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## Can subsidizing alternative energy technology development lead to faster global warming?

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## Can subsidizing alternative energy technology development lead to faster global warming?

**Abstract:** Modelling global climate changes without taking account of the changes in resource markets can produce climate policy with perverse consequences. In even the simplest economic model of emissions of greenhouse gases, naïve policies that ignore markets can lead to perverse outcomes- the opposite of that intended by the policy-makers- such as accelerating global warming. Yet the global climate models that are commonly used to develop climate policy do not adequately model resource markets. As a consequence, we need to develop better models of resource markets within our global climate models.

## Introduction

In his 1945 book “Open Society and Its Enemies”, the philosopher Karl Popper developed the notion of the Law of Unintended Consequences. This “law” of social sciences stated that for every piece of social regulation there will be consequences of the regulation that were not envisaged by the promoters of the regulation. Popper warned that achieving aims through social regulation might be more difficult than was expected.

In some situations we have an even stronger outcome: the eventual result of the social regulation is the exact opposite of what the promoters of the regulation were trying to achieve. I highlight two examples of perverse outcomes in environmental legislation. In both cases the intention of the legislation was to improve environmental quality. The CAFE fleet fuel mileage laws were promoted by the Sierra Club and other environmental groups in the 1970s as a way of increasing average fuel efficiency of the U.S. car fleet. A partial driving ban was imposed on cars in Mexico City in the hope of reducing the amount of driving and improving air quality.

Under the CAFE regulations in the U.S., light trucks were treated preferentially, as a political token to the U.S. agricultural lobby to ensure the passage of the legislation. However this preferential treatment meant that luxury light trucks, the sports utility vehicles, became the most profitable vehicle line for Detroit car-makers. Thus the sports utility vehicle (or “SUV”) was the creation of the environmental lobby’s actions to increase fuel efficiency (see Thorpe 1997). As luxury SUVs have lower fuel efficiency than equivalent luxury cars, the net result of switching consumers from luxury cars to luxury SUVs would be to lower fuel efficiency. Despite (or because of) continuing CAFE standards, Portney et al (2003) reported that the combined new vehicle average fuel economy of US cars fell 6 per cent from 1987 to 2002.

Another case of a perverse outcome was a driving ban on cars in Mexico City in 1989. Based on the last digit of a car’s license plate, cars could not drive on certain days of the week. However Eskeland and Feyzioglu (1997) found that gasoline consumption rose after the driving ban was put in place. They found that residents in Mexico City changed from exporting used cars to the rest of Mexico prior to the ban to importing cars from the rest of Mexico after the ban. Residents of Mexico City presumably responded to the ban by acquiring second cars with different licence plates, and perhaps lower fuel efficiency, to get around the ban.

A similar result could occur in the case of accelerating research and development of renewable energy sources. The hope of renewable energy research is that new sources of renewable energy will lead to less consumption of fossil fuels, lower emissions of GHGs and so less future global warming. This belief is very widespread, but is this belief warranted?

Economists from the Australian Bureau of Agricultural and Resource economics (ABARE) have pointed to the faster development of renewable sources of energy as an efficient means of achieving long-term reductions in emissions of GHGs (Fisher et al 2004 and Ford et al 2006). One of the core planks of the Asia-Pacific Partnership on Clean Development and Climate which had its inaugural meeting in Sydney, Australia,

in 2006 is that accelerating the development of renewable energy is a preferable path to limiting global warming than is the Kyoto Protocol path of quantity restrictions on GHG emissions.

However the perverse possibility exists that faster development of renewable energy technology will lead to faster consumption of fossil fuels, higher rates of GHG accumulation in the atmosphere and higher global warming. This response to new technology may seem impossible at first, however it is a simple market response to changing future prices. As global climate models do not generally have resource prices or resource suppliers in the models, these perverse responses do not appear in our current climate models.

The mistake in current global climate models is to assume that markets are static and that suppliers of fossil fuels will not react to perceived future changes in the market for their product. But it seems only reasonable that the knowledge that future prices of fossil fuels will change will lead to changes in the supply of fossil fuels today. If we incorporate resource prices and suppliers into our global climate models, are the results of climate change policies such as development of alternative energy sources or taxes on carbon emissions affected?

In the next section I lay out the basic model and then explore some simulation work to determine whether we might expect to see a perverse outcome. In order to model the effects of climate change policy, the impact of a policy on the energy market is first produced and then these numbers from a stylized energy market are used in a climate change model to assess the impact on the global climate.

### **A model of the energy market with a renewable substitute**

The simplest model of fossil fuel consumption over time is to assume that we can solve the social planner problem of optimally distributing a limited reserve of fossil fuels across a limited number of time periods. We have a social planner who is trying to maximize the present value of social utility over time. Assume that social utility is separable and additive in time, can be measured in dollar units and that future utility is discounted at the rate,  $\beta$ . Utility at time  $t$ ,  $U_t$ , is assumed to be only a function of energy consumption at time  $t$ ,  $E_t$ . This set-up is a standard one in the resource economics literature dating back to Hotelling (1931).

Energy can be supplied in one of two ways. Fossil fuel consumption,  $E_{ft}$ , draws down a limited supply of a non-renewable resource from initial reserves of  $R_0$ . Fossil fuel can be extracted at a per unit cost of  $C_{ft}$ . We assume initially that the extraction cost is constant over time. The infinite sum of fossil fuel extraction must be less than the initial supply

Renewable energy or “renewables”,  $E_{rt}$ , can be produced at a per unit cost,  $C_{rt}$ , which is declining over time due to development of new renewable energy technologies. The renewable energy might be photovoltaic or wind energy or some other form of renewable technology. Only non-GHG-producing renewables are considered in this

model, as the primary concern that we have is GHG emissions, rather than energy scarcity.

Our social maximization problem becomes a non-linear programming problem over a time period between today, time 0, and an end period, time T:

$$\text{Max } \sum \beta^{t-1} [U(E_t) - C_{ft} E_{ft} - C_{rt} E_{rt}]$$

Subject to

$$E_t = E_{ft} + E_{rt}$$

$$\sum E_{ft} \leq R_{f0}$$

Assume initially that the only policy option available to the government is to subsidize the development of new technologies for renewable energy. Research and development of renewable energy technology will lead to lower per unit production costs for renewables over time. Higher levels of government subsidies accelerate the fall in renewable energy prices leading to a lower path over time for the price of renewables.

Fossil fuel and renewables are assumed to be perfect substitutes, so the price of fossil fuels can not climb higher than the price of renewables. Initially fossil fuels will be cheaper than renewable energy, so social utility is higher initially consuming only fossil fuels. However as there is only a limited level of reserves for fossil fuels, the fossil fuel price will rise over time due to the implicit scarcity price- the “Hotelling rule”.

At some future date, fossil fuel prices will rise above the renewables price, and the economy will switch over from fossil fuel to renewables. At the time of switch-over, all of the fossil fuels will have been consumed. The renewable technology in this case is known as the “back-stop” technology in the natural resources literature (see Dasgupta and Heal 1974).

One consequence of a lower price path for renewables is that the switch-over date will be brought forward in time. Since all of the fossil fuels are consumed by this switch-over date, consumption of fossil fuels must be higher at each point before the switch-over. It is easiest to see this effect in a simple parameterized model. No attempt is made to fit the model to the real energy market. The simulations in the next section are intended to be illustrative of the possibilities, rather than predictive.

## Simulations

Assume that utility of energy consumption is a simple quadratic function:

$$U(E_t) = 10 E_t - \frac{1}{2} E_t^2$$

Our discount rate  $\beta$  is 0.9,  $C_{ft}$  is zero and  $R_{f0}$  is 50. Assume for our first simulation that  $C_{rt}$  is 6. We could assume a declining path over time for renewables, but for our analysis all that matters is the price of renewables at the time of the switch over.

We need only solve for this problem for 10 time periods. The parameter values are chosen so that the switch-over date is inside of 10 time periods. After the switch-over date, history essentially ends, and the solution thereafter is static over time. Conveniently this allows us to express a infinite period problem within a finite period framework. For the first 10 time periods, the solution to this social maximization problem is:

#### Simulation 1

Time	Fossil Fuel Consumed	Price of Energy	Fossil Fuel Reserves	Renewables Consumed
1	7.2	2.8	42.8	0.0
2	6.9	3.1	35.9	0.0
3	6.6	3.4	29.3	0.0
4	6.3	3.7	23.0	0.0
5	5.9	4.1	17.1	0.0
6	5.5	4.5	11.6	0.0
7	5.0	5.0	6.6	0.0
8	4.5	5.5	2.0	0.0
9	2.0	6.0	0.0	2.0
10	0.0	6.0	0.0	4.0

The price of energy is rising over time, and the consumption of energy is falling. During the 9<sup>th</sup> time period, the economy switches from fossil fuels to renewables. After the 10<sup>th</sup> time period and onwards, the price of energy and consumption of energy are constant.

Assume that the government subsidizes the development of renewable energy technologies and drops the eventual price of renewable energies to 4. If we run the simulation again, we get:

## Simulation 2

Time	Fossil Fuel Consumed	Price of Energy	Fossil Fuel Reserves	Renewables Consumed
1	7.9	2.1	42.1	0.0
2	7.7	2.3	34.4	0.0
3	7.4	2.6	27.0	0.0
4	7.2	2.8	19.8	0.0
5	6.9	3.1	12.9	0.0
6	6.6	3.4	6.3	0.0
7	6.3	3.7	0.0	0.0
8	0.0	4.0	0.0	6.0
9	0.0	4.0	0.0	6.0
10	0.0	4.0	0.0	6.0

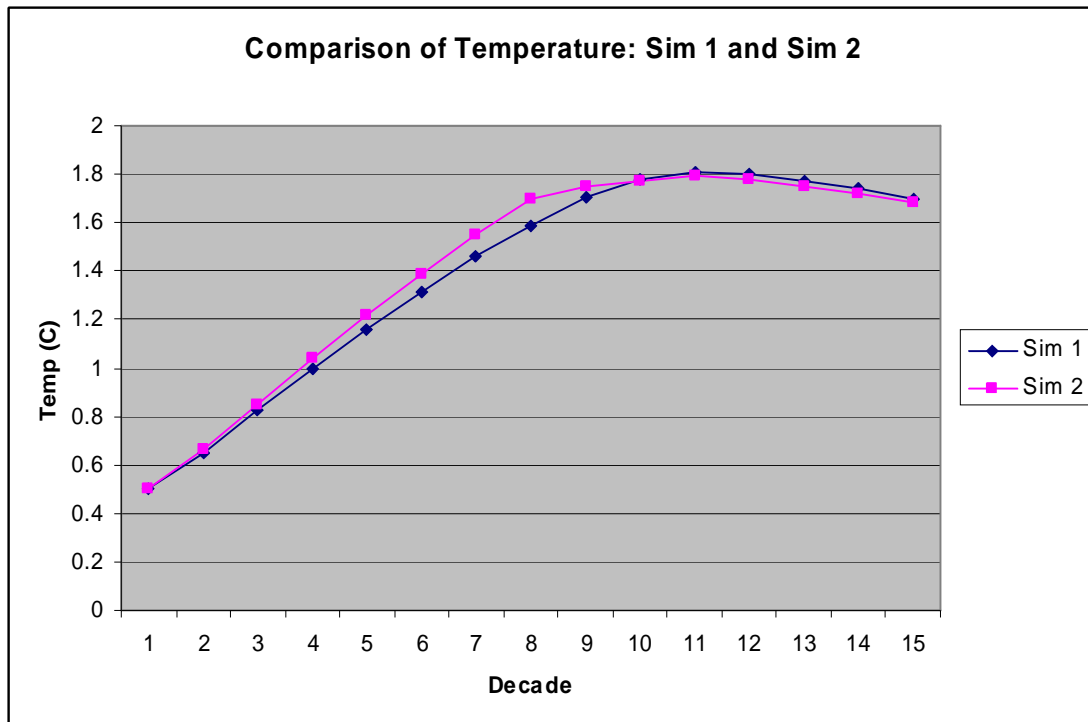
The price of energy is rising over time, and the consumption is falling. The switch-over date has been brought forward to the 8<sup>th</sup> time period. However the path of energy prices is lower and the consumption is higher for all time periods. These changes are identical to the algebraic results of Levy (2000).

As can be seen from comparing the results of Simulation 1 and Simulation 2, a lower eventual price for renewables will accelerate the consumption of fossil fuels. Since the atmosphere is a product of the time profile of GHG emissions, this will produce an acceleration of global warming.

I use Nordhaus' model of global warming, his RICE/DICE model, presented in papers such as Nordhaus (1992, 1999) to illustrate the effects of a faster rate of consumption of a fixed fossil fuel resource. A spreadsheet version of the RICE and DICE models are available through Nordhaus' webpage at <http://nordhaus.econ.yale.edu/>. Interpret each time period in the simulations as decades starting in 2005 and each observation on consumption as annual consumption in gigatons of carbon dioxide equivalents.

The time paths global temperatures under Simulations 1 and 2 are graphed in Figure 1. Temperature is displayed by decade for each of the two simulations. The temperature given here is relative to pre-industrial time, as Nordhaus uses. Approximately the same peak temperature is reached on each time path, however Simulation 2 with the faster time profile for consumption rises faster and peaks sooner than Simulation 1. Temperature ultimately starts to decline in this model as GHG emissions cease after period 9, as the deep oceans slowly pull the carbon dioxide from the atmosphere.





We have an example of Popper's Law of Unintended Consequences. A policy of promoting renewables technology was put in place in order to reduce global warming, however in this simulation, the policy lead to higher global temperatures sooner.

A similar problem arises if we introduce a tax on fossil fuels as a means of reducing GHG emissions. Assume we use the same simulated parameters in Simulation 1 as above with an eventual cost of renewables of 6. If we add a tax on fossil fuel production of 2, then our simulation yields:

#### Simulation 3

Time	Fossil Fuel Consumed	Price of Energy	Fossil Fuel Reserves	Renewables Consumed
1	6.30	3.70	43.696	0.00
2	6.13	3.87	37.562	0.00
3	5.95	4.05	31.615	0.00
4	5.74	4.26	25.873	0.00
5	5.52	4.48	20.356	0.00
6	5.27	4.73	15.089	0.00
7	4.99	5.01	10.094	0.00
8	4.69	5.31	5.400	0.00
9	4.36	5.64	1.036	0.00
10	1.04	6.00	0.000	2.96

Compared to the results in Simulation 1, a tax on fossil fuel production slightly slows down GHG emissions, but the total quantity of fossil fuel consumed is the same. The cost of extraction of the fossil fuels is so low that no tax short of the cost of renewable

energy would lead to some reserves being unused. However if the tax is anticipated by the energy markets, we can have another perverse result. A future tax intended to slow down fossil fuel consumption can actually accelerate the emissions of GHGs.

If the tax is envisaged to occur starting in period 7, the energy market will react in period 1 to the lower anticipated value of future reserves of fossil fuel. Our simulated results are:

#### Simulation 4

Time	Fossil Fuel Consumed	Price of Energy	Fossil Fuel Reserves	Renewables Consumed
1	7.95	2.05	42.05	0.00
2	7.74	2.26	34.31	0.00
3	7.52	2.48	26.79	0.00
4	7.27	2.73	19.53	0.00
5	6.99	3.01	12.53	0.00
6	6.69	3.31	5.84	0.00
7	4.36	5.64	1.47	0.00
8	1.47	6.00	0.00	2.53
9	0.00	6.00	0.00	4.00
10	0.00	6.00	0.00	4.00

Comparing the results of Simulation 4 to the results in Simulation 1, if the energy markets anticipate a future tax on fossil fuel production, producers will accelerate current production, current prices will drop and GHG emissions will accelerate. If we put these numbers through the Nordhaus climate model, we would see the same general path for global temperatures as we saw for the case of accelerated renewables development.

#### **A complication- multiple sources of fossil fuels**

The simulations up to this point have assumed that all fossil fuels were available for extraction at a low and constant cost (relative to market price). Allowing for the existence of different sources of fossil fuels at different extraction costs changes the analysis significantly. Whether we have perverse results now depends on the distribution of fossil fuel costs.

There is a large literature on the optimal extraction strategy when there are multiple sources with differing costs. I assume that extraction costs are constant within each source, but differ across the sources. Heal (1976), Solow and Wan (1976) and Kemp and Long (1980) established that it is always optimal to extract the resource in order of increasing cost sources if there was some mechanism for consumption smoothing or saving in the economy other than the fossil fuel resource itself. Long-lived capital projects should adequately serve this role.

The same simulation numbers from the previous section are used except now there are two sources of fossil fuel. One source has a constant extraction cost of zero with initial reserves of 25, while the other source has a constant extraction cost of 5 with initial reserves of 25. Assuming a renewable technology exists at a constant per unit cost of 6, our simulation produces:

#### Simulation 5

	Fossil Fuel 1	Fossil Fuel 2	Renewables	Price of Energy	Fossil Fuel 1 Reserves	Fossil Fuel 2 Reserves
Time	Consumed	Consumed	Consumed			
1	6.2	0.0	0.0	3.8	18.8	25.0
2	5.8	0.0	0.0	4.2	13.0	25.0
3	5.4	0.0	0.0	4.6	7.6	25.0
4	4.9	0.0	0.0	5.1	2.6	25.0
5	2.6	1.8	0.0	5.6	0.0	23.2
6	0.0	4.4	0.0	5.6	0.0	18.8
7	0.0	4.3	0.0	5.7	0.0	14.5
8	0.0	4.2	0.0	5.8	0.0	10.3
9	0.0	4.2	0.0	5.8	0.0	6.1
10	0.0	4.1	0.0	5.9	0.0	2.0
11	0.0	2.0	2.0	6.0	0.0	0.0
12	0.0	0.0	4.0	6.0	0.0	0.0
13	0.0	0.0	4.0	6.0	0.0	0.0
14	0.0	0.0	4.0	6.0	0.0	0.0

The low cost source is exhausted then the higher cost source of fossil fuels is consumed before the switch-over to renewables occurs. Even though the total reserves of fossil fuels is the same as in Simulation 1, the higher cost of the second source of fossil fuels means that the consumption path is lower than in Simulation 1, and the switch-over date in period 11 is later.

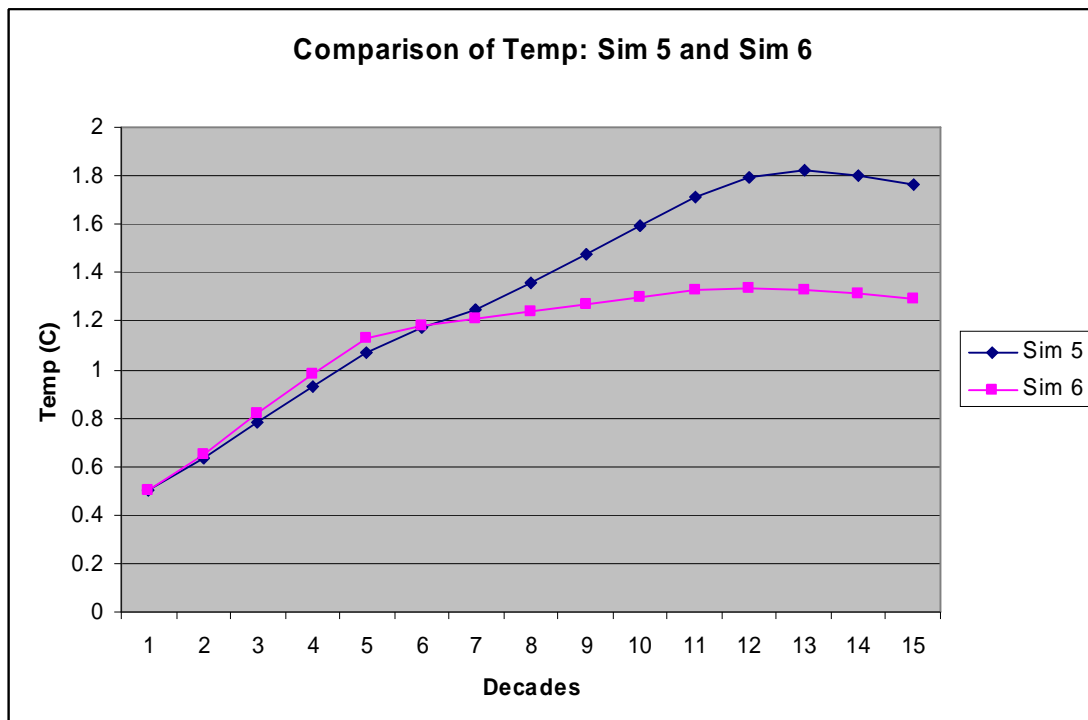
If development of renewables technology will result in a cost of renewables that is greater than the higher cost source of fossil fuels, we will have the same result as in Simulation 2. Development of cheaper renewables sooner will lead to an earlier switch-over date, an accelerated path of fossil fuel consumption and accelerated global warming.

However if the eventual cost of the renewable energy is less than the higher priced source of fossil fuels, our result will be drastically different. If technological development brings the price of renewables production down to 4, our simulated results will be:

### Simulation 6

Time	Fossil Fuel 1 Consumed	Fossil Fuel 2 Consumed	Renewables Consumed	Price of Energy	Fossil Fuel 1 Reserves	Fossil Fuel 2 Reserves
1	7.0	0.0	0.0	3.0	18.0	25.0
2	6.7	0.0	0.0	3.3	11.3	25.0
3	6.4	0.0	0.0	3.6	4.9	25.0
4	4.9	0.0	1.1	4.0	0.0	25.0
5	0.0	0.0	6.0	4.0	0.0	25.0
6	0.0	0.0	6.0	4.0	0.0	25.0
7	0.0	0.0	6.0	4.0	0.0	25.0
8	0.0	0.0	6.0	4.0	0.0	25.0
9	0.0	0.0	6.0	4.0	0.0	25.0
10	0.0	0.0	6.0	4.0	0.0	25.0
11	0.0	0.0	6.0	4.0	0.0	25.0
12	0.0	0.0	6.0	4.0	0.0	25.0
13	0.0	0.0	6.0	4.0	0.0	25.0
14	0.0	0.0	6.0	4.0	0.0	25.0

As in the previous simulations, the cheaper renewables accelerates the consumption of the fossil fuels from the cheaper source. However the more expensive source is not used, instead the economy switches to the renewables at period 4, jumping over the high cost fossil fuel source altogether.



The path of global temperatures for Simulations 5 and 6 are graphed in Figure 2. Developing cheaper renewables technology does accelerate global warming initially as in the earlier simulations, however because the second source of fossil fuels is now

untouched the eventual temperature increase under Simulation 6 is lower. Only half the fossil fuel reserves are used if renewables technology development is accelerated, and this shift in resource use is the dominant effect on eventual global temperatures. However it is easy to imagine that a different result could occur, such as if there were large amounts of “cheap” fossil fuels and only a small reserve of “expensive” fossil fuels.

## **Conclusions**

The answer to the question in the title is “Yes, it can, but...” As always with complex issues, the answers must be hedged with qualifications.

The outcome of cheaper renewables depends on the level of eventual GHG emissions, which in turn will depend on the extraction costs of the different sources of fossil fuels, and on the rate at which they are produced. Developing cheaper renewables has two effects, accelerating consumption of fossil fuels, and a second effect, locking out certain fossil fuels from consumption. These two effects move global warming in opposite directions. If we make policy perspectives about renewables technology, we should include both of these effects in our global climate models.

The outcome of anticipated rising taxes on GHG emissions is identical to faster development of renewables technology. Future taxes lower the value of future consumption and so accelerate fossil fuel consumption today. However future taxes may lock out high priced sources of fossil fuels and so may reduce eventual production of GHGs. The net effect on global temperatures is ambiguous.

What policy response could prevent this acceleration of fossil fuel consumption today? Cheaper renewables and future carbon taxes accelerate consumption today because they reduce the value of future production of fossil fuels. One policy to counter this effect would be to have a declining tax on fossil fuels, or perhaps even a subsidy on future fossil fuel production, to increase the value of future production relative to production today.

The problem we are confronting is that the policy prescriptions which flow out of global climate models are not adequately addressing the incentives facing participants in the energy market. The supply side responses to policy have been ignored in the models used for global climate modelling. That the models biologists use have naïve economic models is not surprising and is even understandable. That the models used by economists have no supply responses is more difficult to accept.

Chakravorty et al. (1995) despite very carefully modelling the process of transitioning from one energy source to alternative energy sources ignore the effect of cheaper renewable energy on the supply of fossil fuels. Likewise in Nordhaus (1992, 1999) a policy path for carbon taxes is modelled without recognizing that the possibility of future taxes will affect the supply of fossil fuels today. Neither the Global Trade and Environment Model (GTEM) used by ABARE economists nor the MMRF-Green model used by the Allen Consulting Group have supply responses in the energy market.

The atmospheric physics is far more sophisticated than the economic modelling in our global climate models. Surely if we are to use global climate models to inform policy-making, we must improve the economic modelling within them.

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