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Climate policy decisions under uncertainty

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The economics of global climate mitigation is discussed when there is imperfect knowledge of future climatic changes, of policy effectiveness and of the policy responses by different countries. Uncertainty is accounted for by using heuristics derived from classical decision rules. These heuristics provide plausible policy rules that depend on only limited information. They emphasize the possibility of “getting it wrong” in terms of the appropriate scale of policy response and from policy failure itself. The minimax rule or Precautionary Principle, which targets “worst case” situations, is not useful unless policies are effective with certainty. However the widespread presumption that policy action is warranted if climate-induced losses without action are “large" relative to costs of policy can be justified using minimax regret reasoning. The global analysis is extended to individual national decision-making when nations jointly play a game against nature with policy spillovers. Simultaneous moves game solutions as well as heuristics are provided and indicate how policy actions are best determined for individual countries rather than for a global authority.

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Climate Policy Decisions Under Uncertainty *

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September 2015

Abstract: The economics of global climate mitigation is discussed when there is imperfect knowledge of future climatic changes, of policy effectiveness and of the policy responses by different countries. Uncertainty is accounted for by using heuristics derived from classical decision rules. These heuristics provide plausible policy rules that depend on only limited information. They emphasize the possibility of "getting it wrong" in terms of the appropriate scale of policy response and from policy failure itself. The minimax rule or Precautionary Principle, which targets "worst case" situations, is not useful unless policies are effective with certainty. However the widespread presumption, that policy action is warranted if climate-induced losses without action are "large" relative to costs of policy can be justified using minimax regret reasoning. The global analysis is extended to individual national decision-making when nations jointly play a game against nature with policy spillovers. Simultaneous moves game solutions as well as heuristics are provided and indicate how policy actions are best determined for individual countries rather than for a global authority.

1. Background. Mitigating climate change generally means making long-term investments in technologies whose effectiveness is highly uncertain. Policy makers will therefore be partly ignorant of the consequences of their policy choices. They do not know what future emissions will be, how these are linked to climate change and what future abatement and damage costs, will be. They might take unnecessary mitigation actions or take inadequate measures. They may get it wrong.

Section 2 discusses the various uncertainties that impinge on national climate policies. Sections 3 and 4 discuss planning under risk and uncertainty respectively. Section 5 makes final remarks.

2. Climate risks and uncertainties. There are scientific uncertainties about the expected extent of climate change associated with accumulated greenhouse gases in the atmosphere and with determining the sensitivity of climate to such accumulated emissions because of uncertain climate feedback effects. There are also uncertainties about the extent of emissions that will occur. These depend on the uncertain climate policies of major emitters. The extent of desired mitigation is also part driven by uncertainties associated with mitigation costs. There are also uncertainties about the prospects for catastrophic events linked to climate change. Finally, there are even uncertainties about calibrating the character of climate

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change induced damages: Climate change has the potential to alter the way all human and non-human life connects to its biophysical environments. It is with bold, and perhaps unwarranted, confidence that such effects are often indexed in terms of GDP (or other) changes.

The policy task of addressing climate change should explicitly incorporate uncertainty. It is inadequate to assume particular climate scenarios and then to devise what are conceived to be appropriate policies that best fit them. Uncertainty is *intrinsic* and must be accounted for in policy design. For example, decisions have to be undertaken in the expectation that they may turn out to be incorrect.

What do we know about climate policy uncertainties? We *do* have substantive scientific argument on likely climate change effects and to a lessor extent on potentially catastrophic effects. We also suspect that costs of addressing climate change, although substantive, are not prohibitive.

We also know that actions to address climate change may have come too late so conventional policies may fail. The long half-lives of greenhouse gases in the atmosphere raise prospects of irreversible changes already having occurred forcing catastrophes either directly or via reliance on risky "last ditch" solutions such as geo-engineering: See Wagner and Weitzman (2015, Chapter 5). Finally, planet earth faces the prospects of other catastrophic events (nuclear war, asteroid strikes) that would either nullify, or at least modify, the case for climate action: See Martin and Pindyck (2015). Geo-engineering issues though not the implications of joint catastrophic risk are discussed below.

3. Planning Under Risk. One starting point for the economic analysis of climate mitigation is use of expected cost-benefit analysis adapted to account for the irreversible effects of climate changes when policy involves irreversible investments under risk when there is the prospect of learning about this risk by waiting. This is "real options" theory: See Dixit and Pindyck (1991).

The main analytical insights of the real options approach assume that a risk-neutral policy-maker is contemplating large irreversible investments on the basis of data that determines investment productivities that evolve as stochastic processes. Policy-makers know the parameters of these processes but only observe the values of key evaluative variables as the future unfolds.

The conjunction of risk-neutrality, investment irreversibility, risk and the prospect of learning create incentives to delay the initiation of investments beyond the times they would be initiated if outcomes were evaluated by replacing random variables by their expected values. Thus a case for caution in initiating projects emerges. Expected benefits must exceed expected costs by a positive quasi-option value that reflects gains from waiting to get improved information.

Such insight is important but the precise extent of caution that arises here depends on the specific numerical parameters of the stochastic processes considered. These depend on the growth rates, variances and, when there are several processes, the covariances of state variables. These data are almost never known so analysis is often conducted using simulated (= "invented") data.

Given the difficulties in operationalizing these procedures it can be questioned whether using simulation does more than verify standard qualitative properties of lower-order, analytical models. These qualitative insights are well known so relying on simulations may not contribute much new.

There are also problems in assuming risk-neutrality. The motivation for this is that public decision makers are viewed as selecting a large number of diversifiable investment projects with risky returns so it makes sense to look at expected outcomes across projects in accord with the Arrow and Lind (1970) theorem. This theorem, however, is inapplicable to climate-sensitive investments since risks then are non-diversifiable and pervasively experienced.

Given non-diversifiable risks and the prospect that climate change itself might lead to irreversible catastrophic environmental effects it is natural to posit risk-aversion rather than risk-neutrality with respect to climate outcomes.

Risk aversion does not necessarily imply positive quasi-option values indicating caution on mitigation policies. Instead it can promote an *anticipatory* case for investing even when expected benefits fall short of costs. Policy makers will *insure* to protect communities from severe irreversible climate change.

This creates a numerical tug-of-war between approaches that rely on risk neutrality and those accounting for risk aversion. Risk-neutrality suggests a case for caution and delay in project initiation while risk aversion seeks earlier anticipatory responses. Without detailed knowledge of both the risks and the extent of risk aversion it is difficult to determine qualitatively, the character of appropriate responses to climatic risk.

4. Planning Under Uncertainty. Pure uncertainty describes situations where possible future states of the world are known – here future possible climate states – but where not even subjective probabilities can be assigned to the states. Thus while climate change is real, measures of climate sensitivity, because they imperfectly capture feedback effects, are too rough to provide much useful probability density information (Pindyck, 2013).

When policy decisions are taken under uncertainty there is the prospect of taking inappropriate decisions. This prospect makes policy designers uncomfortable but it is unsatisfactory – and unethical – to choose the best *possible* decision only for a preferred state of the world – a *maxi-max* policy: See Nozick (1974, p. 298), De Martino (2011, 151-153). The consequences of being wrong must be assessed and incorporated into decision-making. We will argue there are useful classical decision rule heuristics for doing this.

4.1 All-or-nothing mitigation efforts. Initially take a global perspective on mitigation with the world as a whole playing a game against nature. Suppose global mitigation efforts costs a known amount C but global benefits depend on an uncertain future state of the world. In state S_1 mitigation yields large positive benefits by avoiding severe climate change effects and consequent known large economic losses L. In state S_2 mitigation fails to yield benefits because climate change does not occur, so L=0. In S_2 the cost C is incurred but no benefits arise because climate costs are negligible. Finally, in S_3, mitigation is implemented and climate change occurs but the mitigation efforts fail to address climate problems. In S_3, when policy action is taken, both the project cost C and the losses L arise giving total costs C+L.

C is a policy cost and it is reasonable to suppose it is reasonably well known. Taking L to be deterministic is a limiting assumption but it is plausible to believe that policy analysts have a better grasp of the magnitude of expected climate induced losses than the probability distribution that such losses will occur.

This information is summarized in **Table 1**.

	S_1	**S_2**	**S_3**
Mitigate	**C**	**C**	**C+L**
Not mitigate	**L**	**0**	**L**

Table 1: Costs of mitigation outcomes

If probability information were available then this policy problem can be posed as one of minimizing expected costs. Assign probabilities p_1, p_2 and $p_3 = 1-p_1-p_2$ to states S_1, S_2 and S_3. The expected cost from mitigating is $p_1C + p_2C + p_3(C+L) = C+p_3L$ while that of not mitigating is $(p_1+p_3)L$. Then there is an expected value case for mitigating when $C < p_1L$ so *the cost of taking action is less than the expected climate damage cost effectively avoided by taking action*. This is a *standard cost-benefit rule*.

There are two issues involved in implementing this rule:

(i) Evaluating expected damages from not undertaking effective policy involves computing the multiplicative product of quantities that are themselves highly uncertain. First, there is the highly uncertain (though potentially "large") expression for losses (L). Second, there is the poorly understood (though possibly "small") probability of taking both successful and necessary policy action (p_1) to deal with might be a catastrophic event. It is difficult to make sensible judgments about the size of products of form p_1L *even to an order of magnitude* yet this is essential for testing the standard cost-benefit rule.

(ii) With large enough losses L, irrespective of how low the probability (p_1) of successful policy is, there will be an expected value case for undertaking policy action. This is a variant of "Pascal's Wager" problem: See Green (2012). Pascal asked whether it was sensible to believe in God or not. Pascal argued that since we can't prove or disprove God's existence we should wager that God exists, because there is much to gain if it he does and not much is lost if he doesn't. The same argument can be applied in climate policy contexts: Given sufficiently high possible losses (the world might end!) it always makes sense to take action if costs are bounded. Wagner and Weitzman (2015, pp. 77-78) refer to the fact that "fat tails" can dominate cost-benefit analysis as the "Dismal Dilemma".

Indeed this argument for climate activism makes greater sense than Pascal's case since, while science cannot be used to throw light on God's existence, science does confirm the likelihood of at some damage from unmitigated climate change. Standard cost-benefit analysis will be redundant in advancing what policy should be adopted since there will always be a case for action given sufficiently large losses.

These are reasons for not basing assessment on subjectively assigned probabilities. An alternative approach that eschews use of probability information is to choose an action that minimizes the maximum loss than could ever occur. This *minimax* policy provides one motivation for what is called the *Precautionary Principle*: See Chisholm and Clarke (1993), Clarke (2008). This posits infinite risk-aversion and focuses on avoiding extreme very bad outcomes rather than simply pursuing good average outcomes.

The maximum loss that can occur in a climate context is if mitigation is implemented but climate change damages continue to arise. This occurs when mitigation occurs and S_3 arises. It suggests never mitigating if there is any - however remote – possibility of policy failing to work. This is an extreme view. If the possibility of mitigation policy failure is excluded then mitigation should proceed if the policy cost C is less than the avoided climate change loss L, *the standard cost-benefit view*.

A twist on minimax is to suppose that, if mitigation policy fails, a backup policy such as geo-engineering can be employed to offset the impacts of climate change. Suppose this latter costs C_g but creates particular risks itself so that society could then be exposed to distinctive environmental costs L_g. Then if $C_g+L_g > L$ it is again inappropriate to ever mitigate initially since eventual costs from mitigation (including geo-engineering costs) can always conceivably exceed the unmitigated costs of severe climate change. In the plausible situation where $C_g+L_g < L$ the policy and environmental costs of a final geo-engineering effort are less than unmitigated climate change.

Now the case for early mitigation effort requires $C+C_g < L-L_g$ so *initial mitigation effort costs plus geo-engineering costs must be less than the environmental cost reduction caused by using a geo-engineering solution rather than experiencing unmitigated climate change*.

Most analysts see use of minimax as too conservative because *any* possibility of policy failure destroys the case for activism. As motivation for the Precautionary Principle it has been seen as "paralyzing" (Sunstein, 2005).

Can the prospect that mitigation options might fail be retained but still provide a sensible decision heuristic? One approach is to compute the *regret* experienced under various policies and to minimize the resulting maximum regret that could occur. Regret is the difference between the costs incurred when making an investment decision (say c_1) and the cost incurred once the state of the world (c_2) is observed - the *minimax regret decision rule*. This heuristic avoids situations where large losses could have been avoided by incurring relatively low mitigation costs. Regrets for the climate problem are in **Table 2**.

	S_1	S_2	S_3
Mitigate	**0**	**C**	**C**
Not mitigate	**L-C**	**0**	**0**

Table 2: Policy regrets for different mitigation options

If mitigation proceeds and a substantial loss is avoided, because state of the world S_1 occurs, there is zero regret so c_1=c_2. Similarly if mitigation does not occur and either severe climate change does not occur (S_2) or it occurs but the construction is useless (S_3) there is zero regret. If mitigation does not occur but climate change does eventuate then the regret is the loss incurred less the cost saved (L-C). If mitigation occurs and either climate change does not or the mitigation effort proves useless then the regret is only the wasted cost C.

The maximum regret possible with mitigation is C while the maximum without it is L-C so maximum regret is minimized with active mitigation if L-C > C or if:

$$L > 2C. \qquad 1.$$

This is a plausible heuristic: *Once the possibility of policy failure is admitted, a decision to proceed with mitigation requires the expected benefits from action to "greatly" (here at least "doubly") exceed costs*. Note this same condition obtains if state of the world S_3, where policy fails, is omitted since the maximum regrets experienced in state S_2 are those in S_3.

Condition 1. is satisfied in some policy studies of the costs and benefits of global mitigation effort. Thus Stern's (2006) assessment satisfies 1. although this assessment has been criticized for overstating the benefits of mitigation and understating costs. The survey in Tol (2014), and summarized in his Tables 3.1 and 6.2, is much more ambivalent.

The states considered using minimax and minimax regret decision procedures are not entirely "probability free" since a prior empirical judgment is made that these are the plausible and possible states that we seek to focus on. Implicitly therefore some sort of "threshold" probability idea is being introduced. As a recent survey notes "some thresholds would be required to avoid results being dominated by entirely implausible outcomes" (Kunreuther et al. (2013, p. 3)).

4.2 Mitigation policy as a game among nations against nature. Instead of a global game against nature consider a game played between nations involving nature as a passive side-party that partially determines the state of the world. Consider two countries – "China" and the "US". Each has the same policy options described above but these are now individual national policies with global spillovers. Each country can comprehensively mitigate emissions (strategy M) at costs C_c and C_u for China and the US, respectively. Each can, alternatively, do nothing (strategy D) and incur no policy costs. The new possible sources of regret here for one country (say "China") is that the US might either not supply adequate mitigation effort or that it might supply enough so that China's efforts are redundant.

As before one of three states S_1, S_2 and S_3 eventuate. If both countries mitigate in S_1 and S_2 then the only costs are policy costs. In state S_3, where each country's policies fail, China (respectively the US) experience large climate induced environmental damages LL_c (respectively LL_u).

In S_1 if only China mitigates, then it experiences costs C_c+L_u where L_u are climate costs imposed on China because the US does not mitigate. The US also experiences climate costs L_u' because only China mitigates. Symmetrically, if the US alone mitigates it experiences costs C_u+L_c and China experiences costs L_c'. Here L_u, L_u' are less than LL_u and L_c, L_c' are less than LL_c. In S_1, if neither country mitigates, each experiences large losses, LL_c and LL_u respectively. In S_2 the only costs are those of unnecessary policies. In S_3 the policy costs are those in state S_2 but in addition the respective damage costs are experienced. The overall matrix of costs incurred by each country given the various states that occur when the countries pursue the respect policies M and D is in **Table 3**.

China	US					
	S_1		S_2		S_3	
	M	**D**	**M**	**D**	**M**	**D**
M	C_c, C_u	C_c+L_u, L_u'	C_c, C_u	C_c, 0	C_c+LL_c, C_u+LL_u	C_c+LL_c, LL_u
D	L_c', C_u+L_c	LL_c, LL_u	0, C_u	0,0	LL_c, C_u+LL_u	LL_c, LL_u

Table3: Payoffs in a game among countries and nature.

There are several ways of thinking about this policy task.

Simultaneous moves game solution. If either (or both) countries believe states S_2 or S_3 will eventuate with certainty then neither should mitigate. If on the other hand state S_1 is believed to occur with certainty then China has a *dominant strategy to mitigate* if:

$$C_c < L_c' \qquad (2A)$$
$$C_c + L_u < LL_c \qquad (2B)$$

(2A) requires that China's mitigation costs be less than the environmental costs it would face if the US alone mitigated and severe climate change occurred. (2B) requires that China's mitigation costs, plus its environmental costs from climate change assuming it alone mitigated, must be less than the costs it would experience if neither country mitigated.

If both inequalities (2A), (2B) are reversed then China has dominant strategies *not* to mitigate even given the likelihood of severe climate change.

These arguments suppress risk by assuming known states eventuate. But again assigning subjective probabilities p_1, p_2 and $p_3=1-p_1-p_2$ to S_1, S_2 and S_3 is unhelpful. With these probabilities it is straightforward to seek Nash equilibria. The expected payoff matrix is **Table 4**:

China	**US**	
	M	**D**
M	$C_c+p_3LL_c$, $C_u+p_3LL_u$	$p_1L_u + C_c + p_3LL_c$, $p_1L_u' + p_3LL_u$
D	$p_1L_c'+p_3LL_c$, $p_1L_c + C_u + p_3LL_u$	$(1-p_2)LL_c$, $(1-p_2)LL_u$

Table 4: Expected payoffs in the game among nations and nature

Conditions for China to now have dominant strategies to mitigate are analogous to those for the case where S_1 was assumed to occur with certainty. Now however climate losses are replaced by their expected values so instead of (2A), (2B):

$$C_c+p_3LL_c < p_1L_c'+p_3LL_c \Leftrightarrow C_c < p_1L_c' \quad (3A)$$
$$p_1L_u + C_c + p_3LL_c < (1-p_2)LL_c \Leftrightarrow C_c + p_1L_u < p_1LL_c. \quad (3B)$$

Now China's costs of mitigating must be less than the *expected* damages it would experience if it didn't act and the US acted alone on climate. Chinese mitigation must be less than the expected costs it would experience if it "free rode" by relying on US efforts. In addition Chinese mitigation costs must be less than the expected *extra* damages it faces from unmitigated climate change when it acts to address climate change but the US did not. *It must be cost effective to mitigate even if the US does not.*

The quantities that determine the efficacy of this action are crucially the probability, p_1, that severe climate change will occur and can be usefully addressed, the scale of the losses associated with climate change when, in turn, China and the US free ride on the efforts of the other country, and the losses accruing to China when neither country mitigates, respectively L_c', LL_c and L_u.

As in assessing the standard cost-benefit rule in 4.1 there are a highly indeterminate set of cross product terms that must be evaluated in carrying out these evaluations. There are again highly uncertain expressions for losses (L_c', LL_c, L_u) and poorly understood (though possibly "small") probabilities of successful and necessary policy action (p_1). There are also "Pascal Wager" issues: With large enough losses (L_c', LL_c, L_u), irrespective of how small the probability of successful policy (p_1) is, there is always a case for undertaking policy.

Finally, strategic issues between national climate policies are characterized as market failure/Prisoners Dilemma (PD) situations where individual national incentives do not imply cooperative beneficial outcomes – where both countries have dominant strategies not to mitigate even though they would both be better off if they mitigated: See Clarke (2010). Here a PD requires that each of the two inequalities (3A), (3B) be reversed so there are dominant strategies not to mitigate. In addition, there is the requirement that each country must be better off mitigating if both did.

For China this last condition is:

$$C_c + p_3 LL_c < (1-p_2)LL_c \Leftrightarrow p_1 LL_c > C_c. \quad (4)$$

Therefore, expected payoffs to China from mitigating must be less than known mitigation costs – a generalization of the standard cost-benefit rule now adapted specifically for China. A symmetric condition holds for the US. Now neither country will mitigate even given the standard cost-benefit case for doing so.

Given the difficulties of interpreting expected cost terms, of Pascal Wager issues and simply of estimating probabilities it is again of interest to determine how the nations would select policies if they have no subjective probability information but are risk-averse.

Minimax solutions. If China mitigates then the maximum cost it can incur is in S_3 when its costly policy fails. It then incurs costs $C_c + LL_c$. If China plays D then the maximum cost it can incur is either in S_1 when neither it nor the US mitigate or when climate change occurs but both policies fail. This cost is LL_c. Since $C_c + LL_c > LL_c$ it is always more costly, comparing worst outcomes, to mitigate than not to, so China should not mitigate. A comparable analysis applies to the US.

Therefore again the minimax criterion makes little sense unless policy failures (state S_3) can be ruled out since, when S_3 is possible, neither country should mitigate. If S_3 can be ruled out then the maximum cost China can face if it mitigates occurs when the US doesn't is C_c+L_u. If China does not mitigate the maximum cost it can ever face is when the US also does not mitigate and is LL_c.

Thus, if policy failure is ruled out, China will minimize the maximum cost it can face by mitigating whenever $LL_c > C_c+L_u$ so the costs it experiences when no country mitigates must exceed the costs it faces if it mitigates but the US does not.

Minimax regret options. A regret matrix for each country is now computed. In S_1, if the countries spend C_c, C_u respectively, there is no regret. If they mitigate but either S_2 or S_3 occurs the regret is the respective wasted expenditure. Likewise if they do not make mitigate and S_2 or S_3 arise there is no regret. If they do not make these expenditures but S_1 occurs then the regret is the respective climate loss less the saved policy cost. In S_2 and S_3 when one country mitigates and the other does not, only the country mitigating experiences regret equal to the respective cost.

In S_1 if one country mitigates and the other does not then the non-mitigating country experiences climate losses net of saved mitigation costs. What is the regret experienced by a country, say China, which mitigated while the US did not? Conceivably it *could* have acted unilaterally in this situation *to offset all losses it* *faced*. It would then experience still higher mitigation costs $CC_c > C_c$ which would be unwise if $LL_c < CC_c$. For simplicity assume neither country has the option to scale up mitigation in this way, perhaps because this is too expensive. Thus each will experience no regret if it mitigates inadequately when the other country does not mitigate at all.

If China plays M its maximum regret is C_c. If China plays D its maximum regret is LL_c-C_c so the case for mitigation requires $LL_c-C_c>C_c$ or $LL_c> 2C_c$, a generalization of (1) now for each country. If policy costs to each country of mitigating are less than half the damage costs of unmitigated climate change, each should mitigate.

China	**US**					
	S_1		**S_2**		**S_3**	
	M	D	M	D	M	D
M	0,0	0, LL_u-L_u'-C_u	C_c, C_u	C_c, 0	C_c, C_u	C_c, 0
D	LL_c-L_c'-C_c, 0	LL_c-C_c, LL_u-C_u	0, C_u	0,0	0, C_u	0, 0

Table 5:Regrets in the game among nations and nature

This is again a more plausible heuristic than minimax suggesting that, once the possibility of policy failure is admitted, a decision to proceed with mitigation requires possible benefits for each country from mitigation to greatly exceed that country's policy costs. Again, this same conclusion obtains even if the state S_3, where policy fails, is omitted.

4.3 Mitigating a lot or a little. We return to consider global issues but change both the structure of the damages the world faces and its policy options. Suppose a global decision-maker is thinking of either making a substantial mitigation effort to cover possible severe climate change (e.g. 6^{o}C of warming) or a more modest effort to meet less damage (e.g. 2^{o}C warming). The new sources of policy regret that can arise here are under-investing or over-investing in mitigation effort.

As above, large-scale mitigation effort involves cost C and is warranted only with severe climate change. In the absence of such efforts large-scale climate change would impose substantial economic costs $L > C$. If only moderate climate change occurred only a more moderate mitigation effort costing $c < C$ would be appropriate. The absence of any mitigation effort in this latter situation of mild climate change creates damage costs defined as ell < L. Mistakes can also be made in deciding on the appropriate scale of effort. If moderate effort is exerted when severe climate change occurs the cost is defined to be el < L

C, L, c, el and ell are all supposed deterministic. There are three policy options – undertake substantial effort, undertake moderate effort or do nothing. There are also three possible states. Two states involve the moderate or severe climate change mentioned above when mitigation efforts work as planned. A third state arises where severe climate change occurs but where we suppose *both* possible mitigation efforts (large and small scale) fail completely to address climate-induced losses perhaps because environmental irreversibilities have set in. Redefine the states of the world as:

- S_1 where severe climate change occurs that is most successfully met by a substantial mitigation effort costing C,
- S_2 where moderate climate change occurs that can be offset by low mitigation effort costing c or, at greater cost C, by substantial effort.
- S_3 where severe climate change occurs but mitigation effort fails.

Payoffs from the various investments are summarized in **Table 6**.

	S_1	**S_2**	**S_3**
Large scale mitigation	**C**	**C**	**C+L**
Moderate mitigation	**c+el**	**c**	**c+L**
No mitigation effort	**L**	**ell**	**L**

Table 6: Costs of mitigation and climate change

If large-scale efforts are initiated then the maximum cost that can ever eventuate is their costs plus the losses experienced because these efforts fail, namely C+L, under S_3. Similarly, given the decision to proceed with more limited effort, maximum possible losses are at c+L. Finally if no action at all is undertaken maximum losses are L.

Choosing the policy that minimizes the maximum loss – *the minimax policy* – involves not mitigating at all because losses are bounded at L which must be less than C+L and c+L. If either a large scale or moderate mitigation efforts are envisaged then the worst that can happen is that actions are taken at some cost but fail. These costs always exceed L. *Again if projects can fail to achieve their objective entirely then the minimax policy is, as above, to do nothing*.

A more confident policy-maker might rule out state S_3 and assume investments are never unsuccessful. Payoffs then become.

	S_1	**S_2**
Large scale mitigation	**C**	**C**
Moderate mitigation	**c+el**	**c**
No mitigation effort	**L**	**ell**

Table 7: Costs of mitigation and climate change without policy failure

Now the highest cost of undertaking large-scale mitigation is C, of limited effort c+el and from doing nothing L. The minimax policy involves choosing the policy minimizes these three maximum costs. Since L > C it can now never be optimal to not mitigate at all. The choice then is between mitigating comprehensively or on a more limited basis.

The minimax decision is to mitigate comprehensively if C < c+el and on a more limited scale if C > c+el. *The extra costs incurred in making a substantial rather than a limited effort,* (C-c)*, need to be compared with the social and economic losses, el, of making limited efforts when more substantial efforts were required* (el). This rule leads policy makers who know the relative costs to focus only on the social losses associated with making limited policy effort when climate change could be severe.

Minimax regret measures are now discussed when policy failure can occur.

If substantial (limited) mitigation efforts occur and there is severe (moderate) climate change then there is zero regret. Policy was chosen appropriate to the climate change that occurred. If nothing is done and there is severe (moderate) climate change then the regret is the corresponding environmental loss less the policy cost that was saved by not addressing it (L-C and ell-c, respectively). If large-scale mitigation efforts are undertaken when lower scale efforts would have sufficed the regret is the unnecessary extra cost (C-c).

If only low level mitigation effort is undertaken when severe climate change occurs and the policy is effective then the regret equals the net gain that would have been obtained from large scale policy less the net gain that was obtained by utilizing the lower cost option. This is L-C - max(0, el-c) = L-C-el+c if the low level effort does, at least, reduce losses when climate change is severe. Take el > c so this assumption is always met.

With respect to minimum regret policies we are interested in distinguishing between situations where both and where only one of the mitigation policies can fail completely. In assessing prospects for policy failure therefore two cases are distinguished:

Case 1. Here both low and high-level mitigation efforts fail completely to be effective perhaps because both encountered the same difficulty that they were implemented too late. The regrets are then C and c respectively. If either policy was not undertaken there is no regret since each would have failed. The matrix of payoffs is set out in **Table 8A**.

Case 2. Now suppose the high-level mitigation action can fail (e.g. because it was left too late to be implemented) but the low level policy does not (e.g. it relies on an effective adaptation option). To sharpen the analysis suppose the low level policy retains its effectiveness and yields net returns el-c > 0. Then the regret in undertaking the high level policy is its wasted cost C plus the regret from not undertaking a more effective low level adaptation strategy, el-c. Implementing the low-level adaptation strategy involves no regret since it works as effectively as the alternative policies. If there is no policy action at all the regret is the foregone gains ell-c. Payoffs are set out in **Table 8B**.

These cases can also be interpreted as corresponding to two new states of the world that correspond to the situation where, respectively, the large scale policy alone fails and where both active policies fail.

	S_1	S_2	S_3
Large scale mitigation	**0**	**C-c**	**C**
Small scale mitigation	**L-C- el+c**	**0**	**c**
No policy	**L-C**	**ell-c**	**0**

Table 8A: Policy regret in Case 1.

	S_1	S_2	S_3
Large scale mitigation	**0**	**C-c**	**C+el-c**
Small scale mitigation	**L-C-el+c**	**0**	**0**
No policy	**L-C**	**ell-c**	**el-c**

Table 8B: Policy regret in Case 2.

From **Table 8A** the maximum regret that can be experienced with large-scale mitigation is C which occurs if this policy proves ineffectual. With lower level mitigation maximum regret arises in state S_1 if L-C-el +c > c or if L-C > el. Without any active climate policy the maximum regret arises if state S_1 eventuates assuming that L-C > ell-c as is plausible. *Then if both mitigation options can fail completely the minimum regret arises with the low level policy*.

From **Table 8B** the maximum regret with a large-scale policy arises in S_3, with a low mitigation policy or no policy at all in S_1. Regret associated with a low mitigation policy always dominates no policy at all so the minimum maximum regret choice lies between choosing either active policy. A large scale policy is preferred if:

$$C+el-c < L-C-el+c \text{ or:}$$

$$L > 2(C-c) + 2el \qquad 5.$$

Thus justifying a large scale policy using minimax regret requires that losses from unaddressed severe climate change be large relative both to the extra costs of the policy and to the social losses inflicted by utilizing a low level response when climate change turns out to be severe.

This rule involves only one extra item of data over minimax namely the absolute level of losses in using a small-scale policy when ideally a large-scale policy was required. Thus 4 items of data are required of which two c and C are policy cost projections and two measure the losses associated with severe climate change when it is either not mitigated at all or mitigated inadequately.

It can be shown that this same conclusion holds when various classes of policy failure are admitted to the analysis simultaneously – when both policies fail or when either the large or small-scale policy alone fail: See **Appendix.**

With some work the taxonomy of policy failures could be reorganized to include states of the world where only moderate climate change eventuates. It is more complex still to allow for decentralized policy decisions by countries which jointly play a game against nature.

Section 5 Final remarks. Practical policy-makers might not want to use the exact formalism suggested above. The broad logic however might make some sense. States of the world are identified where policies work *and where they fail*.

The advantages of the heuristics used to make climate policy decisions under uncertainty over real option approaches based on risk are several. The implausible assumption that people have sensible subjective probability information on the various possible states of the world has been largely dispensed with. In addition, complex simulations based on the use of invented data, is replaced by procedures that focus on a few key costs and loss estimates.

Of course the assumption that future states of the world are known and that they can be adequately described by a few extreme situations is unattractive. The assumption that unforeseen states of the world ("unknown unknowns") might arise – the *gross ignorance* case - is part captured by admitting policy failure as a possibility. In accord with the risk-averse perspective one captures these unknown states by seeking to model the worst that can happen in these states. In cost-benefit settings the relevant unrecognized states will be situations involving expensive policy failures.

Moving too far in the direction of admitting the general possibility of totally unanticipated states of the world – for example, possibilities of global cooling and situations where employing policies creates harms beyond their costs – suggests a case for adaptive planning and this is difficult to model when large, lumpy, irreversible investments are being made. The general prescriptions are then to not use telescopic vision and open loop policies, to retain flexibility where possible, to place close attention to serendipitous feedback and other such vague homilies.

The minimax heuristic only works if the possibility of policy failure is excluded. In this latter case policy heuristics of the form employ comprehensive policies when the extra costs of so doing exceeds the losses incurred by utilizing smaller scale policies when the larger scale policies were ideally required. This reflects a conservative minimax view.

The minimax regret heuristic works when the possibility of policy failure is admitted with implications depending on the form of the failure. For a large scale mitigation response to make sense, extra costs of undertaking this action rather than a small scale effort plus climate losses incurred when a small response is undertaken when a large scale response was required, must be large relative to possible climate losses arising without any mitigation response. This is a very intuitive heuristic.

Appendix: Minimax Regret Policies with Possible Comprehensive and Specific Policy Failures.

The two minimax regret situations examined in Section 5 can be put together so that various types of policy failure are possible. In all these failure situations severe climate change occurs but:

- S_3 above occurs where both large and small scale policies fail (S_3 in **Table 8A**);
- S_3* (S_3 in **Table 8B**) occurs so only the large scale policy fails.
- S_3** occurs so only the small scale policy fails.

The associated regrets are in **Table 8C**.

	S_1	S_2	S_3	S_3*	S_3**
Large scale policy	**0**	**C-c**	**C**	**C+el-c**	**0**
Small scale policy	**L-C-el+c**	**0**	**c**	**0**	**c**
No policy action	**L-C**	**ell-c**	**0**	**el-c**	**0**

Table 8C: Policy regret with three classes of policy failure

The largest regret if a large scale policy is implemented arises if a small plant would have not failed and is C+el-c. The largest regret if a small scale policy had been implemented is again L-C-el+c in state S_1 if L-C > el-c. Plausibly the largest regret if no policy action is taken also arises in S_1. This is the regret that occurs when climate change is severe and a large scale policy would have been effective. Choosing the minimum regret involves choosing min(C+el-c, L-C-el+c, L-C) ≡ min (x,y,z). Here z > y since L-C > L-C +(c-el) if el > c as assumed – a small scale policy is cost-effective if moderate climate change occurs. Now y-x = L-C-el+c –(C+el-c) = L-2(C+el-c). Thus for a large scale policy to be regret minimizing:

$$L > 2(C+el-c).$$

So, as before, justifying a large scale policy using minimax regret requires that losses from unaddressed severe climate change be large relative both to the extra costs of a large scale policy and to the social losses inflicted by utilizing a small scale policy when climate change turns out to be severe.

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