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Strategic issues in global climate change policy*

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An analysis of prospects for deriving self-enforcing, global, greenhouse gas emission mitigation agreements is provided. Policy spillovers and carbon leakages are accounted for. Situations where mitigation effort should be concentrated in particular countries and where efficient outcomes can be fostered by international trade in emissions permits are discussed. The use of auxiliary policies to transform intractable Prisoner's Dilemma incentive problems to more tractable problems, the role of policy commitments and the strategic implications of 'no regret' and 'adaptation' policies are analysed. Dynamic and repeated game formulations are outlined.

Key words: climate change, global, mitigation, strategic analysis.

1. Introduction

An international treaty is the main way global climate change can be successfully mitigated. A few large countries have a significant impact on aggregate global greenhouse gas emission (GGEs; e.g. US, China, India) but, for emerging economies, per capita emissions are low because of low per capita outputs and energy intensities. In addition, emissions of countries such as China and India have only been large for a brief historical period (Marland *et al.* 2007). While the US and China provide 50 per cent of the world's GGEs, 15 countries provide another 80 per cent leaving another 158 countries providing 20 per cent of emissions (Baumert *et al.* 2005). The sources of GGEs thus comprise both distinct major emitters and a competitive 'fringe' of minor emitters with a significant aggregate impact on global emissions.

An international agreement is essential since individual countries have sovereignty over their economic and environmental activities. Countries are concerned with their individual self-interest but, narrowly pursuing this objective may lead to unsatisfactory global GGE reductions. Yet most countries seek emission reductions since they understand that their societies will be damaged by climate change. Thus, countries hope to be able to negotiate a mutually satisfactory constraint to limit their autonomy in a way that leaves them better off.

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A treaty must be designed so countries have incentives to stick to its rules. Agreements must be ‘coalition proof’ – it should not be possible for individual nations or a coalition to gain by renegotiation (Barrett 2003). A treaty must also be ‘fair’ in the sense that parties acknowledge its legitimacy. A treaty is a strategic instrument of policy restructuring incentives to alter behaviour so it becomes self-enforcing.

This paper develops non-cooperative game models to analyse climate change policy in a strategic setting (for an earlier survey see Carraro 2007). Section 2 provides a static framework where a single developing country (‘China’) designs its climate change policies along with a single developed country (the ‘US’) by adopting ‘all-or-nothing’ policies of ‘mitigating’ or ‘not mitigating’ GGEs. This highlights the split between policy perspectives of developed and emerging countries. The country labels here are partly generic and intended to capture the strategic stance of emerging and developed countries.

Clearly, however, contrasting strategies for a single developed with a single developing country is restrictive because countries face particular climate change circumstances. Thus, while the US is portrayed as facing limited local incentives to address climate change issues, other developed countries, such as those in Europe, face stronger incentives (Cline 2007, p. 21). For analytical purposes the extension to include further countries is important. This is done in Section 3. The issue is the extent to which having an extra country commit to mitigation affects mitigation incentives of other countries.

Section 4 returns to the two-country framework but allows countries to employ ‘no regrets’ and ‘adaptation’ responses. All-or-nothing mitigation responses are not the sole policy options.

In Section 5 repeated and dynamic game issues are considered. Developing countries face an imperative to grow but will often suffer most long-term from climate change. Again, a core issue is the extent to which commitments to mitigate alter responses of other countries.

In Section 6 conclusions are summarised.

2. Two-country model

Consider two countries ‘China’ (C) and the ‘US’ (U). Suppose these countries have only two policy options with respect to their GGEs, either to mitigate them (M) or not (DM). If China mitigates then the gross local benefits it receives are B_c while spillover benefits to the US are B_{cu} . The costs of mitigation for China are C_c . If the US mitigates it gets local gross benefits B_u , provides benefits to China B_{uc} with mitigation costs C_u . Define net national benefits from mitigation as $\pi_u = B_u - C_u$ and $\pi_c = B_c - C_c$. The benefits and costs recognised exclude items related to a country’s perceived international image in terms of mitigation stance. Countries *are* sensitive to international perceptions but such costs and benefits depend on the policy stance of a coun-

Table 1 Payoff matrix for two-country game

Two-country game		US	
		M	DM
China	M	$\pi_c + B_{uc}, \pi_u + B_{cu}$	π_c, B_{cu}
	DM	B_{uc}, π_u	0, 0

try relative to others. For example, a country will experience most national embarrassment if it is an isolated or sole non-mitigator.¹

2.1 No carbon leakages

Suppose initially the economies are closed to foreign trade and investment. Then spillover benefits B_{cu} and B_{uc} and locally incurred policy costs C_c and C_u are independent of the mitigation response of the other country. Thus, spillovers to China from US mitigation do not increase when China does not mitigate rather than mitigate because (perhaps) of carbon leakages.

Table 1 describes the payoff matrix for the countries. Each country has dominant strategies to mitigate (not mitigate) if and only if local benefits received from mitigation exceed (fall short of) country-specific costs. If $\pi_c > 0$ China will mitigate while if, additionally, $\pi_u > 0$ both mitigate. In this limiting case the climate change issue has none of the character of a global ‘public bad’. It is purely a local pollution issue that can be resolved by nationalistically-oriented cost-benefit studies. Otherwise at least one country must consider strategic interdependencies when optimising its mitigation response.

Here apart from a borderline case where local benefits equal local costs, each country always has a dominant strategy of mitigating or not mitigating.

The situation where local benefits exceed local costs may be relevant particularly if net benefits are computed at steady state values. A country, such as the US, may be able to reduce GGEs at low cost even if local benefits are less than those of countries such as China which currently enjoys much lower per capita energy consumption. Moreover, while China has development objectives that involve increasing energy consumption – so opportunity costs of mitigation are high – benefits of forestalling impacts of climate change are large in societies with an agricultural production bias.² Thus there can

¹ Our models also initially abstract from reductions in global costs consequent on trading GGEs. Australia could set 10 per cent GGE cutbacks to 2020 that would cost the same as 5 per cent cutbacks to this date if GGE entitlements were traded (Garnaut Climate Change Review 2008).

² Agriculture is the ‘canary-in-the-mine of global warming’s economic impact’ according to Cline (2007). Warming will hit poor people hardest since these people often have no alternative to farming and agriculture will become less productive with the undernourished finding food supplies even harder to obtain.

conceivably arise a case for mitigation by both rich and poor countries on the basis of national self-interest.

If this is the case then this paper can end here. The only task is to *demonstrate* to governments that costs and benefits are what they are.³

2.2 Carbon leakage effects

Carbon leakage occurs when (i) the mitigation response of a country raises local costs providing countries that do not mitigate with a trade advantage with production possibly moving offshore to non-mitigating countries, or; (ii) GGE taxes in one country add a premium to export prices reducing demand for them in countries without taxes.

These leakages arise if there is no uniform global emissions tax or, equivalently, if there is no free international trade in emissions permits that equalise mitigation costs. If carbon leakages are important the strategic analysis becomes more complex. The empirical extent of likely carbon leakages are a matter of debate.⁴ The Stern Review (2007) argued such effects were likely to be small and evidence from the European Union's experiences with its internal emissions trading scheme tends to confirm this (Convery *et al.* 2008).⁵

With leakages benefits and costs one country gains from mitigation depend on the mitigation responses of other countries. Suppose if the US mitigates but China does not, that the US experiences extra costs L_{uu} and China receives benefits L_{uc} from this unilateral action compared to the situation where both mitigate. Similarly define L_{cc} and L_{cu} as the extra costs and benefits to China and the US respectively when only China mitigates. Table 2 provides the payoffs.

Table 2 Payoff matrix for two-country game with carbon leakage

Two-country game with carbon leakages		US	
		M	DM
China	M	$\pi_c + B_{uc}, \pi_u + B_{cu}$	$\pi_c - L_{cc}, B_{cu} + L_{cu}$
	DM	$B_{uc} + L_{uc}, \pi_u - L_{uu}$	0, 0

³ This is non-trivial. While for many infrastructure projects the costs of new infrastructure projects are often underestimated the tendency has been in pollution control to substantially *overstate* costs. This might reflect the fact that cost estimates for infrastructure projects often rely on estimates of project promoters while cost estimates for environmental projects come from businesses who would prefer no regulation.

⁴ Houser *et al.* (2008) argue that the damages to developed countries from leakages would be small. Most manufacturers (let alone service industries) do not use much energy, the main source of emissions, and so would not suffer big costs. Energy makes up less than 1 per cent of costs of making cars, furniture and computers. Even some energy-intensive industries, such as power generation, should not be much affected. Since they have no foreign competition, they could pass on extra costs to customers.

⁵ A longer version of this paper (available from the author) considers policies for addressing carbon leakages.

Each country now faces more stringent conditions for a mitigation strategy to be dominant on the basis of a local cost–benefit analysis. For the US to have a dominant strategy to mitigate, $\pi_u > \max(L_{cu}, L_{uu})$. Net local benefits to the US from mitigation must now exceed the extra costs the US will impose on itself by mitigating unilaterally and the extra benefits it would receive if China unilaterally mitigated.

2.3 Prisoners' dilemmas

The main way theorists see the global strategic implications of climate change is as a Prisoner's Dilemma (PD) where countries are better off cooperating but where each country has a dominant strategy not to.

With carbon leakages, conditions for the payoffs in Table 2 to be a PD are $\pi_c < \min(L_{uc}, L_{cc})$ and $\pi_u < (L_{cu}, L_{uu})$. Net benefits to each country must not exceed (i) carbon leakage benefits gained were the other country to mitigate alone and (ii) carbon leakage costs incurred were it to unilaterally mitigate. Also, countries must derive positive benefits when they jointly mitigate so $\pi_c + B_{uc} > 0$ and $\pi_u + B_{cu} > 0$. Carbon leakages and favourable spillovers therefore *increase* the likelihood of PD's by making it more likely each country has a dominant strategy of not mitigating. Carbon leakages make it more difficult to secure a global agreement to mitigate.

If there are 'embarrassment' costs from being a sole non-mitigator, or if cost reductions arise with carbon trading that occurs when both countries mitigate, then rewards to each rise when both mitigate. Then prospects for cooperation improve – these effects reverse the effects of carbon leakages. Suppose rewards increase to $\pi'_c > \pi_c$ and $\pi'_u > \pi_u$ with joint mitigation. Then for a PD to arise $L_{uc} + B_{uc} > \pi'_c + B_{uc} > 0$ and $L_{cu} + B_{cu} > \pi'_u + B_{cu} > 0$ so $L_{uc} > \pi'_c$ and $L_{cu} > \pi'_u$. Thus, larger spillovers to each country must occur when the other country alone mitigates. This implies a more stringent requirement than without embarrassment or cost-savings effects. With large enough embarrassment or cost-saving effects the game becomes a tractable *Assurance Game* with two Nash equilibria (both mitigate, both don't) but where each prefer the mitigation equilibrium. Each country has incentives to mitigate when it knows the other will so prospects for cooperation improve.

For example, suppose $B_c = B_u = 5$, $C_c = C_u = 6$ and $B_{cg} = B_{ug} = 4$ and ignore carbon leakages. This is the PD in Table 3. The dominant strategy

Table 3 Prisoner's dilemma when it is collectively rational for all to mitigate

Two-country game		US	
		M	DM
China	M	3, 3	–1, 4
	DM	4, –1	0, 0

for each country is to not mitigate. However, accounting for spillovers were each to mitigate, active mitigation by *both* is appropriate so the optimal cooperative outcome is for *both* to mitigate.

Even without embarrassment or cost-saving effects various game structures arise. For example, in a PD structure, unilateral responses can be the efficient cooperative response with specific relative costs and benefits. Take $\pi_c = -0.5$, $\pi_u = -4$ and $B_{cu} = 10$, $B_{uc} = 1$ and ignore carbon leakage as in Table 4. Again the dominant strategy is for each country to not mitigate. However, accounting for spillovers to both countries, active mitigation by exactly one country provides a more efficient international agreement. An instance might be investment in mitigation effort by one nation in a geo-engineering solution to climate change. Then if both nations mitigate welfare in each increases but by less than would be obtained were it to be done in one country (here ‘China’) alone. Cost, benefit or spill-over asymmetry across countries is necessary, although not sufficient, to establish this case for unilateral action. Thus, for Table 1 to be a PD, $\pi_c < 0$ and $\pi_u < 0$ while $\pi_c + B_{cu} > 0$. For unilateral action to yield higher benefits $\pi_u + B_{uc} < 0$, a contradiction if payoffs are symmetric.

The move from the case where the dominant strategy of each country is to not mitigate to that where China alone mitigates is not a Pareto improvement since China is worse-off though aggregate benefits increase. Both countries can be made better off if one (here the US) compensates the other (China). Consider compensation of $\$ \epsilon$ with $10 > \epsilon > 0.5$. This achieves a Nash equilibrium where China alone mitigates provided the US makes a side-payment of $\$ \epsilon$ to China as in Table 5.

Thus making side-payments is one means of achieving globally optimal GGE reductions. It makes sense if one country has low cost GGE cleanup options but the other gets relatively high benefits from cleanup.

Table 4 Prisoner’s dilemma: collectively optimal for one country to mitigate

Two-country game		US	
		M	DM
China	M	0.5, 6	-0.5, 10
	DM	1, -4	0, 0

Table 5 Prisoner’s dilemma: one country should mitigate once side-payment made

Two-country game		US	
		M	DM
China	M	$0.5 + \epsilon, 6 - \epsilon$	$\epsilon, 10 - \epsilon$
	DM	1, -4	0, 0

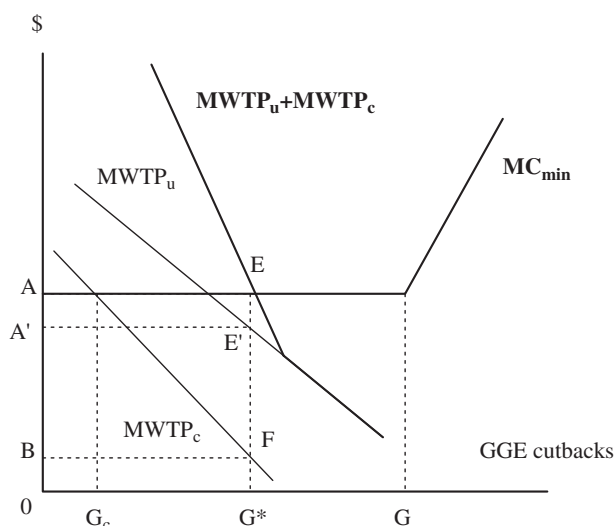


Figure 1 Optimal global policies for mitigating climate change.

This idea is now made transparent by considering continuous GGE mitigation options as in Figure 1 where marginal mitigation costs and willingness-to-pay schedules for mitigation are graphed. China has lower marginal cleanup costs (MC_c) than the US (MC_u) and the marginal willingness-to-pay for cleanup in China ($MWTP_c$) is also lower than in the US ($MWTP_u$). For each cutback level define $MC_{min} = \min(MC_c, MC_u)$. Suppose MC_{min} is constant up to cutback levels G but then increases. Interest centres on situations where cutbacks of size G are made only in China.

Greenhouse gas emission cutbacks are a global public good and the globally efficient cutback is determined at G^* where global willingness-to-pay for cutbacks ($MWTP_u + MWTP_c$) equals marginal cost.

The optimal cutback G^* is implemented only in China because that is where it is cheapest. The total cost is the area AEG^*O . If this cost is allocated on the basis of benefits obtained it can be efficiently met by levying mitigation charge G^*FBO on China and larger charge $FE'A'B$ on the US. As cutbacks are carried out in China this implies a case for an efficiency-based transfer from the US to China.

This outcome can be implemented by an appropriate allocation of GGE quotas. Suppose Chinese and US emissions are E_c and E_u so aggregate emissions are $E_c + E_u$. The preceding analysis suggests this should be cut by G^* by assigning quota of $E_c - G_c$ to China where, as in Figure 1, G_c is the emission cutbacks China would unilaterally seek to make given the optimal international GGE cutback price A . The US gets quota $E_u + G_c - G^*$. If quotas were transferable the US would find it cheapest to meet GGE targets by buying back entitlements $G^* - G_c$ from China leaving China with emissions $E_c - G^*$ and the US with unchanged emissions E_u . This minimises global costs.

This striking result is a consequence of assuming all low cost mitigation options occur in China. Relaxing this assumption can lead to greater sharing of mitigation effort and smaller transfers. For example, if mitigation costs increase with the scale of mitigation, US compensations to China are lower. The general point is that cooperation can be achieved by providing payments which motivate globally efficient cutback efforts.

As is well known PD problems of non-participation in global agreements to reduce emissions can also be resolved via regulatory machinery with failure to mitigate penalised. Thus, with the payoffs of Table 4, if any country which fails to mitigate is penalised \$5 the game becomes the Assurance Game of Table 6 where Nash equilibria involve each country either mitigating or not mitigating but where both will mitigate if either mitigates. If all countries not mitigating are subject to a \$5 penalty then the game described by Table 4 is transformed to that of Table 7 where all countries have dominant strategies to mitigate.

The motivation for such penalties is that countries are better off if they jointly mitigate. There remain, however, PD motivations for not agreeing to such penalties.

One institutional arrangement resembling this involves retaliatory tariffs on exports of countries which do not mitigate (Stiglitz 2006). This proposal differs from the notion of a unilateral penalty on a non-mitigating country because restricting 'gains-from-trade' to a non-mitigating exporting country also restricts gains to mitigating countries which import. It is difficult to design institutions to support such arrangements without this unattractive feature.⁶

Table 6 Assurance game

Two-country game		US	
		M	DM
China	M	0.5, 6	-0.5, 5
	DM	-4, -4	0, 0

Table 7 Game with dominant strategies to mitigate

Two-country game		US	
		M	DM
China	M	0.5, 6	-0.5, 5
	DM	-4, -4	-5, -5

⁶ Retaliatory tariffs – such as the proposed European 'Kyoto Tariff' on non-carbon-taxed US exports may be inconsistent with GATT articles governing free trade. If so, the global benefits the WTO has realised by promoting freer trade are being reduced by environmental losses that stem from the fact that retaliatory tariffs cannot be imposed on countries not mitigating GGEs. This will undermine confidence in WTO processes.

A more satisfactory resolution, due to Gersbach (2008), sees industrialised countries contributing initial amounts to establish a fund, a Global Refunding System (GRS), and then receiving refund payments in accord with emissions reductions. Each nation is free to choose taxes to reduce emissions but all tax revenues go to the GRS. Refunds are provided in proportion to national emission reductions relative to the prior year divided by the sum of global reductions. Initially only a fraction of funds held would be redistributed and the fund would grow due to interest earned and retained tax revenues. Eventually, however, the GRS would achieve its steady state where refunds would equal revenues inclusive of interest. This global agreement is individually self-enforcing. Countries have incentives to set higher carbon taxes than without the GRS to achieve high rates of mitigation to gain high refunds. An individual country can achieve returns that exceed contributions when other countries set low tax rates by mitigating intensively and imposing high taxes. Emerging economies might not be required to contribute initially to the fund but could benefit by imposing taxes and mitigating. Indeed, for a period they might not need to make contributions but simply draw on rewards as a reward for their cutbacks.

This scheme elaborates the idea of imposing a penalty on *any* non-mitigator. A non-mitigator will either lose claim to resources initially or subsequently contributed tax revenues or, in for developing countries, forgo possible financial rewards from mitigating.

2.4 Non-prisoner's dilemma games

Problems of countries refusing to mitigate are resolved if other countries secure large enough gains by living with the defection and maintaining or even increasing the intensity of their own mitigation responses. These are Leadership Games where one player – suppose the US – bears relatively large losses if it does not mitigate even if the other – China – also does not mitigate. This is not a PD. China can *force* the US to carry the mitigation burden. This is illustrated in Table 8. Take $\pi_u = 12$, $B_{uc} = 7$, $\pi_c = -2$, $B_{cu} = 6$. The Nash equilibrium strategies are for the US to mitigate even though China will not.

This may be a practical possibility. Emerging countries face development imperatives that call for increased energy consumption while developed countries may have low costs of complying. It then makes sense for developed

Table 8 Leadership game

Two-country game		US	
		M	DM
China	M	5, 18	-2, 6
	DM	7, 18	0, 0

Table 9 Chicken game

Two-country game		US	
		M	DM
China	M	8, 8	2, 10
	DM	10, 2	0, 0

countries to pursue a leadership role, at least for an interim period, as envisaged under the Kyoto Protocol.

Policy games can also be Chicken Games if there are carbon leakages. See Table 2. Here China must not mitigate if the US mitigates but will mitigate if the US fails to. Thus, $B_{uc} + L_{uc} > \pi_c + B_{uc} \leftrightarrow L_{uc} > \pi_c$ and $\pi_c > L_{cc}$ so $L_{uc} > \pi_c > L_{cc}$. Similarly the US will not mitigate if China does but mitigate if China fails to. Hence $L_{cu} > \pi_u > L_{uu}$. In addition each country must prefer mitigating so $\pi_c + B_{uc} > 0$, $\pi_u + B_{cu} > 0$. If carbon leakage effects are zero then *all* outcomes are Nash equilibria and the game degenerates – choice of strategy by either country is irrelevant. With carbon leakages $L_{cu} = L_{uc} = 10$, $L_{cc} = L_{uu} = 6$, spillovers $B_{uc} = B_{cu} = 0$ and local benefits $\pi_c = \pi_u = 8$ we get the Chicken game of Table 9 with two Nash equilibria where *exactly one* country does not mitigate. Each country prefers the equilibrium where it alone does not mitigate but the other country does. Moreover, both countries prefer joint mitigation to jointly not mitigating. A joint-mitigation strategy maximises policy gains.

Finally, it is useful to know that sometimes the strategic outcome is an Assurance Game with two Nash equilibria (mitigate, mitigate) and (don't mitigate, don't mitigate) but where both countries prefer the first equilibrium to the second.

Such simple agreements are ruled out, at least in the absence of punishments such as retaliatory tariffs or embarrassment costs. Consider Table 1. For China to prefer the mitigation strategy to not mitigating when the US mitigates:

$$\pi_c + B_{uc} > B_{uc} \text{ so } \pi_c > 0.$$

But simultaneously, for China to prefer not mitigating when the US does not mitigate, $\pi_c < 0$, a contradiction. Thus Assurance Game (AG) structures do not readily arise in climate change games. However, as shown in Table 6, an AG can arise if any non-mitigator is subject to a hefty penalty though there remains the task of negotiating and implementing the penalty. It is also worth noting that Assurance games arise naturally with significant carbon leakages. From Table 2 necessary conditions for an AG with leakages are $L_{cc} > \pi_c > L_{uc}$ and $L_{uu} > \pi_u > L_{cu}$. Such a game arises when, for example, $L_{cc} = L_{uu} = 6$, $L_{uc} = L_{cu} = 4$ and $\pi_u = \pi_c = 5$.

3. Multi-country models

A game theoretic analysis with more than two countries is worthwhile because of asymmetrical mitigation incentives among countries. For example, European countries have stronger incentives to mitigate climate change than the US.

A simple extension involves three countries China, the US and 'Europe' (e) with respective local net benefits π_c , π_u and π_e and spillovers B_{cu} , B_{ce} , B_{uc} , B_{ue} , B_{ec} , B_{eu} defined as before. Thus, B_{cu} is the spillover to the US when China mitigates.

With respect to carbon leakages suppose if the US *alone* mitigates it incurs costs L_{uu} and China receives benefits L_{uc} while Europe gains benefits L_{ue} . Similarly if Europe alone mitigates it incurs costs L_{ee} and China receives benefits L_{ec} while the US gains L_{eu} . If China alone mitigates the cost to China is L_{cc} and benefits to the US and Europe are L_{cu} and L_{ce} .

If *both* the US and Europe mitigate, but China does not, then they incur net losses L'_{uu} and L'_{ee} respectively while China gains L'_{uec} . If both China and Europe mitigate but the US does not they incur losses L''_{cc} and L''_{ee} respectively while the US gains L''_{ceu} . Finally if both the US and China mitigate but Europe does not they experience losses L'''_{uu} and L'''_{cc} while Europe gains L'''_{uce} . Initially focus on the decision to mitigate in China.

If China mitigates it faces payoffs of Table 10. If it does not Table 11 payoffs obtain.

Table 10 Payoff matrix with China mitigating

Three-country game		Europe	
		M	DM
US	M	$\pi_u + B_{eu} + B_{cu},$ $\pi_e + B_{ue} + B_{ce},$ $\pi_c + B_{uc} + B_{ec}$	$\pi_u + B_{cu} - L'''_{uu},$ $\pi_e + B_{ue} + B_{ce} + L'''_{uce},$ $\pi_c + B_{uc} - L'''_{cc}$
	DM	$B_{eu} + B_{cu} + L''_{ceu},$ $B_{ce} - L''_{ee},$ $\pi_c + B_{eu} + B_{cu} - L''_{cc}$	$B_{cu} + L_{cu},$ $B_{ce} + L_{ce},$ $\pi_c - L_{cc}$

Table 11 Payoff matrix with China not mitigating

Three-country game		Europe	
		M	DM
US	M	$\pi_u + B_{eu} - L'_{uu},$ $\pi_e + B_{ue} - L'_{ee},$ $B_{ec} + B_{uc} + L'_{uec}$	$\pi_u - L_{uu},$ $B_{ue} + L_{ue},$ $B_{uc} + L_{uc}$
	DM	$B_{eu} + L_{eu},$ $\pi_e - L_{ee},$ $B_{ec} + L_{ec}$	0, 0, 0

What are conditions for there to be dominant strategies to mitigate? Consider the US. If there are no carbon leakages the earlier condition that local net benefits must be positive to motivate mitigation prevails so US, $\pi_u > 0$. With carbon leakages, for the US to have a dominant strategy to mitigate, the payoff from this must exceed that obtained if it defected from a cooperative agreement involving all countries to mitigate, so:

$$\pi_u + B_{eu} + B_{cu} > B_{eu} + B_{cu} + L''_{ceu} \text{ so } \pi_u > L''_{ceu}.$$

Thus for mitigation to be a dominant strategy net local US gains from mitigation must exceed the carbon leakage benefits derived if all other countries mitigate but the US does not.

In addition, the US must achieve greater gains from mitigating when China mitigates but Europe does not than when the US joins Europe in not mitigating:

$$\pi_u + B_{cu} - L'''_{uu} > B_{cu} + L_{cu} \text{ so } \pi_u > L'''_{uu} + L_{cu}.$$

Thus local US gains must exceed the carbon leakage losses avoided by joining Europe in not mitigating plus the carbon leakage benefits accruing to the US if China alone mitigated.

In addition, the US would need to be a net gainer when Europe mitigates but China does not compared to gains enjoyed in joining China in not mitigating:

$$\pi_u + B_{eu} - L'_{uu} > B_{eu} + L_{eu} \text{ so } \pi_u > L'_{uu} + L_{eu}.$$

Thus net gains to the US must exceed the carbon leakage losses incurred by joining Europe in mitigating even though China did not mitigate plus the carbon leakage gains that accrue to the US if Europe alone mitigates.

Finally, the US must gain from mitigation even if the other countries did not mitigate:

$$\pi_u > L_{uu}.$$

So gains to the US must exceed carbon leakage losses sustained from unilaterally mitigating.

To summarise the US has a dominant strategy of mitigating if:

$$\pi_u > \{L''_{ceu}, L_{uu}, L'''_{uu} + L_{cu}, L'_{uu} + L_{eu}\}.$$

Thus benefits of mitigation to the US must exceed costs it would incur if it alone mitigates and the benefits it would realise if it alone did not mitigate but received carbon leakage benefits from those countries which did. In addition, US benefits from mitigation must exceed the leakage benefits obtained if exactly one other country mitigates and the costs that accrue because exactly one other country does not.

Table 12 Mitigation payoffs when China mitigates

Two-country game with carbon leakages when China mitigates		Europe	
		M	DM
US	M	$\pi_u + B_{eu} + B_{cu},$ $\pi_e + B_{ue} + B_{ce}$	$\pi_u + B_{cu} - L'''_{uu},$ $\pi_e + B_{ue} + B_{ce} + L'''_{ue}$
	DM	$B_{eu} + B_{cu} + L''_{ceu},$ $B_{ce} - L''_{ee}$	$B_{cu} + L_{cu},$ $B_{ce} + L_{ce}$

If one country – suppose China – commits to mitigating irrespective of the intent of others the strategy task for remaining countries simplifies to the 2-player game of Table 12.

The conditions for mitigation to be the US's dominant strategy are:

$$\pi_u > \max(L''_{ceu}, L'''_{uu} + L_{cu})$$

Now local gains do not need to exceed the presumably huge costs of going it alone in mitigating (L_{uu}) since the pool of potential carbon leakage losses has fallen – one country has committed to mitigation. Thus, there is an improvement in the prospects for global mitigation when one country commits to mitigation – forces equivalent in effect to ‘moral suasion’ drive more countries to mitigate. But local gains from mitigation must still exceed the large gains a country would receive when it alone does not mitigate but gets leakage benefits from those which do (L''_{ceu} for the US).

Emulation effects and national embarrassment costs from being an isolated non-mitigator improve prospects for coordination following one country's commitment to mitigate. Provided national economic interests are not overwhelming moral suasion intensifies the possibility for mitigation being a dominant strategy – it precisely reverses carbon leakage effects by attaching costs to not mitigating and gains to mitigating.

In addition, improved prospects for avoiding PD issues arise the lower anticipated carbon leakage losses are. Therefore if a developing country like China commits to mitigate and thereby rules out carbon leakage losses for developed countries, an improvement in the prospects for cooperation obtains. If small countries or developed countries commit to mitigate the inducement for other developed countries mitigating is weaker.

The ambiguous prospects for enhanced global cooperation will be re-examined in repeated and dynamic game settings in Section 5.

Alternative approaches to strategy draw on behavioural economics (BE) literature examining conditions under which agents cooperate even though it is not in their individual self-interest to do so (Brekke and Johansson-Stenman 2008). Laboratory experiments suggest people are willing to cooperate if they see others doing so. Evidence suggests people's willingness to contribute to good social causes increases with their perception of the contribution

of others. These are instances of *conditional cooperation*. There is also evidence consistent with *reciprocity* – the social norm that motivates people to reward kind and punish unkind actions towards them. This reciprocity is not conditional on gaining long-term rewards and can even occur in one-shot interactions. *Intentions* of kindness or unkindness matter as well as consequences of actions.

These observations relate to individuals rather than countries interacting strategically. The issue is whether or not agents become more or less cooperative in group situations. The experimental evidence here, unfortunately, goes both ways.

Behavioural economics also provides evidence of self-serving biases. When facts and principles are ambiguous people choose those favouring self-interest. Even if motivated by ‘fairness’ people’s views as to what delivers fairness are conditioned by self-interest. Thus policy-makers in rich countries may avoid ethical discussions involving the energy needs of developing countries because entering into this discussion induces discomfit. Cognitive dissonance may also arise. For example, countries which release much GGEs may change their beliefs to fit their behaviour by coming to believe that damages of GGEs are overstated. See Brekke and Johansson-Stenman (2008) for what can be learnt from BE.

4. ‘No regrets’ and adaptation options

Return now to a two-country world but now admit as candidate policies ‘no regrets’ and adaptation policies. ‘No regrets’ policies address local pollution concerns and energy-saving strategies on the basis of local benefits but have reduced impacts on global environmental concerns than ‘full mitigation’ responses. Adaptation policies involve investments that equip a society to ‘live with’ climate change.

Initially consider ‘no regrets’ options. Strategic payoffs now must distinguish benefits and costs associated with a ‘full mitigation’ and ‘intermediate’ policies (IM). The extent of carbon leakages now depends on the precise policy responses of countries. Let:

- L_{uu} be the carbon leakage costs imposed on the US if it fully mitigates but China does not. L_{uc} are the associated benefits to China.
- L'_{uu} be the leakage costs imposed on the US if it fully mitigates but China pursues ‘no regrets’ options. Benefits to China are L'_{uc} .
- L''_{uu} be the leakage costs imposed on the US if it pursues ‘no regrets’ options but China does not mitigate. Benefits to China are L''_{uc} .

Suppose if both countries mitigate fully or use ‘no regrets’ policies that there are no carbon leakages.

Evidently $L_{uu} > L'_{uu}$ and $L_{uu} > L''_{uu}$, $L_{uc} > L'_{uc}$ and $L_{uc} > L''_{uc}$. The relations between L'_{uu} , L''_{uu} and L'_{uc} , L''_{uc} respectively depend on the net benefits of ‘no regrets’ policies compared to full mitigation.

Table 13 Two-country game with ‘no regrets’ options

Two-country game		US		
		M	IM	DM
China	M	$\pi_c + B_{uc},$	$\pi_c + BI_{uc} - L'_{cc},$	$\pi_c - L_{cc},$
		$\pi_u + B_{cu}$	$\pi_u + B_{cu} + L'_{cu}$	$B_{cu} + L_{cu}$
	IM	$\pi_{ic} + B_{uc} + L'_{uc},$	$\pi_{ic} + BI_{uc},$	$\pi_{ic} - L'_{cc},$
		$\pi_u + BI_{cu} - L'_{uu}$	$\pi_u + BI_{cu}$	$BI_{cu} + L'_{cu}$
	DM	$B_{uc} + L_{uc},$	$BI_{uc} + L'_{uc},$	0, 0
		$\pi_u - L_{uu}$	$\pi_u - L'_{uu}$	

Suppose $BI_c < B_c$, $BI_{cu} < B_{cu}$, $CI_c < C_c$, $BI_u < B_u$, $BI_{uc} < B_{uc}$, $CI_u < C_u$ so there are smaller spillovers and lower costs when pursuing ‘no regrets’.

Similarly define $(L_{cc}, L_{cu}, L'_{cc}, L'_{cu}, L''_{cc}, L''_{cu})$ when China is the more active mitigator and the US less so.

Finally, define $\pi_{ic} = BI_c - CI_c$, $\pi_{iu} = BI_u - CI_u$.

Table 2 is now expanded to Table 13. Inspection shows the ‘no regrets’ GGE policy is a dominant strategy for China if and only if $\pi_c < \pi_{ic} > 0$ so policy yields positive net benefits exceeding those from full mitigation. By symmetry the same condition holds for the US.

Much has been made of the fact that China is committed to ‘no regrets’ (Wang and Smith 1999). If so, from Table 13, the US would choose full mitigation (M) over ‘no regrets’ which is, in turn, preferred to not mitigating if:

$$\pi_u + BI_{cu} - L'_{uu} > \pi_{iu} + BI_{cu} > BI_{cu} + L'_{cu}$$

or:

$$\pi_u - L'_{uu} > \pi_{iu} > L'_{cu}$$

which requires local benefits from full mitigation net of consequent carbon leakage losses to exceed local benefits from partial mitigation which must, in turn, exceed leakage gains accruing to the US if it continued not to mitigate but China pursued ‘no regrets’. This choice is independent of spillovers from

Table 14 Two-country game with adaptation options

Two-country game		US			
		M	A	M&A	D(M&A)
China	M	$\pi_c + B_{uc}$	$\pi_c - L_{cc}$	$\pi_c + B_{uc},$	$\pi_c - L_{cc}$
		$\pi_u + B_{cu}$	$\pi_{au} + B_{cu} + L_{cu}$	$\pi_{amu} + B_{cu}$	$B_{cu} + L_{cu}$
	A	$\pi_{ac} + B_{uc} + L_{uc},$	π_{ac}	$\pi_{ac} + B_{uc} + L_{uc},$	π_{ac}
		$\pi_u - L_{uu}$	π_{au}	$\pi_{amu} - L_{uu}$	0
	M&A	$\pi_{ame} + B_{uc}$	$\pi_{ame} - L_{cc},$	$\pi_{ame} + B_{uc},$	$\pi_{ame} - L_{cc},$
		$\pi_u + B_{cu}$	$\pi_{au} + B_{cu} + L_{cu}$	$\pi_{amu} + B_{cu}$	$B_{cu} + L_{cu}$
	D(M&A)	$B_{uc} + L_{uc}$	0	$B_{uc} + L_{uc},$	0
		$\pi_u - L_{uu}$	π_{au}	$\pi_{amu} - L_{uu}$	0

mitigation and depends only on local benefits from policies less associated leakage costs. Since leakage costs are lower with 'no regrets' responses than with no mitigating by China, incentives of the US to mitigate are strengthened.

Adaptation policies yield no international spillovers. They can be implemented *with* mitigation policies. As before there are policy options M, DM but now also options to only adapt A, to adapt and mitigate (M&A) and to neither mitigate nor adapt D(M&A). For China, define π_c as the net benefits from mitigation alone, π_{ac} as net benefits from adaptation alone and π_{amc} as net benefits from mitigation with adaptation. Analogous notation (π_u , π_{au} , π_{amu}) describes US options. Payoffs are described in Table 14.

Adaptation policies do nothing to alleviate global climate change problems. Indeed they *reduce* global incentives to mitigate. Consider the implications of China committing to pure adaptation. Now the US ranks M&A ahead of M ahead of A ahead of D(M&A) as:

$$\pi_{amu} - L_{uu} > \pi_u - L_{uu} > \pi_{au} > 0.$$

Without adaptation, the case for ranking mitigation over doing nothing is $\pi_u > L_{uu}$. With adaptation this becomes $\pi_u > L_{uu} + \pi_{au}$ which is more stringent when there is an adaptation option for which $\pi_{au} > 0$. Then adaptation reduces climate change costs increasing cost-benefit hurdles for mitigation policies to pass.

Table 14 simplifies if either (i) $\pi_{amu} < \pi_u$ and $\pi_{amc} < \pi_c$ or (ii) $\pi_{amu} < \pi_{au}$ and $\pi_{amc} < \pi_{ac}$ since then *jointly* mitigating and adapting is a dominant strategy for each country. Then analysis reverts to a special case of Table 13 without spillovers or carbon leakages consequent on adaptation. Then, for example, the US would choose mitigation over adaptation which is in turn preferred to not mitigating if:

$$\pi_u - L'_{uu} > \pi_{au} > 0$$

so local benefits from mitigation net of consequent carbon leakage losses must exceed local benefits from adaptation which must be positive.

Other than this special case determinate analysis of Table 14 requires strong assumptions because of the carbon leakages arising with M or M&A policies but not with A. Leaving out leakages, policy is selected on the basis of the highest direct net return.

5. Repeated games and dynamics

5.1 Repeated games

There are enhanced prospects for cooperation in *repeated* PD contexts (Dixit and Skeath 1999). Countries may have a preference for mitigation if failure to

mitigate brings about persisting costly non-mitigation responses by other countries.

In repeated games countries will plausibly adopt strategies that depend partly on the behaviour of other countries in previous periods. Attention has focused on situations where countries might play 'tit-for-tat' (TFT) trigger strategies. This means playing the mitigate strategy if other countries play this strategy. Countries will particularly tend to mitigate if they have low discount rates and so place high value on longer-term benefits. In addition, countries have increased incentives to mitigate now if they expect substantial future benefits with a continued active mitigation policy. If mitigation costs or the net benefits from mitigating were expected to decline, nations would have a propensity to defer mitigation. Likewise, if benefits from mitigation were expected to increase there would be improved prospects for mitigation.

Much policy attention has focused on the possibility of countries cheating on mitigation commitments. This is a profitable strategy if immediate gains from cheating are large and if probabilities of detecting cheating are low. The gains from cheating are reduced if emissions are nationally monitored and cheating is punished. Examining trends in *global* GGEs to determine cheating will be less satisfactory when many countries are involved in GGE mitigation agreements.

This argument for taking a longer-term view of strategic interactions backed up by monitoring for cheating to avoid PDs is bolstered by experiments suggesting that behaviour in repeated games becomes less cooperative through time and converges to the non-cooperative Nash equilibrium unless free riders are punished (Fehr and Gächter 2000).

5.2 Dynamics

The repeated game setting is static and excludes dynamic effects of current policies. There are numerous ways these interactions might be dynamized. Consider a two-country setting with 'China' and the 'US' considering mitigation responses over two periods ('now', the 'future') and ignore carbon leakages. Suppose environmental quality is a luxury good, strongly demanded at developed country incomes but less so at emerging country incomes.

Countries such as China face development imperatives now that provide incentives to forego mitigation and to expand per capita energy consumption. Some positive mitigation response however is called for partly because future incomes are expected to be much higher when greater weight will then be placed on the environment. Also China will face severe impacts from unmitigated climate change and high adjustment costs of reorienting energy consumption plans towards less polluting sources if this is postponed entirely. Countries such as the US may place relatively higher weight on having a quality environment now and retaining that quality into the future but face lower future impacts from unmitigated climate change partly because they have a wider range of affordable low cost adaptation options. In a strategic setting

the US will recognise the dynamic incentives China faces to under-supply current mitigation effort and to more fully mitigate in the future. There will also be recognition by the US that China will face more severe economic costs of adaptation in the future to climate change tempering pressures on China to shift its mitigation response forward. China will recognise increased current and future incentives for the US to mitigate more than it otherwise would in response to a diminished Chinese effort. China will recognise too that that this increased commitment to mitigate will be tempered by an increased US capacity to adapt to climate change.

It is straightforward to formalise a two-period model of these interactions although the reward from doing so may not be great given the ambiguous incentives facing such nations.

6. Conclusions

Strategic models of climate change have been developed which account for international spillovers and carbon leakages. While the PD structure of the strategic task is central the assumptions underlying this view were considered. The situation where current local benefits from mitigation exceed mitigation costs cannot be ruled out even for developing countries. A unilateral case for mitigation can still prevail if account is taken of future costs of dealing with severe climate change. Developed countries may also face dominant incentives to mitigate because of current environmental sensitivities. The case for unilateral action in developing countries is strengthened if developed countries resist joining in co-operative GGE mitigation efforts unless major developing countries also do so.

Developed countries such as the US face relatively lower costs of adapting to climate change and have argued that they will not mitigate unless developing countries also do so because of feared carbon leakages. Some evidence was cited suggesting the prospect for such leakages is exaggerated. If leakages do occur the conditions for mitigation to become a dominant strategy are more stringent and the prospects for PD inefficiencies enhanced.

One approach to addressing these difficulties is to penalise countries which do not mitigate and reward those which do. It may be the case that some countries can bribe other countries to mitigate with sufficiently large rewards. This was illustrated in a public goods setting where one group of countries has a strong preference for reducing GGEs but mitigation efforts are cheaper elsewhere. This outcome could be realised by appropriately allocating GGE quotas with free trade in quotas.

Leadership Games involved smaller countries forcing larger countries to bear the burden of mitigation. Chicken Games, with carbon leakages, involve multiple Nash equilibria with a no-mitigation equilibrium preferred by each country but where countries jointly prefer mitigating to not mitigating at all. Assurance Games are of interest since then a cooperative agreement to deal with climate change can be engineered once some countries commit to miti-

gate. Without carbon leakages such decomposition never obtains unless countries are subject to a hefty penalty should they not mitigate but an Assurance Game can obtain if carbon leakages are strong even without penalties.

An examination of three-country models with carbon leakages enabled assessment of impacts of countries committing to mitigate on the incentives of non-mitigating countries to mitigate. Forces equivalent to 'moral suasion' operate to encourage mitigation because costs of 'going it alone' in terms of carbon leakages are reduced. However, local gains from mitigating must still exceed the potentially large carbon leakage benefits that accrue to a country which 'holds out' on mitigating thereby gaining leakage benefits from countries that do mitigate. The possibility of deriving enhanced prospects for cooperation as more countries mitigate on the basis of social norms reflecting 'reciprocity' was discussed. Self-serving biases and the desire to avoid dealing with 'sensitive' moral issues obstruct cooperativeness. Emphasising the global advantage from cooperation and posing issues in ways that limit the potential to avoid such moral issues provide counterincentives. Sanctions and punishments seem vital to ensure cooperativeness.

If certain countries commit to pursuing 'no regrets' options then additional countries may be induced to mitigate as potential carbon leakages fall.

Finally, the analysis considered the potential for enhanced prospects for cooperation in repeated and dynamic game settings. The prospects for cooperation worsen in a repeated game where payoffs are undermined by cheating, by high discount rates, by falling costs of mitigation effort and by reduced future benefits from mitigation. These results should be fleshed out in a fully articulated growth model – a subject for future work.

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