequential impact on cumulative emissions. Nevertheless, the incentive to avoid paying the carbon tax remains equal to the size of the tax, and if, as seems most likely, the consuming

[8] This problem of carbon leakage has been extensively studied - see e.g. Droege, S. (2009)

[9] There is an extensive literature provoked by this paradox, summarised and extended by van der Ploeg and Withagen (2010).

countries impose this, the world price of oil will indeed be lower than the domestic price in compliant countries.

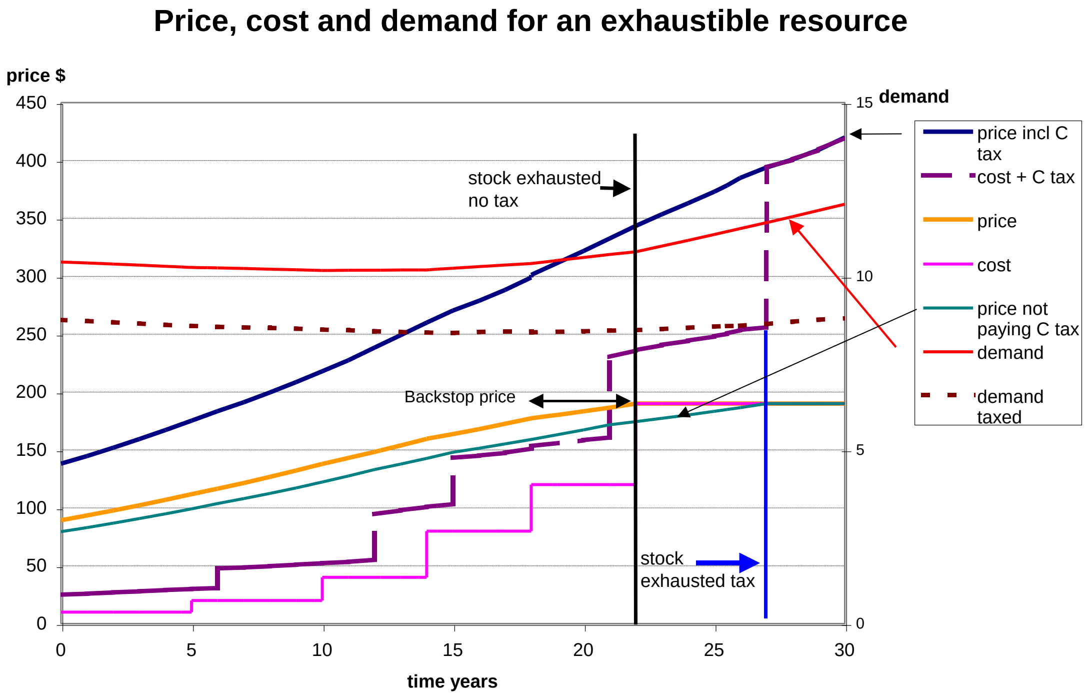

Figure 6 The impact of introducing a global carbon tax

The incentives to impose carbon taxes are thus apparently weak, and the Prisoners' Dilemma real. Indeed, the simple repeated model above is over-optimistic in several ways. First, there are not just two countries but many. Although the same punishment strategy can still support cooperation, the incentives to deviate or cooperate will depend on the size of the costs and benefits which likely change with more countries. Second, the game is not unchanging and infinitely repeated, but changes over time. The damages are (initially) distant, very uncertain and unequally distributed across the planet, with some countries possibly gaining from global warming. All these make the problem more intractable, but there are some positive aspects.

First, there may be local incentives to shift taxes from distorting productive decisions and discouraging work and enterprise (as current income and profits taxes do) to correcting environmental harms, as would a carbon tax. Countries would keep their carbon tax revenues as well as enjoying better future standards of living if climate change is mitigated. Second, many countries already find it attractive to tax oil products, partly as it is easy, and partly to pay for road infrastructure. Figure 7 shows that most EU countries collect about 2% of GDP in oil tax revenue, and that this comes mainly from taxes on road fuels (although this could change with a shift to road pricing and electric vehicles).

If fiscal self-interest is not sufficient to encourage countries to voluntarily accept carbon taxes as a coordinated policy for climate change, then the Prisoners' Dilemma suggests that more powerful sanctions might be needed against non-compliance. The least aggressive of these would be border taxes on the deemed carbon content of any imports from non-compliant countries, justified under the WTO as correcting a subsidy on the fuel used, and rebated to the extent that the country could demonstrate that the fuel was properly charged on its carbon content. That may not be sufficient, but the logic of the Prisoners' Dilemma shows why it might be necessary.

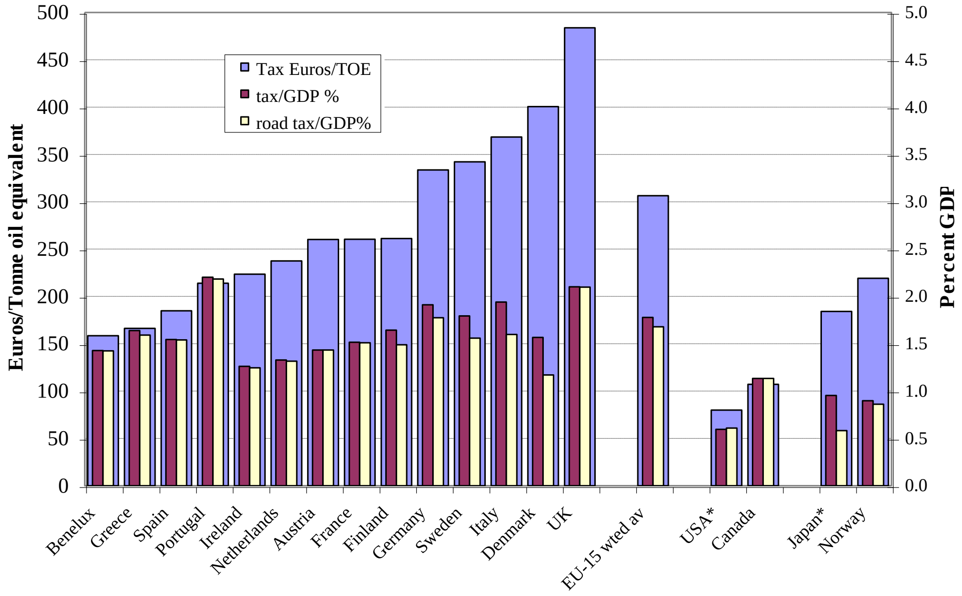

Figure 7 Taxes on oil and products, 2002
Source: IEA, EC

5. Conclusions

This paper provides only a very brief survey of some of the economic principles that are relevant to the analysis of resource shortages and climate change, illustrated for the case where they interact in interesting ways through peak oil and the carbon content of fossil fuels. Exhaustible resource theory, the theory of correcting market failures caused by externalities, public good/bad problems and the difficulty of collective action illustrated by the Prisoners' Dilemma, and its possible resolution in cases of repeated interaction through punishment strategies, all provide tools to guide policy analysis. Stern (2006) took over 600 pages to both quantify and analyse the economics of climate change, specifically asking how to estimate the social cost of carbon and the benefits of mitigating climate change, neither of which have been addressed here.

The aim instead has been to identify the incentives facing key actors (consumers, voters and their governments) and the extent to which decentralised market solutions might be used, with corrective carbon taxes, to reach a more satisfactory solution to climate change and resource scarcity. Even if all conventional oil and gas will eventually be burned, a carbon tax can raise the price of other fossil fuels to the level at which they are either not used (being replaced by zero-carbon alternatives), or their emissions are sequestered to satisfy the 2^0C atmospheric carbon budget.

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