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Technological pathways for reducing emissions: uncertainty and options costs for the teacher's pets

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Summary

Scientists tell us that we need to reduce emissions as fast as possible but there is considerable uncertainty about the technologies necessary to do this and their economic costs. Policy makers in Australia are under pressure to bet the economy on reducing emissions by reconfiguring electricity production using solar and wind as the primary generation technologies. These are the proverbial 'teacher's pets'. They may or may not be the best in class. They may never grow up to achieve too much. But they are certainly popular with the decision-maker right now. Is this a good way to run policy? This paper sets out our preliminary views on the way in which ideas about options and hedging will help answer this question.

To make a good bet we need to consider the full economic costs of different technological pathways including externalities such as material usage, cost of emissions displaced effect on national capacity and the risks associated with uncertainty. It is not enough to look at short term accounting figures.

In this paper we make a start on thinking about how to make the right bets by focusing on the effect of uncertainty about costs and technologies along trajectories. In particular we consider costs associated with the fact that moving along one pathway may require investments and a network and infrastructure that may be unsuitable for alternative technologies. These may have to be unwound if the initial choice turns out bad. For each choice of trajectory, the options cost is the cost of switching to an alternative. A pathway will be a good bet if it is the best option given knowledge of these costs at the time of the choice.

We find using a simple dimensionless model that the more uncertain the technological trajectory the more it must be justified based on large cost differentials today. Given this finding any energy policy that is too reliant an undiversified set of more marginal technologies, say one or two 'pet' favorites, is highly questionable.

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Introduction

Betting the economy

Scientists tell us that we need to reduce emissions as fast as possible but there is considerable uncertainty about the technologies necessary to do this and their economic costs. In Australia there seems to be considerable pressure to make the required changes by using solar and wind as the primary generation technologies and without the possibility of importing back up.. This is unlike California or Germany, for example, that have access to much larger grid systems. This makes the all-or-nothing Australian approach unique amongst industrialised economies. It also places the Australian economy on a risky technological trajectory.

The key question then: is it a good idea to bet the entire economy on these two generation technologies? The truth is, we don't know. What we do know is that nuclear has been shown to be able to replace fossil fuels at scale. As yet there is no evidence that solar and wind can do this. A great deal depends on *unproven* technological advances. On the other hand there are claims that solar and wind will be far cheaper than nuclear. This, as they say, remains to be seen.

The question about betting the economy could be answered by adopting a mini-max strategy. We can simply say it is a bad bet because the risk is too great . There is a great deal to be said in favour of this view. Nonetheless it doesn't give us much information and it doesn't fully consider the possibility of changing trajectories.

In order to get more information on options and pathways we could ask the following: what would make our current trajectory a good bet if we were willing to accept the risk? In order to answer this question we need some way of assessing the risks of different technologies together with their costs on the **same** metric.

Option switching costs

In order to avoid any confusion it is worthwhile stressing the point about the system as a whole and trajectories across time. National **policy is concerned with total current and future welfare.** The government is not an electricity trader. It is not enough to simply base policy on extrapolations from partial and short-term accounting figures. Had we based decisions on current costs in say, 2000, no one would have invested in solar and wind.

A serious assessment of economic costs needs to take into account all externalities including such things as technical capacity, land use, materials and so on. **In this paper we will focus on the economic costs associated with developments along trajectories when there are uncertainties about whether the chosen pathway provides the best, or even a sustainable, energy system.** We leave other costs to a different study.

In particular we will consider costs associated with the fact that moving along one pathway may require investments and a network and infrastructure that may be unsuitable for alternative technologies. These may have to be unwound if the initial choice turns out bad.

A more familiar way to understand these costs is in terms of options or hedging. For each choice of trajectory the options cost is the cost of switching to an alternative.

In order to explore these costs we develop a simple dimensionless model. This may provide the framework for more detailed analysis in subsequent studies.

In short, this simple model shows that *the more uncertain trajectory may only be justified under large cost differentials*. If so, a policy that depends on solar and wind in isolation is questionable.

The problem

The model

Suppose that the problem is to choose a technology to produce some fixed amount of energy at an acceptable cost and level of emissions before we know how every choice will perform at the level of the entire grid. This means that there is a possibility we may need to switch trajectories. If this were costless there would not be an issue. On the other hand, a network developed for one type of generation may be unsuitable for, or make it expensive to switch to, an alternative after some time. It may also result in a loss of capacity where one technology requires higher levels of specialised skills than another. It incorporates costs of having to rebuild infrastructure, fast build times, the cost of having to gain experience and establish suppliers of materials and so on. In some cases a technology may be pushed along a 'bad' pathway because the conditions required to develop an alternative have been displaced by prior decision making and this may have long-term economic consequences. **We will ignore this last possibility and concentrate on the economic value attached to options for switching.**

Imagine that there are only two types of technology. Type α technologies are solar and wind. Type β technologies are things like gas with carbon capture and storage or nuclear. Excluding fossil fuels gives nuclear, although the analysis holds for the more general case.

The characteristics of the α program are uncertain. There are strong arguments that it may fail in its capacity to produce the required energy at an acceptable cost and it has never been tested at scale.

It is known that the β program can produce the energy required at reasonable cost with existing technology and this has already been achieved.

It is also possible that in future *either* the α or the β program may achieve a substantial relative cost advantage. In the absence of better information it is assumed that the probabilities are the same in either direction and this is ignored.

A program that uses α as a stand alone is labelled S_1 with cost s_1. This has a probability of failure given by θ . The alternative is labelled S_2 with cost s_2. This may be configured with different combinations of α and β to be discussed below. If only a β program is employed it has a probability of failure $\sigma < \theta$. This is pursued for completeness below. It is not clear, however, that this assumption can be fully justified. It is always possible to reduce σ by selecting a mix of α and β technologies.

Let x be the cost of producing the quantity of technology of type α necessary to give the required amount of energy and y the cost of type β and let time be $t \in [0, 1]$. If we assume expenditure is constant x_r and y_r can be treated as expenditure to time $t = r$.

It is assumed that, if S_1 won't satisfy the capacity and cost requirement, there is some minimum fraction of type β technology that has to be built. Let this fraction be $w \leq 1$.

Possibilities

The possibilities for S_2 are either a mix of technologies or a program using a β technology alone. If a switch is made in S_1 there is a cost penalty in building the alternative given by $c(t) \geq 1$. This penalty will also apply if S_2 is based on a single technology. It is assumed that this penalty accelerates with the time to the decision point. Let the cost of switching from trajectory S_i to S_j be c_{ij}. This means

$$\dot{c}_{ij} > 0 \text{ and } \ddot{c}_{ij} > 0$$

If program S_2 is a combination of α and β technologies the infrastructures and operating procedures for both technologies are already in place and it is assumed that a switch caries a smaller penalty. For convenience set $c_{21} = 1$ and write c_{12} as c.

We evaluate total costs along a trajectory to some decision point t = r and then project probable costs after that time.

In summary the possibilities are:

A. S_2 a combination of α and β technologies.

The cost functions can be written

$$s_1 = xt + (1 - \theta)x(1 - t) + \theta wcy$$

$$s_2 \leq (1 - w)x + wy$$

evaluated at $t = r \geq q$ where $xq = 1 - w$. In s_2 there is an inequality because either the program switches and total cost falls or it does not change.

It will be noted that the probability of failure, σ, does not appear since there is no switching cost.

B. S_2 a β technology

The cost functions are:

$$s_1 = xt + (1 - \theta)x(1 - t) + \theta wcy$$

$$s_2 = yt + (1 - \sigma)y(1 - t) + \sigma(1 - w)cx$$

evaluated at t = r.

Restatement of question

It is now possible to state the question precisely. How expensive would the β technology have to be relative to the α technology to make it worthwhile starting with the α trajectory? To answer this we work with the dimensionless equation

$$\varphi = y/x$$

Solution

Possibility A

S_2 a combination of α and β technologies. The time required to discover the behaviour of a trajectory gives two interesting cases:

[i] a decision is made at time t = r = (1 – w) when the maximum amount of the α technology has been built and there are no redundancies.

[ii] a decision is made some time after the maximum α technology is built.

Case **[i]:** decision at $t = r = (1 - w)$

The S_1 program will be strictly preferable at the initial time if $s_1 < s_2$. From the inequality this is true if

$$\varphi > (1 - \theta)/(1 - \theta c)$$

For c > 1 we have φ > 1 unless $\theta c > 1$. In this case the inequality is meaningless and program S_1 is never chosen. If $\theta c \to 1$ we have $\varphi \to$ infinity and program S_1 is only worthwhile if it is believed that y > K for some arbitrarily large K.

It is obvious that φ increases in θ . To see how φ behaves as c increases take the partial differential

$$\varphi_c > 0 \text{ and } \varphi_{cc} > 0$$

and it follows that the cost of technology type β that would be necessary for the type α program to be optimal increases at an increasing rate in c. **See Figure 1.**

It is something of a surprise to see that the fraction of type β technology required for the system to satisfy the cost constraint is irrelevant.

Case **[ii]:** Decision at $t = r > (1 - w)$

In this case S_1 has already overbuilt the α technology. For program S_1 to be strictly preferable

$$\varphi > (w - \theta(1 - r))/w(1 - \theta c)$$

and a little algebra shows us that the required relative cost of the β technology is greater than previously.

In this case the fraction of type β technology required becomes important. Differentiating gives

$$\varphi_w = \theta(1 - r)/w^2 (1 - \theta c) > 0$$

and the relative cost of the β technology that would be necessary for the α program to be optimal increases as increases.

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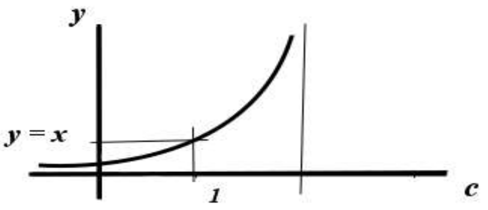
Figure 1. Relative costs of technologies for change in c



Differentiating with respect to t evaluated at the time of decision gives

$$\dot{\varphi} = \theta\,((1 - \theta c + c(w - \theta(1 - r))/w(1 - \theta c)^2$$

hence

$$\dot{\varphi} > 0$$

since S_1 is only meaningful for $1 - \theta c > 0$ and $r > (1 - w)$.

A little work gives

$$\ddot{\varphi} > 0$$

and it follows that as the time necessary to discover whether S_1 works increases, the relative cost of the β technology necessary for the α program to be optimal increases at an increasing rate.

Possibility B

S_2 a β technology. In this case

$$\varphi = 1 - \theta(1 - t) - \sigma(1 - w)c21/(1 - \sigma(1 - t) - \theta wc12)$$

Case **[i].** Probability of failure in β small

Let $\sigma \rightarrow 0$. This means

$$\varphi \rightarrow 1 - \theta(1 - t)/(1 - \theta wc12)$$

with

$$\dot{\varphi} > 0$$

It follows that as $\theta wc \to 1$ from below the relative cost of β required for S_1 to be optimal becomes arbitrarily large.

Case **[ii].** Probability of failure in β is large.

In this case we have the expected results

$$\varphi_\sigma < 0, \ \varphi_\theta > 0 \text{ and } \varphi_w > 0$$

and it is obvious that the characteristics of φ will depend on the assumptions we make about σ and θ.

It is often argued that trajectory S_1 should be preferred because it takes more time to build β technologies like nuclear. Leaving the accuracy of the claim aside it means that c_{12} will be higher at each t > 0.

In this case we get a slightly surprising result. This is that an increase in the time to build the β technology may not increase the value of the S_1 trajectory if the probability of failure is held constant. To see this we use the partial differential to get

$$\varphi_{c12} > 0 \text{ and } \varphi_{c12c12} > 0$$

and the relative cost of β has to increase at an accelerating rate to make S_1 worthwhile.

Remarks

Information on the probability of failure and the minimum technology of each type required varies from crude to non-existent. Nonetheless the message is clear. To justify betting the farm on the S_1 program from the get go would require that the probability of failure of the α program be negligible or the expected cost of β be extremely high.

Both these assumptions seem to us bad bets.

If a relatively large risk of failure in the β program is assumed, the analysis becomes less informative. It is not clear how relevant this assumption is to the problem considered. If this risk were thought to exist it could be made small by using a diversification strategy and selecting an appropriate mix of α and β technologies.

It would be a simple matter to develop applications of this approach to get a range of figures for different estimates of values on risk and build costs

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