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Nationally Self-Interested Climate Change Mitigation: A Unified Conceptual Framework

Fergus Green[*]

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Social scientists have long assumed that actions by states to reduce their greenhouse gas emissions are not in their self-interest because the domestic costs outweigh the domestic benefits and they can "free-ride" on the emissions reductions achieved by others states. Climate change action, on this logic, is a global "tragedy of the commons" and "prisoner's dilemma". While this view is increasingly being challenged by theory and evidence suggesting that much mitigation action would be in states' self-interest, this emerging literature is fragmented and has not succeeded in overturning the traditional assumptions, at least not in key social science reference works such as the reports of Working Group III of the Intergovernmental Panel on Climate Change. This paper seeks to rectify this problem by developing a unified conceptual framework for advancing and evaluating claims about the extent of mitigation action that could be done in states' self-interest, defined (for the sake of facilitating debate) in terms of economic efficiency. The paper concludes that there is a strong prima facie case that the majority of the emissions reductions needed to decarbonise the global economy can be achieved in ways that are nationally net-beneficial to countries, even leaving aside the climate benefits. Accordingly, the default assumption in social science scholarship should be that actions to reduce emissions are nationally net-beneficial. The barriers to mitigation action lie, primarily, not in the macro-incentive structures of states (i.e. climate action is, mostly, not a tragedy of the commons / prisoner's dilemma) but rather within the domestic sphere, at the intersection of domestic interests, institutions and ideas formed in the fossil fuel age.

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> Climate change is a global commons problem, meaning reduction in emissions by any jurisdiction carries an economic cost, but the benefits (in the form of reduced damages from climate change) are spread around the world … [the] public good characteristics of climate protection (non-excludability and non-rivalry) create incentives for actors to 'free ride' on other actors' investments in mitigation. … International cooperation is necessary to significantly mitigate climate change because of the global nature of the problem…
>
> — Intergovernmental Panel on Climate Change (2014)[1]

> [T]he investments and actions [recommended in this book] significantly reduce the carbon in economies but do so at the same time as delivering positive economic and social benefits to nations, even if one puts aside the value of the emissions reductions. In this sense, most of what is necessary for emissions reductions over the next two decades is in the self-interest of the individual nations.
>
> — Nicholas Stern (2015, 85)

1. Introduction

Since climate change emerged as a phenomenon of serious social scientific inquiry, generations of social science reference works have characterised the mitigation of climate change as a classic global collective action problem; a "tragedy of the commons" that has the game-theoretic form of a "prisoner's dilemma" (see, e.g., Stavins et al. 2014, 1007). This characterisation is predicated on the assumption that it is not in the national self-interest of a representative state to take action on climate change, whether or not other states take action. In the rationalist[2] tradition of scholarship, national self-interest is typically conceived in terms of *economic efficiency* — that is, increasing or maximising a state's economic resources (economic benefits relative to costs). The traditional assumption is that climate change mitigation actions are net-costly for an individual state: they impose significant, immediate costs domestically, while the benefits (a marginal reduction in global climate impacts) accrue globally to all states and in the distant future, so the net-present value of those actions to the state is (inevitably) negative. Accordingly, so the logic goes, each state has an incentive to "free-ride" on the emissions reductions of other states. Since the same incentive structure applies to all states, the "tragic" collective outcome of this individually rational behaviour is the under-provision of mitigation action compared with what would be socially optimal.

This logic is increasingly being challenged as scholars and policy practitioners demonstrate ever more ways in which climate mitigation action can be in states' national self-interest, even if the climate benefits of action are ignored (GCEC 2014a; Stern 2014a, 2014b, 2015). What the "national interest" consists in is a normatively controversial question, and this literature often appeals to considerations of national interest beyond narrow economic efficiency, including social welfare, individual well-being, social justice, sustainable development, environmental conservation, responsible global citizenship, and others. There are good reasons for incorporating such diverse considerations into calculations of national interest, especially for an issue as complex and far-reaching as climate change. However, appealing to multiple, wider conceptions of self-interest has had two unfortunate side-effects. First, it has meant those who argue climate mitigation is to a

[1] This quote is from chapter 13 the Working Group III (mitigation of climate change) report of the Intergovernmental Panel on Climate Change (IPCC), authored by Stavins et al. (2014, 1007–1008).

[2] By which I mean social-scientific scholarship that assumes relevant agents (in the present case, states) are rational in the sense that they efficiently pursue consistent, self-interested ends.

significant degree self-interested are largely talking past the economic efficiency monists; their respective claims are non-comparable. Second, it is harder to evaluate claims of national interest using conceptions other than economic efficiency; the efficiency framework, despite its flaws, has the virtue of being somewhat tractable. A further problem is that the literature on nationally self-interested mitigation is fragmented: even where it does advance claims about national self-interest in economic efficiency terms, there is little scholarship that integrates the various strands of literature into a unified conceptual framework or theory.[3] Consequently, the traditional assumptions reign supreme in rationalist scholarship: mitigation action is habitually assumed to be (at least mostly) nationally net-costly and therefore not in states' self-interest; and climate action continues to be framed as a single global prisoner's dilemma.[4]

This paper aims to overturn these assumptions by presenting a unified case for nationally self-interested climate mitigation using an economic efficiency framework. The motivating idea is that, if it can be shown that most mitigation action is in countries' national self-interest *even if one were to adopt an efficiency framework*, then it is likely that action will be self-interested on all of the wider conceptions of national self-interest that scholars have appealed to, and the traditional assumptions should be revised.

The contribution of the paper is to integrate the various disparate strands of the self-interested mitigation literature by positing a single definition of nationally self-interested mitigation action that incorporates two sub-categories of actions: *directly* and *contingently* nationally-net-beneficial mitigations actions. The main function of this framework is conceptual and theoretical: to provide a common and comprehensive conceptual terrain on which competing claims about the net present value of climate mitigation actions can be debated. In the course of developing this framework, however, the paper also presents theory and evidence that points to the potential *magnitude* of costs and benefits from the types of actions considered. It is on the basis of this theory and partial evidence that the paper concludes that there is at least a *prima facie* case that the majority of the global climate mitigation task — decarbonising the global economy within the present century[5] — can be done through actions that are nationally net-beneficial for states. It follows, I claim, that the

[3] An early conceptual framework was developed by participants in an OECD workshop in 2000 (OECD 2000), however much theoretical and empirical work on net-beneficial mitigation action has occurred since that time.

[4] The assumption that mitigation is nationally net-costly remains the point of departure, for example, in a number of important social science reference works on climate mitigation, exemplified by the opening quote to this paper from the IPCC (Stavins et al. 2014, 1007; see also Bernauer 2013, 424). These reference works typically *acknowledge* at least some of the literature concerning net-beneficial mitigation action, but these are framed as marginal or of secondary relevance. For example, in the IPCC's chapter on international cooperation, the point of departure in its "framing concepts and principles" is the assumption that mitigation action is nationally net-costly, which grounds the characterisation of climate mitigation as a prisoner's dilemma / tragedy of the commons (Stavins et al. 2014, 1007). The potential for co-benefits is mentioned five paragraphs later and then virtually dismissed in the same breath: "*some* emission reductions can occur without cooperation due to positive externalities of otherwise self-beneficial actions, or co-benefits … Co-benefits of climate protection are receiving increasing attention in the literature … *However*, policies designed to address climate change mitigation may also have adverse side-effects" (at 1008, emphasis added). Nothing is said about the relative magnitude of co-benefits and side-effects, despite other chapters in the same Working Group III report suggesting a preponderance of co-benefits relative to adverse side-effects (see, e.g., Clarke et al. 2014, 469–472).

[5] See IPCC (2014, fig. SPM.4), which shows that pathways giving a likely (>66%) probability of limiting global temperature increases to within 2°C require zero net emissions before the end of the present century.

burden of proving otherwise should lie with those disputing that claim, in effect reversing the traditional default assumption that mitigation is nationally net-costly.

The paper is structured as follows. Part 2 briefly introduces and defines key concepts. Part 3, the core of the paper, introduces the conceptual framework and illustrates the potential for national net benefits to arise from the different kinds of mitigation action classified within this framework. Considerable attention is focused on the two key conceptual innovations introduced in this paper: the concept of a "contingently net-beneficial mitigation action" (which enables evaluation of the costs and benefits of *sets* of multiple simultaneous or sequenced actions, by one or more states, thus incorporating into the economic analysis dynamic changes and self-reinforcing effects that result from multiple actions) and the associated concept of "contingency risk" (which facilitates the discounting of contingent costs and benefits as a function of the number of actions, number of states, and time required to complete the relevant sets of net-beneficial actions). It also outlines some residual types of climate mitigation actions that may be nationally net-costly, and suggests ways that these can be minimised and managed, drawing on insights from the preceding discussion.

If, as this paper concludes, the majority of mitigation action can be done in ways that are nationally net-beneficial, then one might well ask: why do we not see mitigation action commensurate with the scale of nationally net-beneficial action that is available? To borrow a phrase, why *are* we waiting? Part 4.1 briefly sketches some of the main alternative explanations for the under-provision of mitigation action — most of which locate the real barriers to action within the domestic sphere, at the intersection of interests, institutions and ideas formed in the fossil fuel age. This raises a further question: what implications does this turn to the domestic sphere have for climate policy, international cooperation, and other forms of social agency to mitigate climate change? Answering these important questions is the subject of work-in-progress by the author; Part 4.2 merely provides the sketch of a path forward. Part 5 concludes.

2. Conceptual building blocks: national self-interest, efficiency, and discounting

In order to facilitate debate among rationalist scholars about the costs and benefits of mitigation action on common terms, this paper adopts an economic efficiency conception of self-interest standardly used in rationalist scholarship (Stavins et al. 2014, 1012):

> ***Nationally self-interested action***: an action α taken by a state *A* is nationally self-interested if it increases the discounted value of economic resources available in *A* to produce welfare.[6]

To put it more vividly, an action will be nationally self-interested if it increases[7] "the size of the economic pie" that is (theoretically) available for redistribution within state *A*.[8] This condition is

[6] The conception of "welfare" typically adopted in this context is "the satisfaction of subjective preferences", i.e. those preferences held by individuals within state *A*. I am using this for functional convenience and am not endorsing it in a normative sense. Further, note that increasing efficiency is conceptually different from increasing welfare, though many of the works cited in this paper incorrectly refer to welfare when they really mean efficiency.

[7] Self-interest is often defined in terms of *maximising* net benefits (see, e.g., Carraro and Siniscalco 1998, 563) which is a more demanding conception of self-interest than merely *increasing* efficiency. In practice, in the climate context, there is unlikely to be a great difference between maximising and increasing net benefits.

satisfied when the discounted full social benefits of the action outweigh its discounted full social costs.[9] Hence, for clarity hereafter, I use the phrase "nationally net-beneficial" to refer to nationally self-interested actions (and its opposite, "nationally net-costly", to refer to non-self-interested actions).

Using an efficiency conception to define self-interest has the further functional advantage in this context of allowing claims about self-interested mitigation to be tested empirically and incorporated into standard analytical and decision-making frameworks used in public policy. This is because the market and (using a range of available economic valuation tools[10]) non-market costs and benefits of actions can be measured, quantified and monetised (Ürge-Vorsatz et al. 2014, 572). The incorporation of non-market costs and benefits into the efficiency framework is particularly valuable for present purposes because these are ubiquitous in the climate context (Stern 2015, 94).[11] Quantifying and monetising non-market costs and benefits is challenging and replete with methodological and normative controversy (Hausman and McPherson 2006, chap. 9; Ürge-Vorsatz et al. 2014, 560, 563, 570–571), illustrating the limitations of the efficiency framework in this context (and more generally), but engaging with the still-dominant efficiency framework leaves one with no choice but to attempt to do so as rigorously and transparently as possible.

A further limitation of the efficiency framework is that the results of any cost-benefit analysis will be sensitive to the discounting regime applied (the approach taken to determining the rate at which the monetary value of future costs and benefits is discounted for the purposes of making comparisons with present costs and benefits), which introduces yet further methodological and normative controversy (see Stern 2015, chap. 5 for a discussion of the issues). Advocating any particular discounting regime or discount rate is beyond the scope of this paper. I simply acknowledge that the extent to which mitigation action is nationally net-beneficial (or net-costly) will depend on the discounting regime used. Analysts in this context should be transparent about, and justify, their

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Most of the debate is concerned with ascertaining whether actions are net-costly or net-beneficial. There are further reasons to abandon the maximisation requirement in this case: it is never possible to evaluate the costs and benefits of all possible actions anyway (we must settle on a sub-set of possible choices); combinations and sequences of actions matter greatly in this context (see section 3.2), further complicating any attempt to maximise efficiency; some experimentation is inevitably necessary to determine costs and benefits of different kinds of actions; and much real world climate action attempts to achieve reasonable "second-best" outcomes, not first-best efficiency. Accordingly, I adopt the weaker but more practicable definition of "increasing" net benefits. Nonetheless, I acknowledge that in some situations the distinction will matter to the outcome. For example, in many least developed countries, access to finance is severely constrained and there may be a great many actions that could be done to increase net benefits in addition to climate mitigation, and in some cases maximising net benefits may require spending scarce funds on (say) public health or education initiatives at the expense of climate mitigation.

[8] Note that it is the *distribution* of that pie which determines aggregate *welfare*. I say "theoretically" available for redistribution because society's capacity to redistribute economic resources can be constrained by the incentive effects of redistribution (the so-called "leaky bucket" problem) and by various psychological, social, cultural, political and institutional phenomena. Pies, in other words, often come pre-sliced.

[9] When this condition is satisfied, the "winners" are, assuming costless transfers, able (though not necessarily required) to compensate the "losers" from the policy and leave no-one worse off and at least one person better off. Thus it gives rise to a "potential Pareto improvement". This logic applies inter-temporally as well as across agents at a single point in time (Broome 2010).

[10] These can broadly be divided into revealed preference methods and stated preference methods (Atkinson and Mourato 2008, 318).

[11] For example, many benefits and co-benefits of climate action are unpriced and therefore their value is not directly reflected in calculations of commonly used economic indicators such as GDP and national income.

selection of discounting regime and should analyse the sensitivity of their cost-benefit analyses to a reasonable range of discount rates.

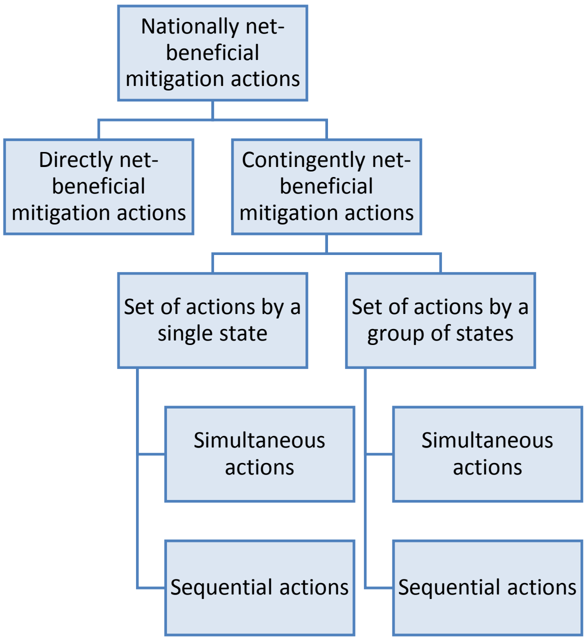
3. A conceptual framework for nationally self-interested mitigation actions

Drawing on the above definition of a nationally self-interested action by state *A* and defining a *mitigation action* as an action that has the effect of reducing greenhouse gas emissions (anywhere), we can define a *nationally net-beneficial mitigation action* as follows:

> ***Nationally net-beneficial mitigation action****:* an action *α* taken by state *A* is a *nationally net-beneficial mitigation action* if *α* has the dual effect of increasing economic efficiency in *A* and reducing greenhouse gas emissions (anywhere).[12]

Using the above definition, it is possible to integrate existing strands of the literature on self-interested mitigation action into a unified framework. To do so, I draw a distinction between two sub-types of net-beneficial mitigation actions: *directly* nationally net-beneficial actions and *contingently* nationally net-beneficial actions.[13] Figure 1, below, illustrates the structure of this typology.

Figure 1: Typology of nationally net-beneficial climate mitigation action



3.1 Directly net-beneficial mitigation actions

I define a directly net-beneficial mitigation action as follows:

[12] As I shall explain below, an action can be classified under my framework as a *contingently* net-beneficial mitigation action even if one or both of these effects are not the direct result of the action, so long as both results are the ultimate effect of a set of actions including the mitigation action.

[13] In the interests of efficiency, I hereafter drop the “nationally” after “directly” and “contingently” when using these terms (e.g. as per Figure 1).

> ***Directly net-beneficial mitigation action***: a mitigation action α taken by a state *A* is a *directly net-beneficial mitigation action* if α, on its own and without any further action, would be net-beneficial to *A*.

The focus here is on a static analysis of the costs and benefits associated with the relevant action, leading to an identification of those actions whose total discounted social benefits outweigh total discounted social costs, *based on current market prices or agents' current subjective valuations*.[14] The analysis is "static" because the cost-benefit framework assumes that the relevant action/project is marginal and not itself capable of changing either the prices/valuations that are used to evaluate costs and benefits or the values and preferences of individual agents that influence those prices/valuations.

3.1.1 Private financial net benefits from mitigation action

A great deal of mitigation action is likely to be nationally net-beneficial even on a narrow, financial cost-benefit analysis taking account of private financial costs and benefits only. For example, the direct savings from many kinds of energy efficiency measures (e.g. in industry, transport, buildings, and appliances) will often mean energy efficiency actions are net-beneficial in this sense (Somanathan et al. 2014, 1169). Similarly, in energy supply, the cost of electricity supplied from solar PV, onshore wind and some other types of renewable energy generation are in many parts of the world cheaper than more emissions-intensive energy sources, meaning supplying incremental energy demand through the former is net-beneficial in these cases (REN21 2015, 62, 73), at least so long as additional system integration costs needed to integrate renewable technologies (Bruckner et al. 2014, 543) are low.[15] (This static approach by definition ignores the crucial dynamics of innovation and the systemic aspects of energy transition, which are discussed in section 3.2.3).

3.1.2 Net benefits from co-benefits (relative to co-costs) of mitigation action

Evaluating the efficiency effects of a mitigation action requires accounting for its full social impacts: not just the private financial costs and benefits of the action, but also its other positive effects ("co-benefits") and negative effects ("co-costs" or "adverse side effects") which can together be called *co-impacts* (Ürge-Vorsatz et al. 2014, 555–558). Given the systemic technological and social changes needed to mitigate climate change, it is unsurprising that the vast majority of mitigation actions have co-impacts, and therefore that taking account of those co-impacts significantly changes the outcomes of economic assessments of the efficiency of those mitigation actions (Ürge-Vorsatz et al. 2014, 552, 574–575). When the co-impacts of decarbonising energy systems and other urban infrastructure are taken into account as part of the cost-benefit analysis, they are likely to substantially increase the scale of net benefits (GCEC 2014a, 43–45). This is because, for most of the changes needed to mitigate climate change, especially in cities and energy end-use, the co-impacts of mitigation action are overwhelmingly positive (i.e. co-*benefits*) (Clarke et al. 2014, 469–472).

[14] I refer to current subjective valuations because it is people's subjective valuations that directly determine the value of non-market goods and services when elicited using stated preference methods.

[15] As energy storage and intelligent network technologies continue to be developed and deployed, and their costs continue to fall (Nykvist and Nilsson 2015; REN21 2015), it is likely that in the not too distant future the levelised costs of intermittent renewables *with storage* will become cheaper than new-build coal and gas in many parts of the world. The innovation and energy systems dynamics associated with this transition are discussed in sections 3.2.3 and 3.2.4, below.

Moreover, where the private financial value of mitigation actions is net-costly, incorporation of co-impacts will for many mitigation actions flip the economic assessment at the national level from being net-costly to net-beneficial (GCEC 2014a, 43–45). These effects of incorporating co-benefits into a static cost-benefit analysis of mitigation actions are illustrated in Figure 2, below.

The large and growing literature on the co-impacts, particularly co-benefits, of climate actions, focuses mainly on sector-specific actions and effects, but also includes some analysis of co-impacts at the macroeconomic level, and across multiple sectors.[16] Table 1 contains a truncated list of some of the most important potential co-impacts of mitigation actions, for illustrative purposes. Table 1 also includes co-benefits drawn from the literature on knowledge spillovers from innovation (discussed below), which has developed more recently and hence is largely excluded from the meta-analyses of co-benefits from which most of the contents of Table 1 is drawn.[17]

Table 1: Key co-impacts of various climate change mitigation actions (economic efficiency co-impacts only)

Co-benefit	Key examples of actions typically resulting in co-benefits *(co-costs in italics)*
Public health impacts	Reduced outdoor air pollution (from substitution away from fossil fuels in energy supply). Reduced indoor air pollution (from substitution away from traditional biomass to clean cook-stoves/electricity). Reduced deaths and illnesses from coal mining (from reduced use of coal for energy). Reduced transport deaths and injuries, and prevention of inactivity-related diseases (both associated with transport modal shift away from private passenger vehicles). *Increased nuclear waste, legacy site management, and risk of accidents associated with increased use of nuclear power.* *Increased adverse health impacts associated with carbon capture and storage (CCS), including increased air pollution and other health & safety impacts associated with additional upstream energy activity (due to the "energy penalty" associated with CCS) and increased risk of* CO_2 *leakage (from underground storage of* CO_2*).*
Energy security impacts	Reduced exposure to energy price volatility (associated with the shift from energy systems reliant on imported fossil fuels to energy systems based on indigenous low- or zero-carbon energy sources, energy demand management, energy efficiency, energy storage, transport electrification and transport modal shift).[18]
Energy access impacts	Policies aimed both at alleviating energy poverty and controlling GHG emissions in developing countries (e.g. distributed solar PV for off-grid households) have the potential to significantly improve the living conditions of over 2 billion people who lack access to modern energy services. Such measures can provide significant benefits from security (e.g., fewer risks associated with biomass collection and combustion), comfort, productivity, and income-earning opportunities for the concerned population.
Agriculture, forestry and land-use impacts	Improved ecosystem services (from better agricultural & land-use practices; reductions in airborne pollutants).

[16] For a useful overview of the main types of sectoral co-impacts, see Table 6.7 in Chapter 6 of the IPCC's Working Group III report (Clarke et al. 2014, 469–471) and Ürge-Vorsatz et al. (2014, Table 1, also showing some macroeconomic effects).

[17] A number of important co-costs associated with fossil fuel dependence (or co-benefits of clean alternatives) are difficult to quantify and monetise, and thus are not captured in the table. For example, consider the economic value of the social costs associated with "petro-dictatorships" (oppressive and corrupt oil-producing countries).

[18] Energy security can be adversely affected by the intermittency of renewable energy sources such as solar PV and wind after a certain level of penetration of these sources in the electricity grid, if the other measures mentioned here are not taken.

Productivity impacts [co-benefits only insofar as not already counted as private financial benefits]	Increased material and energy efficiency at micro (firm, household) scales (from energy efficiency measures in buildings, appliances, transport and industry). Rural development and other productivity benefits from various levers (see GCEC 2015b, 3–4) linked to REDD+ and restoration of degraded land. Reduced congestion and increased productivity (from compact city design and transport modal shift). Higher labour productivity (associated with better building design and efficiency). Knowledge spillovers from innovation in lower-carbon goods, services and processes (induced through direct support for innovation and carbon pricing/regulation). [Note: such spillovers have an important dynamic aspect to their value — see footnote 23, below.]
Macro-economic performance impacts	Macro-consequences (increased industrial competitiveness and total factor productivity) associated with micro-level improvements in efficiency and innovation (see immediately preceding category). Increased efficiency of tax system (from removal of perverse fossil fuel subsidies). Stimulus effect of investment (e.g. in infrastructure, energy efficiency) where economy performing below efficiency frontier.

Sources: (Clarke et al. 2014; Coady et al. 2015; Dechezleprêtre, Martin, and Mohnen 2013; GCEC 2015b; Ürge-Vorsatz et al. 2014; World Bank 2012; Zenghelis 2014a)

Note: This list is not intended to be exhaustive, but rather to illustrate the main types of co-impacts and to motivate the subsequent claim as to the potential size of relative co-benefits. Includes co-impacts measured in terms of economic efficiency only and does not include additional co-impacts described or measured in terms of social welfare, equity or non-economic environmental values (cf, e.g., Clarke et al. 2014, 469–471).

Whether and to what extent these co-benefits materialise will, as with all co-impacts, "be highly case- and site-specific, as they will depend importantly on local circumstances and the scale, scope, and pace of implementation, among other factors" (Clarke et al. 2014, 472). Nonetheless, there are good reasons to think that co-benefits will often be large, both in absolute terms and relative to co-costs, with the result that much of the global mitigation action required will be (more) net-beneficial when co-impacts are included in the analysis (Clarke et al. 2014, 469–472; GCEC 2014a; Stern 2015). Figure 2 illustrates how the potential scale of net benefits from various mitigation actions grows when even just a few co-benefits of sectoral mitigation actions are taken into account.

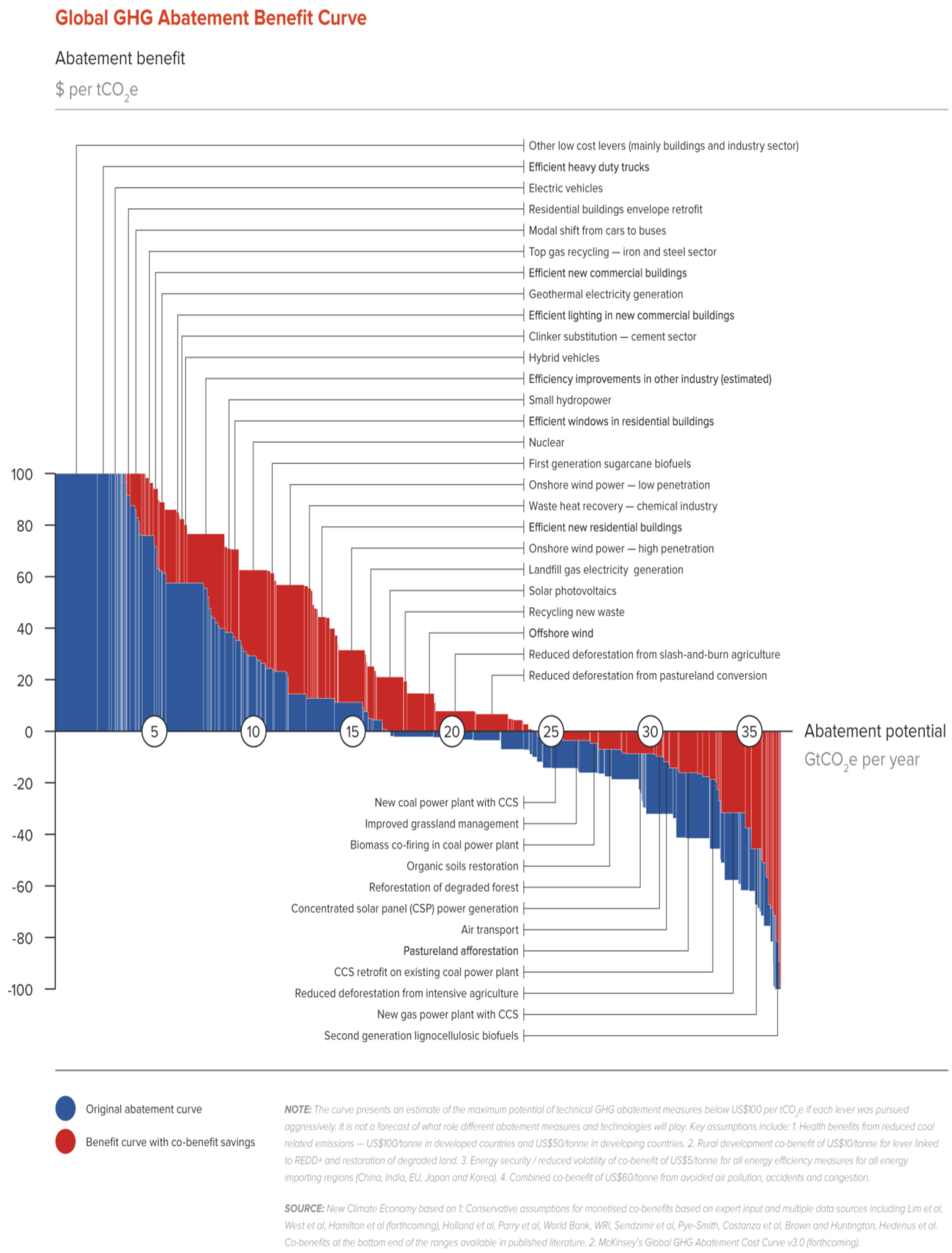
Two areas with among the largest potential co-benefits are improved public health (from reduced air pollution) and knowledge spillovers (from clean technology innovation). Brief discussion of some recent findings in these two areas further illustrates the potential scale of net benefits when co-impacts are accounted for.

Public health co-benefits from reduced air pollution

In their review of a selection of cost-benefit analysis studies that included analysis of co-impacts,[19] Ürge-Vorsatz et al. (2014, 574) find that "co-benefits can amount to as much as 50% to 350% of direct energy benefits from technology-based investments in energy efficiency and renewables", with health co-benefits typically dominant.

[19] The selection of studies analysed by Ürge-Vorsatz et al. (2014, Table 3) "was primarily based on the availability of disaggregated results by categories of social benefits to assess in a quasi-quantitative fashion the relative weight of each category with final profitability indicators (net present values or benefit-cost ratios)" (at 574).

Figure 2: Illustrative global greenhouse gas abatement benefit curve based on static analysis of private financial costs and benefits alone (blue) and when some key co-benefits are also included (red)



Source: GCEC (2014a, fig. 6) based on sources cited in source note in chart. See GCEC (2015b) for discussion of the methodology used.

The Global Commission on the Economy and Climate (GCEC) also finds great potential for net-beneficial mitigation action from its 2°C-consistent scenario to 2030,[20] and it, too, identifies the health benefits of reduced air pollution, associated with coal substitution in the energy sector and modal shift in the transport sector, as a very large category of co-benefit (GCEC 2014a, 34–36). A background paper for the Commission's report (Hamilton 2015) estimated the social costs of premature deaths from exposure to ambient $PM_{2.5}$ (airborne particulate matter measuring less than 2.5 micrometres in diameter), expressed in terms of dollars per tonne of CO_2e emitted in 2010, at approximately US$70/t$CO_2$e in developing countries and approximately US$150/t$CO_2$e in developed countries (GCEC 2015b, 3).[21] To illustrate the significance of these figures, they are respectively two and four times the official value for the social cost of carbon (i.e. the social benefit of abating one tonne of CO_2e, considering only avoided climate damages) produced by the US Government's Interagency Working Group on Social Cost of Carbon (IAWG) (US$37 in 2015) (IAWG 2013; Shelanski 2013).[22] In other words, the value of just one category of air pollution co-benefits (which covers mortality only, not morbidity) associated with reducing fossil fuels, is between double and quadruple the US Government's official value of the climate benefits from the same reductions in fossil fuels. Other studies find similar levels of social costs from local air pollution (Holland et al. 2011; Parry, Veung, and Heine 2014; West et al. 2013). Coady et al. (2015, 38) conclude that the cost of untaxed local air pollution externalities from fossil fuels was equivalent to 3% of global GDP in 2013 and forecast an increase to 3.4% of global GDP for 2015.

It is partly for these reasons that *The Lancet* Medical Journal's Commission on Health and Climate Change concluded that "tackling climate change could be the greatest global health opportunity of the 21st century" (Watts et al. 2015).

[20] The Commission's headline conclusion is that 50–90% of the abatement (14–18GTCO_2e) needed to get from the IPCC's median baseline emissions projection in 2030 (68GTCO_2e) to its median emissions projection for pathways with a likely (>66%) chance of holding the average global temperature rise to 2°C (42GTCO_2e) could be achieved through actions "that would bring not only climate benefits, but also multiple economic and social benefits" (GCEC 2015a, 1). The Commission notes that "[i]n *many* cases, the measures have the potential to achieve net benefits (*understood broadly*) even before considering climate benefits" (at 1, emphasis added). This formulation is therefore wide enough to include actions that are not net-beneficial *in an economic efficiency sense* for the state implementing the action and therefore not strictly consistent with the definition of a nationally self-interested mitigation adopted in this paper. However, the Commission's analysis underscores the more general point being made here, which is that the potential co-benefits from mitigation action are likely to be very large.

[21] The cost varies significantly by country, reflecting different levels of exposure to particulate matter (specifically PM2.5), income levels and other factors (GCEC 2015b, 3). The analysis is based on an estimation by the Global Burden of Disease project of the World Health Organization of the number of deaths resulting from ambient PM2.5 exposure for all countries in 2010, as described in Lim et al. (2012). The Commission, erring on the side of conservatism, ultimately adopts for its analysis the somewhat lower estimates for air pollution costs of US$50/t$CO_2$e in developing countries and US$100/t CO_2e in developed countries in 2030 (GCEC 2015b, 3).

[22] Note that this social cost of carbon value is likely significantly lower than the true cost of carbon due to the exclusion of climate impacts that are well-established in the scientific literature but not easily quantifiable as a cost, and due to the adoption of assumptions in the Integrated Assessment Models used to determine the social cost of carbon which likely further underestimate the economic damages associated with climate change (Stern 2013, 2015, 139).

Beneficial knowledge spillovers from clean innovation[23]

Innovation has wide co-benefits in the form of "knowledge spillovers" — the new knowledge that is produced by an innovation and can be used by other innovators, begetting further innovation, and yet further spillovers. Innovation in "clean" technologies, services and processes is not only crucial to the task of climate change mitigation, it is also highly knowledge-intensive. Dechezleprêtre, Martin, and Mohnen (2013) compare the relative intensity of knowledge spillovers from clean and dirty technologies in two industries responsible for large amounts of greenhouse gas emissions — energy production and transportation — using a rich dataset of 3 million citations received by over a million inventions patented in more than 100 countries. Their results "unambiguously show that clean technologies induce larger knowledge spillovers than their dirty counterparts" in both industries (at p. 31): clean patented inventions receive 43% more citations than dirty inventions (at p. 3).[24]

The authors conclude that the relative knowledge intensity of clean innovation is explained by two factors. First, clean inventions evidently have more general applications than dirty inventions (i.e. they are more likely to have the characteristics of a "general purpose technology"), since they are more highly cited outside of their originating field, and are cited by a wider range of sectors on average (at pp. 4, 27–29, 31). Second, clean inventions are relatively new and undeveloped, whereas the dirty technologies they replace are much more mature and developed. Therefore clean technologies might benefit from early returns to scale and steep learning curves (at pp. 29–32). Indeed, comparing clean technologies with other radically new technological fields such as information technology (IT), biotechnologies and nanotechnologies, the authors observe that "knowledge spillovers from clean technologies appear comparable in scope to those in the IT sector, which has been the driver behind the third industrial revolution" (at pp. 4–5).

The patents and citations analysed by the authors also show that a high proportion of knowledge spillovers — on average, 50% — occur within the same country, i.e. from inventor I_1 to inventor I_2 where both are within state *A* (Dechezleprêtre, Martin, and Mohnen 2013, 2014).[25] For present purposes, this carries the important implication that clean innovations — and institutions and policies to support them — are likely to bring significant *national* co-benefits on the basis of knowledge spillovers alone, thus further increasing the net benefits (or reducing the net costs) from

[23] There is an important "dynamic" aspect to knowledge spillovers, since most of the social value from a particular invention derives from the knowledge being put to new uses by other agents in the future (though the mere creation of new knowledge arguably also creates social value insofar as other agents have a willingness to pay for it). Accordingly, it could reasonably be argued that this category should be included in section 3.2.3 of this paper, on dynamic sets of actions, rather than here in the discussion of static co-benefits. I include it here because the intention of this section is to focus on the value created by single actions by states (e.g. the public support for innovation, which has wider social benefits that accrue over time), whereas the discussion of innovation in sections 3.2.3 and 3.2.4 focuses on multiple actions by states that together bring down the costs of clean technologies over time. The mechanisms at work in each case are distinct but related.

[24] The 29 September 2013 version of the working paper by Dechezleprêtre, Martin, and Mohnen (2013) cited here refers to four sectors (energy, vehicles, fuels and lighting), but the paper was, at the time of writing, being revised to focus only on the categories of "energy production" and "transportation"; the quantitative and qualitative results are not affected (pers. comm. Antoine Dechezleprêtre, 27 June 2015).

[25] Only the qualitative point, and not the specific 50% average figure, is included in the two papers referenced here. The 50% figure is, nonetheless, one of the results from the data analysed in the two papers cited (Dechezleprêtre 2015; pers. comm. Antoine Dechezleprêtre, 29 May 2015).

climate mitigation policies that encourage such innovation (e.g. innovation support and carbon pricing).[26]

3.2 Contingently net-beneficial mitigation actions

3.2.1 Theoretical introduction

Contingently net-beneficial mitigation actions defined

The above discussion of co-impacts recognises the great potential for individual mitigation actions to be nationally net-beneficial to states based on current market prices or agents' current subjective valuations. Important though the single-state, single-action, static perspective on co-benefits is to a full accounting of net benefits, it misses the arguably even more important potential for nationally net-beneficial mitigation action that can arise from *multiple, complementary actions* (by one state or a group of states), and from *dynamic changes in technology, prices, values and preferences over time*, especially when complex-systemic effects are brought into the analysis (Aghion et al. 2014).

In this part of the paper, I incorporate these factors into the analysis of net benefits by considering as variables the number of *states* taking actions, the number of *actions*, and the *timing* of actions. These variables can be represented as follows:

- States are represented by capital letters (*A, B, C, …*);
- Actions are represented by numbers and are associated with states using subscript numbers (e.g. action *1* of state *B* is expressed as B_1); and
- The time at which an action is taken is represented by *t* and is associated with state-actions using superscript numbers (action *1* of state *B* at time *t+2* is expressed as B_1^{t+2}).

With this in mind, I define a *contingently net-beneficial mitigation action* as follows:

> ***Contingently net-beneficial mitigation action***: a mitigation action taken by a state, *A*, is a *contingently net-beneficial mitigation action* of *A* if the action is one of a set of actions the aggregate effect of which is net-beneficial to *A*.

The basic idea is that there are actions that state *A* could take that, *contingent on further actions being taken* (by it or by other states), would yield net benefits to *A*.[27] Below, I consider three types of contingently net-beneficial mitigation actions, each of which introduces a new variable:

1. Multiple, simultaneous actions by a single state (A_1, A_2, A_3, …) (discussed in section 3.2.2);
2. Multiple, sequenced actions by a single state (A_1^t, A_2^{t+1}, A_3^{t+2}, …) (discussed in section 3.2.3);
3. Actions taken by more than one state, be they simultaneous or sequenced, e.g. (A_1, B_1, C_1, A_2, D_1, D_2) (discussed in section 3.2.4).

[26] Of course, it also implies that on average 50% of the benefits from such actions will spill-over to other countries. But this does not diminish the point that there are strong national co-benefits from clean innovation. The existence of cross-border spillovers does, however, provide a strong rationale for international cooperation on innovation. The extent of national net benefits available from innovation suggests that such international cooperation will more likely take the form of a coordination game than a prisoner's dilemma. This point is noted in Part 4 and will be taken further in a follow-up paper.

[27] Remember I am excluding from the analysis, for the sake of argument, the climate benefits from such actions.

Nationally net-beneficial action sets

Since a contingently net-beneficial action is defined as an element of a *set* of actions, I also introduce here the concept of a *nationally net-beneficial action-set*, being a set of actions the aggregate effect of which is net-beneficial. Note that in the third type of case just mentioned, involving actions by more than one state, the fact that a set of actions is cumulatively net-beneficial is a necessary but not sufficient condition for the set of actions to be net-beneficial *for each participating state* (i.e. for each state that has at least one action in the set). Accordingly, in section 3.2.4, which discusses international action sets, I focus only on action sets that meet the more stringent requirement of being nationally net-beneficial *to all participating states*.[28]

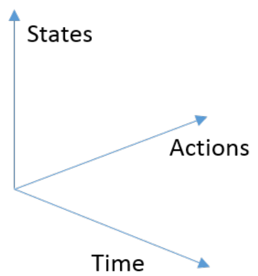
Contingency risk

A consequence of the "contingent" nature of the net benefits associated with the actions discussed in this section of the paper is that there is a risk that the net-beneficial action set will not be completed, leaving those states that take net-costly actions stuck with the net costs but without the offsetting net benefits that would have accrued if the additional actions in the set had been taken. I call this *contingency risk*. We can conceptualise contingency risk, *R*, for a state (in respect of a given nationally net-beneficial action set) as a function of the three variables introduced above:

$$R = f(N_a, N_s, t_\delta)$$

> *Where: N_a refers to the number of actions, additional to the action in question, needed to complete the set; N_s refers to the number of states involved in taking these remaining necessary actions; and t_δ refers to the amount of time between the action in question and the completion of the set.*

Figure 3: Contingency risk as a function of three variables



The common theme in these variables is that they represent the degree of *control* that any particular national government has over the completion of the set, which diminishes as more actions are required, more states are involved, and more time passes.

Contingency risk is discussed where relevant in each of the next three sections, and section 3.2.5 draws some general conclusions about contingency risk.

3.2.2 Multiple, simultaneous actions by a single state

[28] To be clear, I am assuming no transfers from "winner" states to "loser" states as part of these sets. So to count as a net-beneficial action set in this analysis, the action sets must be net-beneficial from the perspective of each individual state without Pareto-motivated international transfers.

Here we consider nationally net-beneficial action sets involving one state, *A*, taking simultaneous actions that are, in aggregate, nationally net-beneficial to *A*. The idea is to capture the complementarities among sets of actions that necessarily include mitigation actions.

A good example of this kind concerns fiscal reform. Two effective types of mitigation actions that states can take to cut greenhouse gases are reducing/eliminating fossil fuel subsidies and levying a carbon tax (or other charge[29]) on emissions-intensive activities (Somanathan et al. 2014, 1159–1167). Aside from any national efficiency-enhancing effects these measures may have on their own, the reduction in government expenditure associated with reduced fossil fuel subsidies, and the increase in government revenue associated with carbon taxation,[30] yield additional revenues for governments, other things being equal (Coady et al. 2015, 24). If these additional revenues are applied, or "recycled", toward complementary, efficiency-enhancing fiscal policies, then the net benefits of the policy increase (or the net costs fall) (Goulder 2013; Stavins and Bennear 2007). For example, other inefficient taxes could be reduced, or productive, efficiency-enhancing expenditures (e.g. on infrastructure, innovation or education/skills) could be increased (Coady et al. 2015, 31).

In this type of case, contingency risk can be presumed to grow with the number of (simultaneous) distinct actions involved in the action set, since additional actions raise the complexity of the government's reform task (the number of government agencies and officials involved, non-government stakeholders involved, and veto points may all increase, etc.).[31] However, the marginal contingency risk of additional actions is generally likely to be relatively low in this kind of case, since the actions contemplated here are ultimately in the control of a single government at a single point in time. Contingency risk in these cases can be minimised through effective strategic planning, coordination across government departments, and stakeholder engagement.

3.2.3 Multiple, sequenced actions by a single state

Here we consider nationally net-beneficial action sets involving one state, *A*, taking multiple sequenced actions that are, in aggregate, nationally net-beneficial to *A*. The idea here is to capture not merely the complementarities among actions, but also *dynamic* changes in technical options, prices, or values over time, and hence the importance of sequencing actions. Sequencing is especially important because actions can have self-reinforcing feedback effects. Below I consider the example of dynamic technological innovation in energy systems, which involves both systemic complementarities and self-reinforcing effects (Aghion et al. 2014). Some of the effects considered below have an essential international dimension. The international aspects are discussed in section 3.2.4, but because the same basic dynamics are also applicable to purely domestic actions and the systems to which they relate, they are introduced here. I conclude the present section with an illustrative example of a nationally net-beneficial action set containing actions by a single state that exploit these effects/dynamics.

Innovation plays a central role in expanding the technological frontier and changing relative prices of goods and services over time, and thus it "requires analysis of dynamic and constantly evolving,

[29] This could include the auctioning of tradable emissions permits under a cap-and-trade scheme.
[30] Or the increase in government revenue from a cap-and-trade scheme in which the tradable carbon permits are auctioned.
[31] However, the political feasibility of the actions may rise, since complementary actions can enable the development of wider and deeper coalitions to support the set of actions.

rather than static, economies" (Aghion et al. 2014, 4). Importantly, innovation is not just a dynamic phenomenon, but one that occurs in a particular *direction* due to the presence of many self-reinforcing mechanisms (Dosi and Nelson 1994; Dosi 1982) in both the early stages (research and development (R&D)) and later stages (demonstration and deployment / adoption) of a product's innovation cycle.[32]

The *research and development* of new technologies is self-reinforcing because scientists and technology developers work in areas that are well-funded and where their colleagues work, so ideas emerge and feed-off one another cumulatively (Aghion et al. 2014, 6). For example, Aghion et al. (2012), using firm-level data from the automotive sector, show that innovation decisions of firms are self-reinforcing (firms tend to direct innovation towards what they are already good at) and are influenced by the practice of the country where the researchers/inventors are located.

The *demonstration and deployment / adoption* of new technologies is self-reinforcing in numerous ways. As new technologies enter the market, their costs tend to fall over time as a result of (i) economies of scale (the more the market expands, the more of the new good is produced, allowing producers to spread their fixed costs over a larger number of revenue-earning units) and (ii) "learning by doing" (savings are made throughout the supply chain as repeat iterations lead to discoveries of more efficient production methods) (Bruckner et al. 2014; International Energy Agency 2015).[33] But since new technologies are initially more costly relative to incumbents (whose costs are lower as a result of decades or centuries of accumulated scale and experience, and for other reasons), they will tend not to be adopted unless there are government subsidies or other incentives for their production or use. Additionally, incumbent technologies benefit from being able to utilise existing supply infrastructure (e.g. pipelines and port infrastructure for oil and gas supply), whereas alternatives may require new infrastructure to be built (e.g. new, "smart" electricity transmission and distribution infrastructure to connect renewable energy sources and to better manage variable and decentralised electricity output) (Aghion et al. 2014, 6–8). Similarly, on the consumption side, the benefits of many energy-related technologies to a given user rise with the number of others using it ("network effect") (Aghion et al. 2014, 6–7; Farrell and Klemperer 2007). For example, the more people who drive combustion engine vehicles, the more petrol stations and roads there are likely to be, and the more that social and ideational phenomena such as social norms and social network effects (Granovetter 1978; Lane 2011; Watts 2002) are likely to increase demand for those vehicles. Finally, on both the production and consumption side, incumbents tend to benefit from institutional arrangements (e.g. regarding power system planning, design, operation,

[32] This binary representation of the innovation chain is very coarse but is appropriate for present purposes because the types of self-reinforcement mechanisms that exist at the R&D stage are meaningfully different from those that exist in subsequent stages. Demonstration could just as well be grouped with R&D (i.e. RD&D), as it sits in the middle of the innovation chain. I separate "adoption" from "demonstration and deployment" with a forward-slash because they are two sides of the same coin rather than separate "stages". Following Aghion et al. (2014, 6), I associate deployment (and demonstration) more with supply-side economic phenomena (e.g. economies of scale) and adoption more with demand-side economic phenomena (e.g. network effects), but because of the important relationships between them I prefer to group them together conceptually.

[33] While falling technology costs are the norm in the clean energy context, they are not a given, as recent cost increases in novel nuclear technologies have shown (Bruckner et al. 2014, 542). Moreover, some technologies may exhibit rising costs *at certain phases* of their evolution, as some renewable energy technologies have done, even though a longer-term perspective reveals a strong downward trend in costs (see Bruckner et al. 2014, 542 for discussion).

investment, tariffs/pricing, and markets) geared to the maintenance and expansion of the existing energy system, which are often ill-suited to optimising the net benefits from a flexible, decarbonised energy system (Miller et al. 2015, chap. 4; REN21 2015, 32).

Each of the factors mentioned above means that there are typically high costs for both producers and consumers involved in switching to new technologies and their associated infrastructure ("switching costs") (Aghion et al. 2014; Farrell and Klemperer 2007). Moreover, switching is made difficult by the fact that the coordination of multiple private and public agents, suppliers and consumers is often required to effect the switch ("coordination problems") (Fleurbaey et al. 2014; Yarime 2009). It is widely acknowledged that the current, fossil-fuel based energy system is characterised by these (and other) self-reinforcement mechanisms and is therefore highly inert,[34] thereby diminishing the prospects for alternative technologies and systems to emerge (Aghion et al. 2014; Unruh 2000).

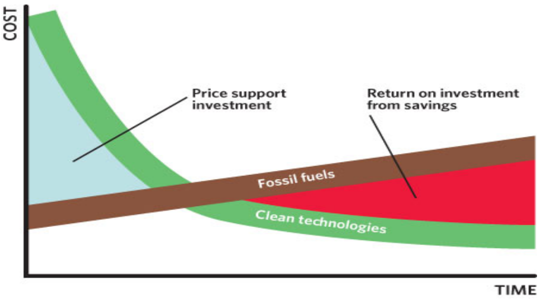
For the purpose of analysing dynamic changes in the economics of mitigation actions, these features of technology systems have two very important implications. First, the early phase of a transition away from incumbent technologies is likely to entail relatively high direct financial costs.[35] Displacing the incumbent system with clean alternatives requires a strong policy "push" toward clean innovation through the provision of new infrastructure, institutions, fiscal measures and so on, so as to shift expectations about future costs and benefits (Acemoglu et al. 2012; Aghion et al. 2014, 7–9), and some such actions will, viewed in isolation, be net-costly. But the second implication is that the clean technologies and associated innovation/technology systems will, after a certain critical mass of investment in innovation (from R&D to deployment), infrastructure and institutional reform, become cheaper than the incumbent, high-carbon technologies and systems, because the former will increasingly enjoy the same kinds of complementarities and self-reinforcing benefits that the latter system enjoys now (Aghion et al. 2014, 8); the energy system could "tip" from dirty to clean (Lenton 2013, 21). After that point, it is easy to see how an energy system fuelled by sun, wind and water could bring perpetual savings in direct costs compared with one based on "digging fossil fuels out of ever more remote places and transporting [them] across the world in pipes and ships" (Aghion et al. 2014, 8).[36] Thus, for many net-beneficial action sets (especially those involving the decarbonisation of large-scale, self-reinforcing technological systems), it will be the case that the costs of individually net-costly actions within the set are relatively large, but because the future benefits are even greater, the total net benefits from the full set of actions is also large. This is illustrated schematically in Figure 4, below.

[34] It is also sometimes referred to as being "path-dependent". Path dependence means that "current and future states, actions, or decisions depend on the path of previous states, actions, or decisions" (Page 2006, 88).

[35] Though not necessarily *net* costs once the full social costs and benefits are considered, for all the reasons considered elsewhere in this paper.

[36] An implication of this finding is that carbon pricing and some forms of innovation support would need only be "temporary", i.e. to redirect innovation and production toward the clean path (Acemoglu et al. 2012).

Figure 4: Schematic illustration of cost savings from switch to clean technologies



Source: Climate Bonds Initiative (2009).
Note: This diagram is highly simplified. Of course, the learning and cost pathways for different clean technologies are and will be heterogeneous, as will be the cost pathway for fossil fuels. It is merely included to illustrate the general point in a simple way that can be readily grasped.

Recent economic analysis from the International Energy Agency (2015, 16) concludes that, due to a combination of direct financial energy-efficiency benefits and direct financial cost savings in low-carbon energy supply alone, *the entire energy transition* needed to stay within a 2°C warming scenario ("2DS") would be net-beneficial (and, due to the location of the costs and benefits, we can infer it would generally be *nationally* net-beneficial for the states involved):

> Economic analysis shows that fuel cost savings more than offset the additional investment costs of the 2DS, creating a compelling case for investing in the transition to a low-carbon global energy system. About USD 40 trillion additional investment (relative to the USD 318 trillion expected to be invested anyway in the business-as-usual 6°C Scenario [6DS]) is needed to transition to a global low-carbon energy system in the 2DS. This represents less than 1% of the cumulative global GDP over the period from 2016-50 and sets the stage for fuel cost savings of USD 115 trillion – i.e. almost triple the additional investment.

Thus, the Agency concludes, "the 2DS results in net savings of around USD 75 trillion compared with the 6DS" if the fuel cost savings are undiscounted; "[d]iscounting the future investment needs and fuel cost savings lowers the net savings to USD 31 trillion (discount rate of 3%) or USD 8 trillion (10% discount), but still yields net benefits" (International Energy Agency 2015, 64–65).[37] To put these savings into perspective, the combined wealth of the poorer 50% of the world's people in 2014 was estimated at less than US$2 trillion (Hardoon 2015, using data from Credit Suisse 2014).

The international dimensions of the transition are important (and are considered in the next section), but the basic logic applies in principle to unilateral action by states (albeit more so to larger and wealthier states whose actions are more likely to affect technological and price trajectories).

To take a single-state example, consider a combination of actions by a state that includes: (i) a carbon tax; (ii) various policy mechanisms to support clean energy innovation (research, development, demonstration and deployment); (iii) a green investment bank to overcome financial barriers to the commercial demonstration and deployment of low-carbon technologies; (iv) the provision of network infrastructure such as smart-grids and electric vehicle (EV) charging stations; and (v) additional, non-price policies to encourage and facilitate the take-up of energy efficient technologies and processes. Due to the complementarities, self-reinforcing effects and other

[37] Compare GCEC (2014a, 210–212, 2014b).

beneficial interactions among these policies, their combined effect would likely be much more net-beneficial than the sum of the effects of each individual policy undertaken without the others.[38]

In these types of cases, contingency risk is a function of not only the number of distinct actions required to complete the action set but also the associated time needed to undertake them. If the time required extends beyond the life of one government's term, contingency risk is likely to be higher than if it is within the life of a single government (though even in the latter case contingency risk will rise with time, since time brings the potential for unforeseen events to disrupt policy agendas). Contingency risk in these cases can be reduced through effective strategic planning, upfront commitment to a sequence of reforms, and building cross-party political consensus.

3.2.4 A set of actions taken by a group of states that is net-beneficial to all states in that group

Here we consider nationally net-beneficial action sets involving more than one state taking action, be it intentionally coordinated or pursued independently. These cases are more complex because of the involvement of more than one state, and hence the introduction of strategic calculation. Here, sequential actions — and the dynamics of international cooperation, along with the dynamic cross-border effects of individual actions — are especially important. Recall from section 3.1 that I will limit the analysis here to those action sets that are nationally net-beneficial from the perspective of all states taking an action within the relevant set.

Net-beneficial action sets of this kind will exist when the actions in the set are positively reinforcing, such that the payoffs to participants increase the more actions are taken by states within the group.[39] Heal and Kunreuther (2010) highlight how positive reinforcement can lead to "cascades" of actions and "tipping points" in a variety of dynamic contexts and they demonstrate formally how the same phenomena can emerge in static, non-cooperative games, creating multiple equilibria. Applying these insights to the climate change context, they explain that "if there are positive reinforcing effects or strategic complementarities between agents' [i.e. states'] choices of strategies to reduce emissions, then it may be possible to tip the system from the inefficient to the efficient equilibrium" (Heal and Kunreuther 2012, 58), and the same logic applies in a dynamic context. Thus, they argue, "there may be a subset, ideally a small one, of countries who, by adopting GHG abatement policies, can trigger a movement by the rest in the same direction" (at p. 15).

More specifically, Heal and Kunreuther (2010, 2012) show that tipping will occur when there are "increasing differences" between participation and non-participation[40] — that is, when the net

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[38] See generally Stern (2015, chap. 3). On the complementarities/beneficial interactions between: carbon pricing and public support for innovation, see Acemoglu et al. (2012), Dechezleprêtre, Martin, and Mohnen (2013), Fischer and Newell (2008), Fischer (2008), Popp (2006), and Somanathan et al. (2014); network infrastructure investment, innovation support and carbon pricing, see Aghion et al (2014); green investment banks and each of the other elements discussed here, see Mazzucato (2013), Mazzucato and Penna (2014), and Zenghelis (2012); and energy efficiency and carbon pricing, see Somanathan et al. (2014, 1181).

[39] Heal and Kunreuther (2010, 88) consider similar sets of situations in a static game-theoretic framework: "these are all games that show the increasing differences property that is associated with supermodularity. Agent *i*'s payoff to a choice increases if *j* makes that choice as well. One can also think of this as strategic complementarity."

[40] Heal and Kunreuther use "cooperation"/"non-cooperation". I use "participation" to mean taking an action within an action set, which may or may not involve "cooperation", which I take to connote an intentional and explicit form of international engagement (as distinct from a mere unilateral action that has positive international spillover effects, with which I am also concerned).

benefits a state gets from participating in the action set increase as another agent participates, and indeed increase further for each successive state that participates. This could occur as a result of *benefits increasing* with participation, *costs decreasing*, or *both*.[41] Below I consider two examples of strategic complementarities and self-reinforcement mechanisms that exhibit increasing differences through the reduction of costs (the first example also entails increases in benefits through knowledge spillovers, though I leave this aside for now as it was discussed earlier).

Self-reinforcing effects from technological innovation in the energy system

Here I consider some international dimensions of the complementarities and dynamic effects associated with technological innovation in the energy system, discussed in the previous section.

First, much of the physical infrastructure in the global energy system is transnationally-oriented (e.g. cross-border oil and gas pipelines; LNG export and reception/regasification facilities; oil transportation and refining networks, etc.) and there are significant transnational network effects (e.g. in vehicle types/fuels), all of which give rise to strategic complementarities with cross-border elements. Physical supply infrastructure may become less internationalised as the energy system decarbonises because most zero-carbon technologies do not require fuel for operation (which is often imported), and because there will be an increase in the proportion of decentralised generation — all of which will make the energy system transition easier than it might otherwise be if greater international coordination in physical infrastructure were required. By contrast, in some regions (e.g. Europe) greater cross-border electricity grid interconnection may be needed to balance supply and demand across a grid with high proportions of renewables, which would give rise to coordination challenges, but also to self-reinforcing effects that lead to "increasing differences" from participation/non-participation. Moreover, in some regions there will likely be cross-border network effects on the consumption side, for example in electric vehicles (e.g. if I can charge my EV in France but not in Germany because few people in Germany use EVs, then an EV in France may be less valuable to me).

Second, and more importantly, knowledge production and exchange occur within global networks,[42] including international research networks, multinational companies, foreign direct investment, international trade in goods and services, international supply chains, cross-border movements of labour, the international intellectual property system, and so on. Accordingly, some of the knowledge produced through R&D, and through the "learning-by-doing" associated with the demonstration and deployment of clean technologies, spills-over to other countries (Dechezleprêtre and Glachant 2014; Dechezleprêtre, Martin, and Mohnen 2013; Peters et al. 2012). These partly-internationally-externalised benefits from clean innovation are therefore also associated with "increasing differences", since costs fall, and knowledge spillovers rise, for all participating states the more other states participate.

The relatively high financial costs associated with the early and middle aspects of technological innovation mean contingency risk for early movers could be relatively high. Here, explicit

[41] It could also result from costs increasing with non-participation (if non-participants are penalised by participating states, e.g. through border adjustment measures), as Heal and Kunreuther (2012) show. I leave this aside here for reasons of space and simplicity, but it is certainly relevant, and could increasingly become important as more powerful states deepen their action/participation.

[42] Though there are strong local clustering effects.

international coordination to share upfront costs across a number of states may be necessary for the realisation of net benefits to all participating states (Peters et al. 2012, 1305). In this respect, the literature on international technology cooperation (e.g. de Coninck et al. 2008; Newell 2010), and the wider literature on international "club goods" (see Falkner 2015), offer insights into how such cooperation could be structured. Some countries have a very important role to play in the early and middle stages of technological innovation, like the US and China, respectively.[43] We could reasonably expect that where such countries are involved, the necessary early actions could be structured within action sets involving only a small group of key countries (meaning the contingency risk associated with early actions would be relatively low, compared with the case where many smaller countries engaged in the same actions). We have already seen these dynamics — self-reinforcing R&D, demonstration, and deployment/adoption led by a few key countries — at work in solar, wind, and battery technologies to such an extent that, as noted earlier, in many parts of the world, solar PV and onshore wind are already cheaper than incumbent fossil fuel-based energy generation options (International Energy Agency 2015; REN21 2015) and battery storage costs are falling rapidly (Nykvist and Nilsson 2015).

In this regard, expectations are particularly important: the more states and non-state agents expect other states and agents to undertake the relevant actions, and hence for international markets for clean technologies to grow and costs to fall, the more they will be inclined to act themselves, and the earlier the tipping point will come (Acemoglu et al. 2012; Aghion et al. 2014, 7–8). Perceived inevitability of decarbonisation to avoid climate change can help to direct expectations toward transition, as can the desire to avoid stranded assets from a delayed-and-then-rushed transition: many countries may rationally decide to work with the asset depreciation cycle to transition their energy system and industries, seeing additional value in making upfront investments because of the reduced risk of stranded assets later.[44]

Self-reinforcement through coordinated carbon pricing in trade-exposed sectors

A different self-reinforcement mechanism that would increasingly reduce costs between states as more countries take action pertains to policies that impose carbon prices — be they explicit (carbon tax or cap-and-trade schemes) or implicit (e.g. mandated technology standards) — on domestic firms producing highly traded or trade-exposed products (Heal and Kunreuther 2012, 56). Many fear that such measures, if pursued unilaterally by one state, would harm the competitiveness of its industries, causing emissions- or energy-intensive production to "leak" to other states with weaker carbon prices. There is little evidence that leakage has occurred as a result of existing policies, though it cannot be ruled out if more stringent carbon pricing policies, commensurate with the scale of decarbonisation required, are pursued unilaterally (Dechezleprêtre and Sato 2014). The more the

[43] For example, the US and other OECD countries are the main producers of research and development output due to their superior capabilities for breakthrough innovation (Aghion et al. 2014, 10–11). Large emerging economies like China, India and Brazil have critical roles in manufacturing, demonstrating, and deploying/adopting clean technologies, as they have strong capabilities in these areas as well as large internal markets that can reap the benefits of scale and network effects (Breznitz and Murphree 2011; International Energy Agency 2015, chap. 7–8; Mazzucato 2013; Nahm and Steinfeld 2014). This is not to suggest that other countries don't have a role to play: remember, we are focusing here on innovation in large-scale technological systems with high levels of inertia and that necessarily involve the actions of more than one state; it is only natural that there will be a disproportionate role for the larger states.

[44] I am grateful to Dimitri Zenghelis for raising this point.

level and sectoral scope of national carbon prices/regulations are coordinated ("harmonised") across states, the lower the costs to any one state, since the state's competitors will incur similar carbon costs, reducing the incentive for production to leak to those countries (Dechezleprêtre and Sato 2014). Again, the coordination of actions among states can reduce the direct costs of individual states' actions and thereby increase the net present value of those actions (Heal and Kunreuther 2012, 56).[45]

Negative feedbacks

It must be noted that there will also be negative feedbacks in the transition to a decarbonised world. Negative economic feedbacks from the actions mentioned above will likely include: (i) falling prices for fossil fuels and the products in which they are inputs (as demand switches to clean alternatives), in turn causing some states to demand more of them; and (ii) encouraging fossil fuel producers to bring forward the extraction and supply of fossil fuels in the expectation of future regulated limits on production (the so-called "green paradox") (Sinn 2008, 2012). While the feedback effects of the actions considered above are likely to be overwhelmingly positive, it will be important to keep the negative feedbacks in mind and mitigate them through additional actions, particularly quantity controls on the supply side (Collier and Venables 2015; Sinn 2008, 2012).

3.2.5 The net-present value of contingently net-beneficial mitigation actions

One of the strengths of thinking about actions in terms of contingent net benefits is that it can help to refocus policymakers and others away from a fixation on the net costs of single actions and toward seeing present actions as part of a broader domestic or international mitigation strategy for achieving net-benefits. However, since it is *almost always* possible to imagine a succession of subsequent actions that, ultimately, could tip the total set of actions to being net-beneficial to all participating states, a mechanism is needed to distinguish between a net-costly action and a contingently net-beneficial action.

Discounting for contingency risk provides this mechanism. Contingency risk should be factored into the cost-benefit analysis by discounting the future costs and benefits proportionately to the probability that they will not materialise. This discounting should be additional to the temporal discounting of future costs and benefits due to the diminishing marginal utility of money. In practice, estimating the contingency risk of actions will be far from an exact science. Nonetheless, understanding contingency risk as a function of the three variables discussed in this section can enable at least a qualitative judgement to be made that would be helpful to decision-making.

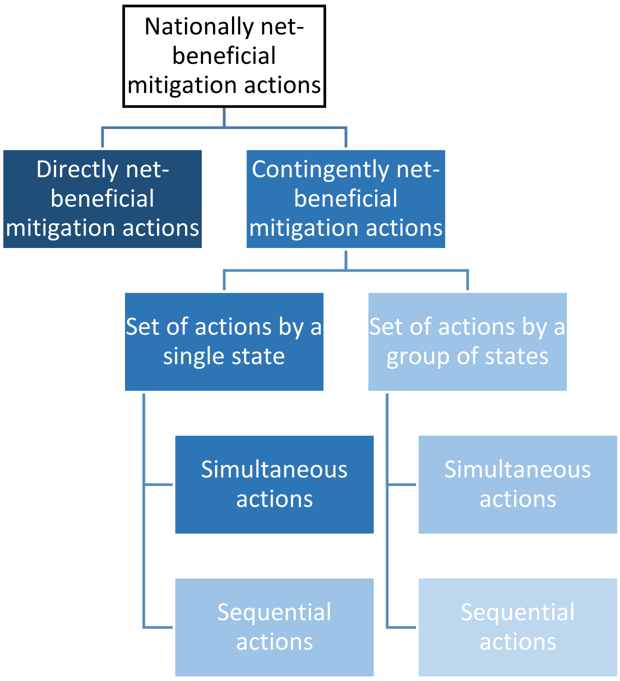
States can in this way envisage contingently net-beneficial mitigation actions as being on a sliding scale of contingency risk. The closer an action is to the origin of the three-dimensional plane representing contingency risk shown in Figure 3, above, the more likely it will be contingently net-beneficial; the further away from the origin it is, the more likely it will be net-costly.[46] Figure 5,

[45] Even with such coordination, there remains the possibility that some such actions in relevant sectors — like, steel, cement, international aviation and shipping and exported fossil fuels — may remain net-costly for some states, in which case cooperative action in these areas would have the structure of a prisoner's dilemma. This possibility is explored in the subsequent sections.

[46] In section 4.1, I suggest that contingency risk may supply a significant part of the explanation for the under-provision of net-beneficial mitigation actions in practice.

below, recapitulates the typology presented earlier but adds a schematic representation of contingency risk by shading categories more lightly the more contingent variables are involved.

Figure 5: Typology of nationally net-beneficial mitigation actions with associated contingency risk



Note: The shade of each box (other than the top box) represents the degree of "contingency risk" associated with the action (darker shades indicate types of actions that are subject to lower contingency risk in virtue of N_α, N_s and/or t_δ — see section 3.2.1, above — being lower).

It remains to say a few words about those residual actions that are (for now, at least) appropriately classified as nationally net-costly.

3.3 Residual, nationally net-costly mitigation actions

Some mitigation actions will — after full accounting for direct and contingent net benefits and discounting for time and contingency risk — remain nationally net-costly. These actions are likely to be concentrated in particular sectors with particular characteristics.

Most importantly, stringent actions in emissions-intensive or energy-intensive sectors that produce highly traded or trade-exposed products could to some extent be nationally net-costly. In section 3.2.4, it was noted that actions in these areas are subject to increasing differences in costs as more states take such actions, giving rise to the possibility of nationally net-beneficial action. It may be that this applies up to a point (e.g. a particular level of carbon pricing), beyond which the action becomes nationally net-costly, even under cooperation/harmonisation. It is possible to imagine this point might occur once major energy, carbon, and material efficiency gains are exhausted in industrial sectors like steel, aluminium and cement,[47] and in transport sectors like international aviation and shipping.[48] Actions to limit exported fossil fuels may also be net-costly to some extent.[49]

[47] For example, it appears from the vantage point of today's technological frontier that *full* decarbonisation of some such industrial processes will require carbon capture and storage (Fischedick et al. 2014), which is likely

Insofar as actions within these sectors *are* nationally net-costly, international cooperation *would* take the form of a prisoner's dilemma, making the international politics of action more difficult in such sectors. Nonetheless, the framework developed in this paper yields important insights that help to put the mitigation task in these sectors into appropriate perspective and to generate ideas for managing that task effectively.

First, the net-costly aspects of action in these sectors, though significant, would likely constitute a minority of the global mitigation task. Industrial emissions were 21% of global direct emissions, and 11% of global indirect emissions from electricity and heat production, in 2010 (together, around 24% of total emissions) (IPCC 2014, fig. SPM.2). Shipping and aviation (both international and domestic) constituted less than 3% of global direct emissions in 2010 (IPCC 2014, 6; Sims et al. 2014, fig. 8.1). And there are substantial mitigation opportunities in the relevant industrial and transport sectors that would likely be nationally net-beneficial, especially with appropriate international coordination to reduce leakage and accelerate innovation, and once national co-benefits are factored-in (Allwood and Cullen 2012; Fischedick et al. 2014; Sims et al. 2014). Thus, the presence of some residual nationally net-costly action within these sectors does not undermine the overall conclusion drawn in this paper (see section 3.4) that there is a strong *prima facie* case that the majority of the global mitigation task can be achieved in ways that are nationally net-beneficial.

Second, even where the actions mentioned in the previous paragraph do not result in national net benefits, they would likely result in substantially lower national net costs. States may actually be (and certainly *ought morally* to be) willing to incur some manageable national net costs in the interests of achieving the (global) climate benefits of mitigation which this paper has (purely for the sake of argument) otherwise ignored. The willingness of states to do so may increase if major emissions reductions are being made in sectors where mitigation is nationally net-beneficial, and hence the goal of avoiding dangerous climate change comes within reach.

Third, while there may be technical limitations in net-beneficial mitigation opportunities in the above-mentioned, net-costly sectors from the perspective of today, the prospect for radical innovations in these sectors, if the right incentives are put in place now, cannot be ignored. We are, after all, in the midst of simultaneous revolutions in information technology, nanotechnology, biotechnology, and materials, and the "new energy-industrial revolution" is just beginning (Perez 2013; Stern 2015).

Fourth, insofar as mitigation action in these sectors remains nationally net-costly, the fact that the value of net benefits from action in other sectors is likely to be so high means that additional

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to be expensive in private financial terms as well as entailing significant co-costs to society associated with additional upstream energy production (to operate the CCS) and the externalities associated with solvent toxicity, and CO_2 transport and storage risks (Bruckner et al. 2014, 532, 543).

[48] Note that, in the case of international shipping, carbon price increases alone are unlikely to be sufficient, as principal-agent (split-incentive) problems render the international shipping industry relatively insensitive to price changes (see Johnson, Johansson, and Andersson 2014).

[49] Some supply-side actions to reduce exported fossil fuels (and hence both domestic process and fugitive emissions, and overseas fossil fuel combustion and process emissions where the fuel is consumed) could be nationally net-costly even under international cooperation. On this issue, see Collier and Venables (2015) for a good discussion of the international cooperative dimensions of supply-side measures to phase-out coal. In 2010, 40% of total primary energy production was supplied by exports (19% of coal production, 54% of oil production, and 30% of gas production) (Bruckner et al. 2014, 520, based on IEA world energy balance data).

economic resources from net-beneficial actions would likely offset net costs in the net-costly sectors.

These insights suggest the importance of sectorally-focused, small-group international cooperation in these (potentially partially-)net-costly sectors in order to increase bargaining efficiency, and to isolate areas that genuinely have the structure of a prisoner's dilemma games from those identified in section 3.2.4 that have the structure of international coordination games, thus avoiding the potential for the challenges of the former to retard progress in the latter.

3.4 Putting the analysis together

The potential for nationally net-beneficial mitigation action across the individual categories discussed in sections 3.1–3.2 looks, from the theory and partial evidence adduced there, very large indeed. But even this category-by-category, summative approach belies the true scale of the potential for net-beneficial mitigation action that comes from considering the categories of actions *together* — particularly when the static co-benefits of individual actions are considered alongside the dynamic and systemic potential for reductions in direct costs associated with those actions, and alongside the potential benefits from even modest levels of coordination among a few key states.

We have seen that many actions to decarbonise our fossil fuel-based energy system are likely to be net-beneficial *now* when full co-impacts are taken into account, especially due to the co-beneficial reductions in air pollution and to knowledge spillovers from innovation. This suggests that many actions that might otherwise only be considered net-costly, or contingently net-beneficial, from the perspective of private financial costs and benefits could in fact be directly net-beneficial. It means, in turn, that the "early" actions in action sets involving international coordination are much more likely to be taken unilaterally by states (or rather, the sets would actually be much smaller when co-impacts are taken into account), meaning some tipping points and cascades could be triggered without the need for explicit international coordination, leading inexorably to the widespread international take-up of net-beneficial actions (Hannam et al. 2015; Heal and Kunreuther 2012).

Looked at the other way, as the private financial costs of clean technologies and services come down due to the self-reinforcing effects of innovation and the complementarities associated with systemic transitions, the co-benefits of these actions will multiply. This co-beneficial multiplier effect will be particularly important with regard to knowledge spillovers, given the novelty and general purpose characteristics of clean energy innovation highlighted in section 3.1.2. It is this effect more than any other that holds the potential for a well-managed, deep decarbonisation transition to unleash a "new energy-industrial revolution" (Stern 2014a, 406, 2015).[50]

All things considered, I conclude that there is a very strong *prima facie* case that most of the mitigation action needed to stay within the internationally-agreed 2°C limit is likely to be nationally net-beneficial.

This claim is difficult to "prove" beyond reasonable doubt. One reason is a practical one: the task of tallying up the costs and benefits of all possible actions by all states would clearly be impossible.

[50] Standard economic models used to project the costs of reducing emissions into the future ignore these important effects *by design*, since they assume that technological progress is exogenous, rather than endogenous to the models (see Zenghelis 2014b).

Another reason is principled: there is not even a theoretically "right" answer to this question because the uncertainties, risks, endogenous processes and structural shifts associated with cost-benefit analysis of this scale necessitate the careful application of expert judgement, hence results (though not necessarily the overall conclusions) would differ from analysis to analysis.[51]

However, the same evidential and theoretical difficulties are faced by proponents of the view that most mitigation action is nationally net-costly, whom one could equally ask to "prove" that most of the required action is, indeed, net-costly. Given these difficulties, a reasonable means of resolving the debate is, I suggest, to allocate the burden of proof on the basis of the strength of the *prima facie* case (based on theory and partial evidence, such as I have presented in this paper). Since there is a strong *prima facie* case that most of the global mitigation task is likely to be nationally net-beneficial, this should become the default assumption concerning the nationally-specific net present value of mitigation actions; those who claim otherwise should bear the burden of proving otherwise.

This argument, if sound, has deep implications, both for social science scholarship on climate mitigation and for real-world efforts to mitigate climate change. These are explored briefly in Part 4.

4. Alternative explanations for the under-provision of mitigation, and their policy implications

4.1 Why *are* we waiting?

If, as I have argued, the majority of mitigation action is likely to be nationally net-beneficial, then it is incorrect to describe the majority of mitigation action as having the structure of a prisoner's dilemma/tragedy of the commons. Accordingly, the unconducive macro-incentive structure of states (i.e. the incentive to "free-ride") should be rejected as the primary explanation for the under-provision of global mitigation action, and relegated to a secondary explanation having potential application only to the (likely small) number of situations/sectors where mitigation is not directly or contingently net beneficial to states, such as those discussed in section 3.3.[52]

There is growing case study evidence to suggest that co-benefits — one sub-species of nationally self-interested mitigation actions considered in this paper — are "a particularly strong rationale and basis for sectoral [mitigation] action" (Somanathan et al. 2014, 1152), especially in large, rapidly industrialising countries (Bailey and Compston 2012) such as India (Dubash 2011; Fisher 2012) and China (Green and Stern 2015; Kostka and Hobbs 2012; Qi and Wu 2013; Qi et al. 2008; Richerzhagen and Scholz 2008; Teng and Gu 2007; Tsang and Kolk 2010). Nonetheless, there is also, clearly, a

[51] Moreover, important normative decisions have to be made even within the economic efficiency framework, such as the scope of agents/entities to which moral considerability is extended (costs and benefits to *which agents* are counted?), and whether the contingent valuation of non-market costs and benefits should be done on the basis of "willingness to pay" or "willingness to accept" (this requires a normative decision about who has the relevant property rights, in the Coasian sense). Recall from Part 1 that the economic efficiency framework was selected for the analysis in this paper not because it is the "best" framework to use, but because it is the standard framework used in rationalist scholarship relevant to climate change mitigation, and the purpose of this paper has been to engage with and challenge the most basic assumption about the value of climate mitigation held by most within that scholarly community.

[52] Even if it were the case that only a *substantial minority* of mitigation action was nationally net-beneficial, the standard explanation would need to be qualified as only applying to the actions that are nationally net-costly.

discrepancy between the amount of mitigation action actually occurring in the world and that which one might expect to see if states rationally pursued their national self-interest as typically defined in rationalist scholarship. The inescapable (and unsurprising) implication is that states do not always, or even mostly, act rationally in the sense of increasing economic efficiency, at least when it comes to climate mitigation.

It follows that an alternative explanation, or set of explanations, must have greater power than the prisoner's dilemma/tragedy of the commons theory to explain the prevailing global under-provision of climate mitigation. Briefly, some of the alternative explanations explored by social scientists to date include the following (note most of these are mutually consistent and reinforcing, rather than mutually exclusive alternative explanations):

Domestic factors (interests, institutions and ideas)

- The present (high-carbon) energy system is extremely inert, involving many self-reinforcing technological, institutional, social and political mechanisms (including but not limited to those discussed in Part 3 of this paper) — a phenomenon that has been labelled "carbon lock-in" (Unruh 2000).
- Elected officials, other policymakers and political parties have diverse interests and priorities that include, alongside the national interest, their own private interests, primarily remaining in power (Besley 2006; Persson and Tabellini 2000). Accordingly, special interest groups, which can affect politicians' and parties' electoral prospects, play an important role in policy development and implementation generally (Grossman and Helpman 2001) and in the climate context specifically (Dietz, Marchiori, and Tavoni 2012). Institutional arrangements can also make it more difficult for politicians to act in the national interest (Harrison and Sundstrom 2010a, 2010b). And to the extent they *are* motivated to act in the national interest, public officials may (in some cases, quite reasonably) have conceptions of the national interest that differ from improving economic efficiency. Ideational and partisan influences are likely to be especially important in influencing officials' beliefs about climate change and their prioritisation of mitigation action (Fielding et al. 2012; Harrison and Sundstrom 2010a).
- The distributive effects of nationally net-beneficial mitigation actions — i.e. on whom, where and when the costs and benefits are distributed — make the politics of climate mitigation very challenging.
    - At the elite level, the economic and political power of agents who stand to lose from climate mitigation actions is great. In particular, climate policies that raise the price of fossil fuels and other sources of greenhouse gas emissions or improve energy efficiency will tend to concentrate losses on fossil fuel producers, fossil fuel-based electric utilities, energy-intensive manufacturers, and manufacturers of energy-intensive products, which will tend to oppose such policies (Falkner 2008, 97–99; Hughes and Lipscy 2013, 458–460).[53] Many firms in these sectors and their industry groups are financially and politically powerful — some are among the most powerful

[53] Where policy imposes direct costs on firms, they may be in a position to pass these onto the public, e.g., in the form of higher energy prices (see next point). However, under sufficiently stringent policies to decarbonise the global economy, there would be a high substitution effect away from high-carbon goods and services.

actors in the global economy[54] — and have proven themselves adept at bending policymaking to their own interests in both climate and other fields of regulation (Grubb, Hourcade, and Neuhoff 2014; Helm 2010; Paterson and Newell 2010; Pearse 2007; Skodvin, Gullberg, and Aakre 2010). These existing political-economy patterns act to reinforce the "carbon lock-in" that arises from technical-institutional patterns (Unruh 2000).

  - Distributive effects at the mass public level can also make the politics more difficult. Despite the fact that the costs of mitigation (when passed downstream) are dispersed widely among heterogeneous and non-organised agents (e.g. taxpayers and/or consumers of carbon-intensive goods and services), the most relevant additional costs, e.g. on energy prices, accrue privately and immediately and are rendered salient through consumption patterns and media reportage. In some cases, such as the provision of new (low-carbon) infrastructure and local-industrial transition, the costs will be concentrated on geographically-specific sections of the public, which can lead to local political opposition that delays or raises the costs of some mitigation actions (see, e.g., Petrova 2013). For this and other reasons, the geographic aspects of climate policy are also important (Bailey and Compston 2010).

- Climate policy gives rise to a pronounced problem of "credible commitment" or "political uncertainty", a particular kind of time-inconsistency problem that can hamper efforts to establish the policy in the first place (Bernauer 2013, 425; Brunner, Flachsland, and Marschinski 2012; Helm, Hepburn, and Mash 2003; Hovi, Sprinz, and Underdal 2009).
- People and firms tend to discount heavily longer-term costs/benefits, while shorter-term effects loom large in decision-making. Since many of the *national* benefits from mitigation discussed in this paper arise in the medium and long term (let alone the *very* long term global climate benefits), their future value may be excessively discounted by agents in the real world. For politicians and firms, such "short-termism" is heavily influenced by institutions (formal and informal rules) and by organisational and social factors (see generally Fleurbaey et al. 2014, 303; Mackenzie 2013, 28–32, 44–46).[55] For the general public, the most important causal mechanism behind the discounting of future policy benefits is *perceived uncertainty* about these benefits arising in practice (Jacobs and Matthews 2012b).[56]
- Many (if not *all*) countries have institutional or governance arrangements are that are inadequate to the task of developing and implementing even net-beneficial actions (see Somanathan et al. 2014). Constraints on access to low-cost finance and access to technology

[54] Eight out of the top ten, and 19 out of the top 30, largest companies (ranked by revenue) on the Forbes Global 500 list (2014) fall within one of these sectors, and five of the top six are oil majors (see http://fortune.com/global500/). For a detailed account of the financial and political power of one such oil major (Exxon) and the ways in which it is exercised, see Coll (2012).

[55] Mackenzie (2013, 28–32) explains why the argument that politicians have incentives to discount future benefits because of short-term electoral cycles is, though related, conceptually distinct from the argument that citizens discount future costs and benefits, because the former have incentives to discount that are additional to those associated with responding to the policy preferences of the latter.

[56] Jacobs and Matthews (2012b) reject the more commonly assumed explanations for discounting among the general public: they find only modest evidence for positive pure-time preference (impatience) and no evidence for consumption-smoothing (citizens seeking to schedule policy earlier because earlier benefits can help even out, or "smooth", the flow of income over time).

on reasonable terms are two particular types of institutional and governance deficits that are likely to especially constrain states' capacity to implement net-beneficial actions (see GCEC 2014a). Mitigation action is likely to be particularly challenging in resource-rich, developing states with weak institutions and poor governance,[57] since they are likely to face a combination of relatively high financial costs of mitigation, political opposition to action from vested interests in the resource sector, and low capacity to carry out desirable action.

- Ideational, discursive and normative factors, as they apply to individual policymakers (including through partisan or intra-party factional ideological commitments), other elites, or among the general public also help to explain the under-provision of climate action around the world. These factors can include politicised "knowledge disputes" over the science of climate change, or "normative principles", such as those of political leaders or more widely-held societal norms that shape the way problems and solutions are framed, discussed and evaluated (Eckersley 2013; Harrison and Sundstrom 2010a; Oreskes and Conway 2010).
- Finally, while the above points are more or less common to most countries, there are often highly-specific barriers within particular countries that need to be taken into account.

International factors (barriers to coordination)

- Where net-beneficial mitigation actions have cross-border effects such as spillovers — e.g. low-carbon innovation and carbon pricing in emissions-intensive and highly traded or trade-exposed industrial sectors (see Part 3, above) — barriers to international coordination may partly explain the under-provision of these types of mitigation actions (lack of coordination may also be explained by one or more of the above domestic factors).

It can be seen from the above brief survey that the major barriers to action (at least in those cases where the enjoyment of net benefits is not contingent on action by other states) are likely to lie at the intersection of domestic interests, institutions and ideas formed in the fossil fuel age (cf Harrison and Sundstrom 2010b). Evidently, a particular challenge pertains to the domestic *distribution and redistribution* of costs and benefits across agents, places and time. The fact that the costs of nationally net-beneficial mitigation action are biased toward the near term and concentrated on a small number of powerful agents, whereas the benefits are biased toward the medium-to-long term and enjoyed widely across society — and that institutions and dominant ideas privilege incumbent interests and short-term considerations — is, I speculate, the most important explanation for the global under-provision of mitigation action. In any case, an important task for future social science research is to identify the relative importance of these different theories and factors in particular settings (cf Bernauer 2013), especially those where the potential for nationally net-beneficial mitigation action is greatest.

The framework developed in this paper can, I suggest, assist such future research. For example, by using a pure efficiency conception of national self-interest and excluding distributional/welfare considerations, this approach can help to illuminate where the barriers to mitigation action have nothing to do with (national-level) economic efficiency, and to separate these out from instances where national efficiency considerations are relevant (see section 3.3, above). Additionally, the concepts of a "contingently net-beneficial mitigation action" and "contingency risk" could help to

[57] The literature on the so-called resource curse debates the causal relationship between these issues. See Ross (2015) for a review of the voluminous literature on this topic.

illuminate barriers that stem from the challenges of coordinating multiple (simultaneous or sequenced) actions by a single government or by multiple governments. For example, recent research by Jacobs and Matthews (2012a, 2012b) on the reasons why members of the public heavily discount the future benefits of policies (namely, because of perceived uncertainty as to the benefits ever being realised) suggests that convincing the public about some of the medium to long-term national benefits of climate actions explained in this paper — for example, the multiple benefits stemming from early-stage clean energy innovation — may be especially challenging, and cannot be disentangled from wider challenges concerning trust and confidence in government and public institutions (Jacobs and Matthews 2012a, 2012b).

4.2 Implications for policy and wider forms of social agency on climate mitigation: from *outside-in*, to *inside-out* climate action

If most of the global mitigation task can be achieved in ways that are nationally net-beneficial, and therefore it is the other barriers, surveyed above, that instead explain most of the under-provision of global climate mitigation, it follows that policy and wider forms of social agency should focus on overcoming these other barriers, rather than trying to solve a (non-existent) single global prisoner's dilemma. The policy actions that ought to be taken will depend on what the specific barriers to action are in any individual case. Nonetheless, some general policy conclusions are suggested by the fact that the explanations/barriers listed above in section 4.1 are likely, in some combination, to provide a more powerful explanation of the under-provision of mitigation action.

First, most of the barriers to realising nationally net-beneficial mitigation actions are domestic in nature (or at least not *inherently* international in nature). This implies the need for an inversion of the traditional "outside-in", or "top-down", focus of climate policy. Under the UNFCCC and its Kyoto Protocol, which are predicated on the assumption that most mitigation action is nationally net-costly and climate change is a global prisoner's dilemma (see Stern 2014b, 2015), the international plane is conceived as the primary and ultimate level of action — where global goals and national targets are agreed, according (in theory) to a logic of equitable "burden-sharing" — and the role of individual states is conceived as being limited to implementing internationally agreed goals/targets.[58] Under a logic of nationally net-beneficial mitigation action, where action is hampered by a wide range of predominantly-domestic barriers, the domestic sphere should be the primary focus of mitigation activity, with international policy playing a secondary (yet still important) role; the appropriate two-level of model climate mitigation should be, from the perspective of states, *inside-out*.

There are three general rationales for international cooperation on climate mitigation under this inside-out approach. First, international cooperation retains a necessary function (at least from a rationalist perspective) with respect to those contingently net-beneficial mitigation action sets that necessarily involve actions by more than one state (e.g. some types of support for innovation[59] and some impositions of carbon pricing on emissions-intensive, highly traded or trade-exposed industries). Second, for the (minority) of actions that are simply net-costly, even when taken by groups of states (see section 3.3), international cooperation also has a necessary function. However,

[58] This focus has moderated to some extent under the current round of negotiations toward an agreement in Paris in late 2015 (see Green 2014). However, a coherent alternative based around mostly-nationally-self-interested mitigation has not yet emerged.
[59] See above footnote 26 and accompanying text.

the form and content of both these kinds of international cooperative activities will not necessarily follow the same policy logic that has underpinned the UNFCCC/Kyoto model. Rather, international cooperation in these cases should be focused on completing the specific net-beneficial action sets to which it is addressed (in the case of the former) or on the specific sectors or activities where mitigation remains nationally net-costly (in the case of the latter).

Third, even in those areas where there is no *necessary* international action involved, international cooperation can play an important role in helping to reduce other, domestic barriers to nationally net-beneficial action, and (to put it more positively) supporting and accelerating net-beneficial domestic transformations — for example, through targeted support to facilitate low-cost finance for low-carbon infrastructure, technology access and transfer, and capacity-building (Averchenkova, Stern, and Zenghelis 2014; Fay et al. 2015; Stern 2015).[60] Again, the international response would be more effective if focused appropriately on overcoming the real barriers to net-beneficial action in particular states.

This justified shift in how climate action is framed — not as a single global prisoner's dilemma, but as a nuanced combination of nationally net-beneficial actions, numerous small-group international coordination games, and (in a minority of cases) some small-group prisoner's dilemmas — would, if appropriately popularised, have immediate effect on climate action at the domestic and international level. This is because the way a cooperative "game" is set-up and framed affects how agents expect others to play it, which in turn affects how they play it themselves (Barrett and Dannenberg 2015; Stern 2014b); there is a "performative" element to the economics of climate action (Cameron and Hicks 2014, 54). If states see their task as coordinating and collaborating with others to achieve mutual net-gains, they will expect stronger cooperative action from others, and the desired cooperation will be more likely to occur than if states expect everyone else to avoid "burdens" and to "free-ride". A similar logic applies at the domestic level: if, for example, banks perceive low/zero-carbon lending to be dependent on domestic policies by states that are "suckers" in a prisoner's dilemma, they are surely more likely to perceive such lending to be riskier than if the relevant domestic policy is nationally self-interested.

Finally, if I am correct in speculating that most of the under-provision in mitigation action is likely attributable to the domestic politics of distributing and redistributing the costs and benefits of decarbonisation among agents and over time, then policy responses and other reform-oriented agential interventions need to become much more sensitive to the *political and institutional* effects, and other "policy feedbacks", of policies (Jordan and Matt 2014; Lockwood 2013, 2014; Patashnik 2003, 2008; Pierson 1993; Urpelainen 2013). It is little use aiming for "first-best policy" in a domestic context characterised by extremely powerful elite interests hostile to mitigation action, flawed institutions, a general public with shallow concern for climate change, agents who heavily discount future benefits, and (in many countries) dominant cultural and social norms hostile to the values necessary for a low-carbon transition. In fact, the general theory of the second best warns us that such attempts at first-best policy may well be *harmful* to a long-term strategy of decarbonisation (Lipsey and Lancaster 1956; Wiens 2012). Rather, policy needs to accommodate the growing political

[60] The provision of such support, it should be noted, does have the characteristics of a prisoner's dilemma, since it will typically be net-costly to the countries providing the support, while other countries enjoy the global mitigation benefits of such support. However, this is also an area that is governed to some extent by international moral norms, generating shared expectations that richer countries will provide such support.

science and other social science literature concerned with the political and social aspects of low-carbon transition[61] if it is to have a hope of unlocking the enormous potential for national net benefits associated with the decarbonisation of the global economy.

5. Conclusion

This paper has developed a conceptual framework for advancing and evaluating claims to the effect that action to mitigate climate change is in the national self-interest of a given state, where self-interest is understood in terms of economic efficiency. The framework unifies hitherto disparate strands of literature on the static and dynamic analysis of costs and benefits, on single-action and multi-action mitigation strategies, and on unilateral and multilateral action. This unification is enabled primarily through the conceptual innovation of a "contingently net-beneficial mitigation action" and the associated concept of "contingency risk", which facilitate the extension of economic analysis beyond the perspective of "single-state, single-action, static point in time" — a perspective that is ultimately inadequate to the task of understanding the economics of the fundamental, multi-decadal, structural transitions associated with the decarbonisation of the global economy (Aghion et al. 2014; GCEC 2014a; Grubb, Hourcade, and Neuhoff 2014; Stern 2015). These conceptual innovations facilitate the identification by states and other actors of nationally net-beneficial *sets* of actions, the appropriate discounting of contingent benefits (and costs) within those sets due to contingency risk, and the identification of strategies to mitigate that contingency risk.

The paper has also adduced theory and partial evidence that, in combination, provides a strong *prima facie* case that most of the mitigation action needed to decarbonise the global economy this century — and thus give a reasonable chance of staying within the internationally-agreed goal of limiting increases in average global temperature to within 2°C — is likely to be nationally net-beneficial, and therefore nationally self-interested (all the more so if a conception of national self-interest appealing to wider values beyond efficiency is adopted). Accordingly, the paper has argued that scholars and practitioners should adopt this conclusion as their default assumption, shifting the burden of proving that action is nationally net-costly onto those who wish to make that claim. On this logic, the classic rationalist framing of climate change as a single global prisoner's dilemma and tragedy of the commons should be abandoned. Since only a minority of the mitigation task, mostly limited to certain identifiable sectors, is likely to entail nationally net-costly actions, the prisoner's dilemma framing should at most be applied to relevant actions in those areas only.

The key challenge for social science scholarship and for policy and other forms of social agency is, respectively, to identify and to overcome the real barriers to mitigation action. The brief survey in Part 4 pointed to a considerable body of existing research, largely in political science and other social sciences outside of economics, which has begun to identify these factors. This research suggests that most of the real barriers to action are domestic in nature, lying at the intersection of interests, institutions and ideas formed in the fossil fuel age. These domestic barriers retard the pursuit of national net benefits from mitigation action because most of the costs from such action are concentrated on powerful agents and biased toward the short term, whereas the benefits, though

[61] For example: (Compston and Bailey 2008, 2012; Compston 2009, 2010a, 2010b; Giddens, Latham, and Liddle 2009; Giddens 2011; Lockwood 2013, 2014; Mitchell 2008; Perez 2009, 2013; Smith, Stirling, and Berkhout 2005; Urpelainen 2013).

arguably much greater, are biased toward the medium and long term and accrue mostly to the public at large.

Overcoming these barriers is unlikely to be easy. But in a world of finite resources that is running out of time to keep global emissions under control, better we concentrate on solving the real problems, not the illusory ones.

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