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Thoughts on the Economics of Secondary Benefits between Climate Change Mitigation and Air Pollution Regulation

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Abstract: Secondary benefits (or costs), otherwise known in the literature as co-benefits or ancillary benefits, are the added net benefits that can be attributed to policies that are above and beyond the primary benefits of climate policies. For example, the primary benefit of greenhouse gas emission reduction is to reduce the magnitude of future climate change; the secondary benefits are expressed in terms of changes in the patterns and concentrations of other pollutants and their secondary compounds. The paper follows a brief review of studies that attempted to quantify health co-benefits with a discussion of the basic underlying economic structure built on first principles of economic thought. It not only portrays the complexity that erupts when there are multiple and interdependent positive or negative externalities across different sources, but also examines several, sometimes surprising conjectures that apply more widely to secondary benefit considerations of all stripes. Concludes remarks synthesize these conjectures for health contexts, for more general policy evaluations beyond the health sphere, and for aggregate constructions such as the social cost of carbon.

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1. Introduction – Definition and Illustrative Examples.

Secondary benefits (or costs), otherwise known in the literature as co-benefits or ancillary benefits, are the added net benefits that can be attributed to policies that are above and beyond the *primary benefits* of climate policies. For example, reducing the emissions of greenhouse gases (such as carbon dioxide (CO_2), methane, CFCs, etc.), via a carbon tax or cap and trade, is directed at achieving a more stable climate vis a vis Article 2 of the United Nations Framework Convention on Climate Change. The primary benefit of greenhouse gas emission reduction is to reduce the magnitude of climate change later this century and beyond. The secondary benefits are expressed in terms of changes in the patterns and concentrations of other pollutants and their secondary compounds (including particulate matter, volatile organic compounds, sulfur and nitrogen oxides, and ozone). Conversely, policies directed at non-climate objectives (such as reducing air pollutants to protect human health) create their own secondary benefits (or costs) that can be calibrated in terms of progress toward achieving a stable climate somewhere along an emerging long-term greenhouse gas (GHG) emissions scenario.

Examples abound. Two examples of secondary benefits are: (1) abatement of greenhouse gas emissions through energy efficiency improvements typically reduces conventional air pollution; and (2) acid-rain reduction by switching from coal-fired power generation to gas-fired-power cut carbon dioxide emissions as well. We can add other examples, but the main point is made: Policies interact.

Two examples of secondary costs are: (1) burning diesel fuel emits less CO_2 per mile traveled than gasoline, but burning diesel emits more particulate matter than gasoline; air pollution therefore climbs if citizens reduce their CO_2 emissions by switching to diesel fuel for their cars and trucks; and (2) if sulfur emissions are reduced by placing scrubbers on smoke-stacks, then energy use and hence carbon dioxide emissions will increase. These lists can be extended, but the fundamental point is made: Secondary benefits can, in some cases, be secondary costs.

In either case, assessments of the net benefits of either GHG mitigation strategies or programs designed to influence air pollution must take account of these sorts of joint interactions in the welfare calculus.

Another issue to consider can be shown by combining two of the examples: if most sulfur oxides are removed by scrubbing, then energy efficiency programs would reduce carbon dioxide emissions but have little impact on sulfur oxide concentrations. Put another way, while it is true that agriculture, energy, and transportation sectors create environmental problems (and, in some cases, opportunities) besides climate change, these potential sources of secondary (net) benefits in the climate world are not necessarily a major reason to reduce GHG emissions. Nor are climate-related damages always a major and necessary reason to reduce conventional air pollution. The myriad of potential and often complex interactions must be considered simultaneously in ways that reflect varying degrees of importance and political constraints.

The paper proceeds as follows. Section 2 offers a brief review of studies that attempted to quantify health co-benefits, not in an effort to be comprehensive, but rather to provide motivating content for what follows. Section 3 presents some basic underlying economic structure. It portrays not only the complexity that erupts when there are multiple and interdependent positive or negative externalities, and also supports several conjectures that apply widely to secondary benefit considerations of all stripes. Section 4 concludes with remarks that synthesize these conjectures for health contexts, for more general policy evaluations, and for aggregate constructions such as the social cost of carbon.

2. The State of Play in Considering Secondary Benefits among Health Risk Experts with Particular Attention to Climate Change.

Climate policies may benefit health through several pathways, including reducing exposure to air pollutants, increasing physical activity, and reducing the incidence of diet-related disease (Haines et al. 2009). Chang et al. (2017) review forty studies quantifying the health co-benefits and co-harms of climate change mitigation policies related to air quality, transportation (including exercise), and diet that were published from 2009 and through 2016. The scenarios used ranged from specific policy proposals to hypothetical counterfactuals, and from global estimates to stakeholder-informed local guidance. More recent studies tended to have more sophisticated methods to address complexities in the relevant policy system. Most studies indicated significant, nearer term, local ancillary health benefits that offset a significant portion of the costs of implementing those policies, with the co-benefits accruing sooner than the benefits of reducing greenhouse gas emissions. That is, in many instances, the health co-benefits of some mitigation policies could make sense anyway because of the improvements to population health without considering the benefits for achieving climate policy.[1] However, studies were more suited to describing the interaction of climate policy and health and the magnitude of potential outcomes than in providing specific accurate estimates of health co-benefits. Further, at this stage, meta-analyses of the literature are not possible because of the diversity in methods, scenarios, exposures, temporal scales, and other considerations.

Ambient air pollution was estimated to cause over 3 million deaths worldwide in 2012 (WHO 2014). Combatting climate change can reduce air pollution by reducing co-emitted air pollutants. Power plants, other stationary sources, certain industrial processes, mobile sources, burning of carbon-containing fuels, and agricultural activities are sources of greenhouse gases, including carbon dioxide and methane; they also can emit a range of pollutant particles and gases that directly or indirectly affect health through primary inhalation or secondary reactions associated with a wide range of impacts, including premature deaths (IPCC 2014). Therefore, reducing emissions from these sources could reduce greenhouse gases and benefit health. Further, higher temperatures associated with climate change may increase health risks by increasing the secondary formation of two key air pollutants with well-documented adverse health impacts: particulate matter ($PM_{2.5}$ and PM_{10}) and ozone (Fiore, Naik, and Leibensperger 2015, Silva et al. 2013).

The broad range of policy scenarios investigated precluded more detailed conclusions than mitigation policies would result in health co-benefits, with the extent of co-benefits varying by policy specifics, the air pollutants considered, and analytic choices of geographic and temporal scale, demographic and socioeconomic changes over the study period, and health outcomes included, inter alia (Chang et al. 2017). Estimates of the co-benefits ranged from \$2 to \$380/metric tonne of CO_2 avoided (Nemet, Holloway, and Meier 2010) and \$700 to \$5,000/tonne for avoided methane emissions (Shindell et al. 2012).

Chang et al. (2017) note that the literature emphasizes co-benefits. Co-harms are rarely reported. At the bottom end of the income distribution in rich countries, however, “heat or eat” is a real trade-off (Bhattacharya et al. 2003, Beatty, Blow, and Crossley 2014). Improved insulation would alleviate this problem (Howden-

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[1] This does not imply that realising these health benefits is best done through greenhouse gas emission reduction; there may be other, cheaper ways.

Chapman et al. 2007, Sovacool 2015) but more expensive energy would exacerbate it (Wier et al. 2005, Metcalf 1999, Rausch, Metcalf, and Reilly 2011).

While most of the literature on the ancillary benefits of climate policy is focused on power generation, Chang et al. (2017) also review papers on transport. Particularly, a switch from private cars to public transport would reduce carbon dioxide emissions, local air pollution, congestion, and road accidents. A switch to walking and cycling would have positive effects on fitness, but may increase injuries. In Europe, a switch from petrol to diesel engines was a key part of the strategy to reduce carbon dioxide emissions from transport. The concurrent, perhaps concomitant, underreporting of particulate emissions has led to substantial negative effects on health (Barrett et al. 2015, Chossière et al. 2017).

Agriculture is the main source of methane and nitrous oxide emissions, while food processing, transport and storage contributes to emissions of carbon dioxide and HFCs. A change in diet would thus have an impact on greenhouse gas emissions. It would also impact health. Chang et al. (2017) review the handful of studies on diet choice and find that it is too early to conclude whether the association between climate policy and health is positive, negative, or negligible.

3. Characterizing Optimal Solutions to the GHG and Conventional Air Pollution Control Problems without and with Secondary Benefits.

3.1. A Two Market World with Independent Pollution Problems.

To explore the intricacies of evaluating secondary economic benefits (or costs), it is perhaps most constructive to begin by describing a simple Case 1 - a "stove-pipe" world in which regulatory options for responding to various sources of economic inefficiencies are completely independent from one another.[2] To that end, because the focus is on health externalities caused by pollution, consider a world in which the production of economically valued goods in two markets for two different goods (X and Y) create derived demands for productive activities that create pollution of two types – emissions of greenhouse gases (denoted by G), and emissions of conventional air pollution (denoted by A). Assume, for the sake of argument, that the production of X generates emission of pollutant G and that the production of Y generates emissions of pollutant A. These goods are demanded by collections of consumers at quantities that decline as their prices increase. Also assume initially that these emissions are not regulated.

The producers of X and Y make their business decisions informed by estimates of the respective demand curves for their products. For social planners, though, these demand curves also support the calibration of "derived demand curves" that reflect

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[2] Subsequent cases in the Section will increase complexity up to and beyond analytically representing secondary benefits of pollution control technologies.

the incremental (marginal) values to producers and consumers of the last units of pollution generated by the production and sale of X and Y at their quoted prices. To be clear, these calibrations ultimately take advantage of the analytical fact that product demand curves can be employed to quantify the origins of "derived demands" for all inputs, including pollutants G in the production of X and A in the production of Y. In this downstream context, the marginal benefits of positively valued products are translated rigorously into "demand schedules for pollutants" - schedules that are often viewed as de-facto reflections of the "marginal benefits (MB)" of pollution (denoted in this discussion by MB_{GX} and MB_{AY}, respectively).

The producers of X and Y also face private production costs derived from their distinct production technologies and input prices for capital investment, labor, energy, materials, and the like (as well as the costs of pollutants if they are regulated by an outside authority). Given this information, producers find it possible to calculate the minimum cost of producing either X or Y in any quantity. For simplicity, assume that these minimum costs are linear in output so that the costs of producing every unit of output that is delivered to either market are the same (denoted by MC_X and MC_Y); it is not necessary that $MC_X = MC_Y$.[3] This allows the definition of the "marginal net benefit (MNB)" for either pollutant (denoted by MNB_{GX} and MNB_{AY}) to be simply derivative schedules that represent the difference between the MB_{GX} and MB_{AY} schedules and the associated MC_X and MC_Y schedules.

In an unregulated laissez-fair world, producers would produce and sell outputs of X and Y consistent with profit-maximizing levels of pollution under the assumption that pollution is free. To express this equilibrium more analytically, Case 1 has an equilibrium where emissions of G^*_{X1} and A^*_{Y1} equal G_{Xmax} and A_{Ymax} – quantities that are characterized by $MNB_{GX} = 0$ and $MNB_{AY} = 0$. See the two panels of Figure A1 for a graphical depiction of these characterizations.

Net marginal benefits reflect only part of what can be thought of as the net social value of pollution. To see why, now consider the extra social costs of exposure to both G and A; i.e., consider Case 2 wherein "negative externalities" are added to the true cost of producing X and Y. To make things as simple as possible, let the production of positively valued products X and Y release emissions of greenhouse gases and conventional air pollutants in proportion with any chosen production level (the proportions can be different for G and A). Let the costs of each additional unit of exposure to either type of pollution increase with exposure at an increasing

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[3] This is a common assumption consistent with "constant returns to scale" up to a capacity constraint. That is, doubling employment of all inputs at the same time always doubles output while it doubles total costs. If you start with 1 unit of output, then this process yields 2 units that cost twice as much to make (i.e., an increase of 1 unit that costs as much to produce as the first).

rate from a non-negative minimum at zero emissions. Denote the resulting marginal social cost (MSC) schedules by MSC_G and MSC_A.[4]

Now assume that technologies exist which have been designed explicitly to reduce the proportions of G_X and A_Y associated with each unit of either X or Y. These technologies come with their own, potentially different cost profiles. In all cases, though, the costs of each incremental (one unit) reduction in the emissions of either G or A (relative to G_{Xmax} or A_{Ymax}) increase with the total amount of G or A removed from the effluent stream – that is, the marginal costs (MC) of direct pollution control (denoted by MC_G and MC_A) increase with the difference between the resulting residual emissions and the maximum emissions threshold: e.g., $(G_{Xmax} – G_X)$ and $(A_{Ymax} – A_Y)$.

Producers have no ground to include the marginal social costs of their emissions into their laissez-faire output decisions, even though technologies exist to reduce their emissions at the margin. Were they to do so, their emissions would fall, their output would fall, and so their profits would also fall because their total costs (production plus mitigation) would climb with no compensating private benefit. A regulatory authority equipped with practical policy tools must therefore be introduced to take advantage of the potential to improve social welfare by reducing exposure to harmful pollutants and thereby reducing the social costs of these externalities across the population.

If this authority were to consider one pollutant at a time without any recognition of possible interactions, then it would design policies to achieve two optimal (but myopic) control targets for residual emissions (denoted G^*_{X2} and A^*_{Y2}) for the producers of X and Y – one for greenhouse gases (denoted by the difference $(G_{Xmax} – G^*_{X2})$) and another for conventional air pollution (symmetrically denoted $(A_{Ymax} – A^*_{Y2})$). To achieve optimality in either market in this version of Case 2, the authority would enact policies that would limit emissions to levels that would be characterized by equality between:

(1) the marginal benefit of the associated output *net of the marginal private cost of production and the marginal private cost of limiting residual emissions to the appropriate level* on the one hand; and

(2) the marginal social cost of exposure to those residual emissions.

That is to say, optimality would require reducing emissions from the producers of X and Y to levels where $(MNB_{GX} – MC_G) = MSC_G$ and where $(MNB_{AY} – MC_A) = MSC_A$, respectively.[5]

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[4] This assumption reflects the shapes of most exposure-response curves – incremental health risks and associated damages increase at an increasing rate, especially when there exist thresholds of critical sensitivity to exposure.

[5] Similar specifications of optimality apply to the producers of Y.

To see why, suppose that one condition or the other were not true. Suppose, just for the sake of argument, that (MNB_{GX} – MC_G) > MSC_G. That would mean that increasing the production of X so that emissions of G rose by a proportional amount would increase net private benefits (the left side of the equation) faster than it would increase the social costs of exposure to greenhouse gases. In words, this change in output would improve net social welfare – increasing both net private benefits and social costs, but increasing benefits more quickly than costs. If, on the other hand, (NMB_{GX} – MC_G) were less than MSC_G, then a reduction in output would reduce net private benefits for G more slowly than the proportional reduction in the emissions of G would reduce the social costs of exposure (working the same reasoning backwards). Again, this change in output would improve net social welfare. In summary, unless the equality condition is met exactly, changing the output of X and the emissions of G together and proportionately in one direction or the other would always improve social welfare; only at an outcome characterized by equality would an incremental change of both output and (proportionately) emissions in either direction leave social welfare unchanged at its maximum.

Because $MSC_G > 0$ and $MSC_A > 0$, if follows that including mitigation costs in the net private benefit equations requires that marginal net benefits at the optima for both pollutants must climb to reach positive values for marginal social costs; and because the marginal benefit schedules for both G and A are downward sloping, these increases in MNB mean that emissions must fall. In other words, including mitigation and social costs of emissions in the optimization calculus means that the $G^*_{X2} < G_{Xmax}$ and $A^*_{Y2} < A_{Ymax}$, and that total output of X and Y would both decline proportionately in moving to the optimum. It also follows that reducing emissions to G^*_{X2} and A^*_{Y2} would increase net total social welfare because G^*_{X2} and A^*_{Y2} solve the optimization problems (by definition) even though G_{Xmax} and A_{Ymax} were both in the choice sets.[6]

The two panels of Figure A2 display this result graphically; notice that G_{Xmax} and A_{Ymax} serve as anchors for schedules that reflect the marginal costs of mitigation as negatively sloped lines that climb as residual emissions fall. These schedules lie under the marginal net benefit schedules for both G or A (otherwise, the optimal level of production of X or Y (or both) and the optimal levels of emissions of G or A or both would be zero.

Finally, the initial explorations in Cases 1 and 2 provide evidence for the validity of a first general conjecture:

Conjecture # 1: ***The optimal set of conventional air pollution control and GHG emissions control rates depends on specific combinations of a large collection of contextual demand and cost parameters.***

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[6] Again, similar specifications of optimality apply to the producers of Y.

These parameters include variables that define the derived demands for G_X and A_Y, the private costs of production for X and Y, the correlations between units of output and levels of pollution, the costs of mitigating the emissions of G_X and A_Y, and the social costs of exposure to the residual emissions of G_X and A_Y.

The discussion on optimal emission control began with Baumol and Oates (1971) and Baumol (1972).

3.2. Adding Secondary Benefits (Positive or Negative) to the Two Market World with Externality Issues.

Now suppose, to frame Case 3, that the production of X and Y also produces un-regulated emissions of conventional air pollution and greenhouse gases, respectively. Assume, again for simplicity but without loss of generality, that only the producers of X face greenhouse gas constraints and that only the producers of Y face restrictions on the total emissions of conventional air pollution from both sources.[7] In this case, to take account of positive emissions of A imported from the market for X (denoted by ΔA_X^+), regulators must recognize that the producers of Y would operate along a marginal mitigation cost curve anchored at a maximum of $(A_{Ymax} + \Delta A_X^+)$. Similarly, and using parallel notation, the producers of X would find the maximum emissions of greenhouse gases anchoring their marginal mitigation cost curve at $(G_{Xmax} + \Delta G_Y^+)$, where ΔG_Y^+ represents the emissions of greenhouse gases imported from the market for Y.

Repeating the analysis with modified notation from Subsection 3.1 with the new marginal cost anchors, $G^*_{X3} > G^*_{X2}$ would now be the second-best optimum level of emissions for G for the producers of X (who are saddled by the penalty of imported emissions from the production of Y) and $A^*_{Y3} > A^*_{Y2}$ would now be the second-best optimum level of emissions for A for the producers of Y. Panels A and B of Figure A3 display these new optimality conditions for this new context. G^*_{X3} and A^*_{Y3} are still characterized by the familiar equality of the marginal net benefits of pollution (including private production costs and private mitigation costs) and the marginal social cost of exposure. The advent of $\Delta G_Y^+ > 0$ and $\Delta A_X^+ > 0$ simply moves marginal mitigation costs up and to the right so that total residual emissions must be allowed to increase if efficiency is to be achieved in response to the imported pollutants.

Case 4 finally adds the complication of technological co-benefits. Assume, for the sake of argument that the technology employed by the producers of Y to reduce

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[7] This assumption is consistent, with extreme versions of two stylized facts that apply to the United States. First, stationary sources of carbon emissions like power generation plants face restrictions on their GHG footprints, but mobile sources like automobiles do not (at least not directly). Secondly, as noted in Section 2, damages from exposure to conventional air pollution accrue much more quickly than climate damages, and so the resulting urgency (as well as technical difficulties in implement control strategies) brings regulators to focus on these more traditional pollutants emitted from primary sources regardless of existence of secondary sources of harm.

their emissions of A also works to reduce their emissions of G by a fraction α_{GY} of ΔG_Y^+ (where $0 < \alpha_{GY} < 1$). This would mean that the effective maximum emissions level from which the marginal cost of the mitigation efforts undertaken by producers of X would be anchored by the sum of G_{Xmax} and $((1-\alpha_{GY})\Delta G_Y^+)$ – a smaller number than before because $\alpha_{GY} > 0$. It follows that the Case 4 second-best optimal residual emissions G^*_{X4} would now be lower than G^*_{X3} (even though direct emissions from the production of X would be higher). Why? Because subtracting $((1-\alpha_{GY})\Delta G_Y^+)$ from the maximum anchor supports an interesting observation – the reduction in secondary emissions of G by the producers of Y removes the last and most damaging units of GHG emissions from the total emissions upon which the mitigation target for the producers of X is determined. From a regulator's perspective, the marginal damage of direct GHG emissions by the producers of X is not as damaging as it was before interdependency with the Y market was recognized. Also, social welfare achieved by restricting GHG emissions climbs relative to Case 3 because residual emissions fall (so social costs decline) and mitigation costs are diminished to some extent.

Panels A and B of Figure A4 portray this Case 4 equilibrium; notice that A^*_{Y4} is supported by parallel reasoning supported by a marginal control cost anchor for the producers of Y equal to the sum of A_{Ymax} and $((1-\alpha_{AX})\Delta A_X^+)$. But is social welfare maximized across both markets by the combination of G^*_{X4} and A^*_{Y4}? Probably not, because additional tweaks in the regulation of conventional air pollution would be required since imported emissions of G from the producers of X (and the imported emissions of A from the producers of Y) would change with the advent G^*_{X4} and A^*_{Y4}. As a result, the functional anchors of marginal control costs for G and A. In this variant, denoted Case 5, social welfare would be maximized only if the control targets for both types of pollution were jointly and simultaneously determined.[8] For the purpose of comparing outcomes that will result from adding even more real-world complication with this first-best social optimum in a world with these interdependencies, let G^{**}_{X5} and A^{**}_{Y5} denote these efficiency benchmarks; they are associated with $((1-\alpha_{AX})\Delta A^{++}_{X5})$ and $((1-\alpha_{GY})\Delta G^{++}_{Y5})$; see Figure A5.

3.3. Sector Specific Emissions Controls Applied only in One Sector Secondary Benefits.

It is possible that the regulatory authority, reflecting a political context, for example, would confine its control options to only one pollutant. For the sake of argument, suppose that direct control of the emissions of greenhouse gases in the production of X were ignored in Case 6. The resulting second best optimum would then have to work under the reality that the producers of X would revert to $G^*_{X1} = G_{Xmax} > G^{**}_{X5}$. Regulators would be forced to choose a single second best control rate for A that would be calculated along a marginal control cost schedule for the producers that is anchored at A_{Ymax} plus $(\alpha_{AX}\ \Delta A_{Xmax}) > (\alpha_{AX}\ \Delta A_X^{**})$. Imported emissions of A from the

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[8] This discussion does, however, suggest an incremental sequence of adjustments of the regulatory targets that could converge to the optimum, a la the Cournot model of duopoly (Mansfield and Yohe 2004, Chapter 12, pages 428-432).

producers of X would contribute so much to residual emissions of A that the second best optimum would rise above A^{**}_{Y5} even though the control rate applied to total emissions of A would increase to target $A^{*}_{Y6} < A^{**}_{Y5}$. Social welfare would therefore fall relative to the (G^{**}_{X5} and A^{**}_{Y5}) optimum because the control rates for both G and A are wrong (A would be over-regulated and B clearly under-regulated). Figure A6 displays this constrained equilibrium.

Two more conjectures can now be advanced with confidence:

Conjecture #2: ***Restricting the application of regulatory controls designed to reduce the emissions of two (or more) pollutants to one control mechanism design to address one pollutant necessarily reduces welfare.***

Conjecture #3: ***A failure to apply one or more control options for one or more pollutants leads to two fundamental conclusions:***

(1) the decline in net welfare losses grow significantly as one policy disappears from consideration in the list of policy options, and

***(2) first-best solutions to joint policy discussions need as many policy tools as there are policy objectives*.**

In this case, there are two objectives – the efficient joint regulation of two distinct types of pollutants from both of two distinct sources.

Conjectures #2 and #3 can, of course, be traced back to Tinbergen (1952).

3.4. A Final Case in Which Regulators Think that Climate Change is a hoax.

This is a Case 7 where regulators think that they are justified in ignoring options to reduce the emissions of greenhouse gases. If, however, they nonetheless recognize that some degree of constraint of the emissions of G from the producers of X would fortuitously produce secondary reductions of total emissions of A, then they could consider placing restrictions on those producers. Doing so would move the anchor for the marginal control costs facing the producers of Y down to some degree. Certainly each unit of reduction in the emissions of G below G_{Xmax} would increase marginal control costs for the producers of X with no private or perceived social benefit, but each unit would also reducing the second-best optimal control rate for A (since it would lower the applicable marginal control cost anchor). This secondary effect would, of course, hold the potential of improving social welfare by reducing the control costs for the producers of Y (by reducing the control target for A from A^{*}_{Y1} to something like A^{*}_{Y7}) and by reducing the social costs to those who suffer damages from exposure to A (if secondary reductions in the emissions of A from the producers of X were greater than ($A^{*}_{Y1} - A^{*}_{Y7}$). Imposing some modest control costs on the producers of X by requiring that they emit $G^{*}_{X7} < G_{Xmax}$ would be a downside, but the costs would be removing the least expensive units of pollution of GHG emissions on the way down to G^*_{X7} would not accumulate very quickly. One should expect regulators could arrange that these countervailing cost increments could be smaller than the benefit side for a non-negligible interval.

Conjecture #4 ***In a world where decision-makers think that "climate change is a hoax", the efficient second-best jointly determined control rate on GHG's could still be positive.***

4. Some Concluding Remarks.

Evaluating secondary benefits is complicated by interactions of context – contexts that include consideration (at least qualitatively) of the efficacies of conventional air pollution regulations and GHG mitigation schemes in terms of direct net benefits; secondary net benefits that move both directions with multiple policies designed to confront multiple non-climate externalities that can be positive (amplifying) or negative (countervailing), and separating the two causal directions to avoid double counting, over-statement, and/or under-statement of cumulative net welfare value.

As the cases show, assumptions about the context affect the efficiency of different sets of policies. Including secondary net benefits in estimates of the social cost of carbon for use in evaluating non-climate policies directed at other economic and/or social objectives must be done with care to avoid omissions and double counting. For example, to avoid double-counting, evaluations of non-climate policies like increasing CAFÉ standards for automobiles that reflect the value of reduced GHG emissions are most credible if they use an estimate of the social cost of carbon that reflects only the direct benefits of GHG reductions. Evaluations of the net welfare value of GHG mitigation initiatives must also be done with understanding of the sources that derive the underlying second-best environments.

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Captions for Figures 1-6

Figure 1: *Illustrative schematic diagrams for Case 1* showing marginal benefit and net marginal benefit schedules (designated MB and MNB, respectively) for greenhouse gases and conventional air pollution contrasted with two marginal social cost schedules (denoted MSC) for each. Absent regulation that would reflect the social cost of either type of pollution, G_{Xmax} and A_{Ymax} would be emitted from the X and Y markets.

Figure 2: *Expanded versions of the illustrative schematics for Case 2* showing the marginal cost schedules (denoted MC) for installing and implementing emissions reducing technologies emanating up and to the left from anchors at G_{Xmax} and A_{Ymax}. In this case, regulated emissions would be G_{X2}* and A_{Y2}* where MSC equals MC.

Figure 3: *Further expansion of the schematics to accommodate leakage between emissions sources for Case 3* equal to ΔG_Y^+ and ΔA_X^+, respectively. The MC anchors move to the right by those amounts supporting higher optimal emissions totaling G_{X3}* and A_{Y3}*, respectively. Now, regulation would be characterized by $MSC = MC^+$ for both G and A.

Figure 4: *Case 4* is reflected by moving the MC anchors back to the left by amounts equal to the simultaneous reductions in G and A generated by control technologies applies for A and G emissions in the market for Y and X by $\alpha_Y \Delta G_Y^+$ and $\alpha_X \Delta A_X^+$. Since the reverse accommodations are smaller than ΔG_Y^+ and ΔA_X^+, emissions are now $G_{X4}^* < G_{X3}^*$, $A_{Y4}^* < A_{Y3}^*$ where $MSC = MC^{\Delta}$.

Figure 5: *Case 5* reflects the first best optimum when the complications of Cases 2 through 4 are combined. Equilibrium emissions are G_{X5}** and A_{Y5}** - values that need not conform to any of the previous equilibria.

Figure 6: *Case 6 considers the case in which regulators refuse to regulate emissions of greenhouse gases.* Emissions of G from the market for X would revert to G_{Xmax} so that there would be no countervailing reduction of conventional pollution emissions. As a result, actual emissions of conventional pollution from the Y market would be regulated to $A_{Y6}^* > A_{Y5}^{**}$. Notice that MC_A^+ is now anchored by A_{Xmax}.

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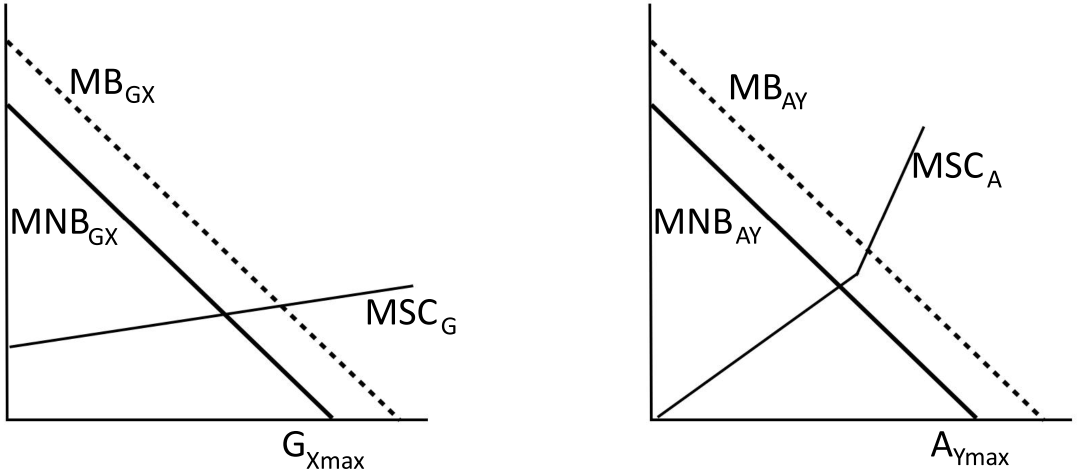
Figures

Figure 1



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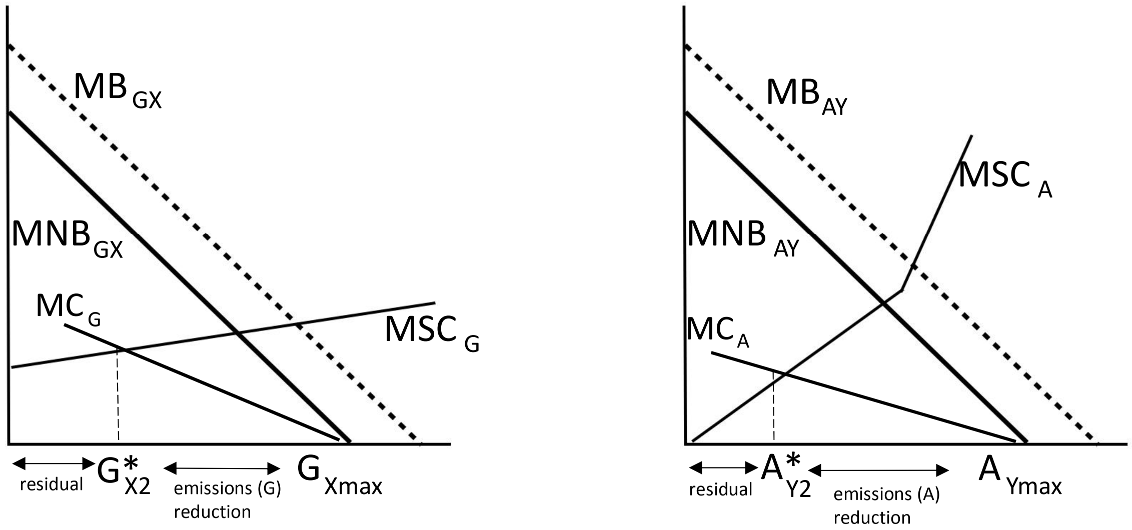
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MSC_G
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G*_X2
emissions (G) reduction
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A_Ymax

Figure 3

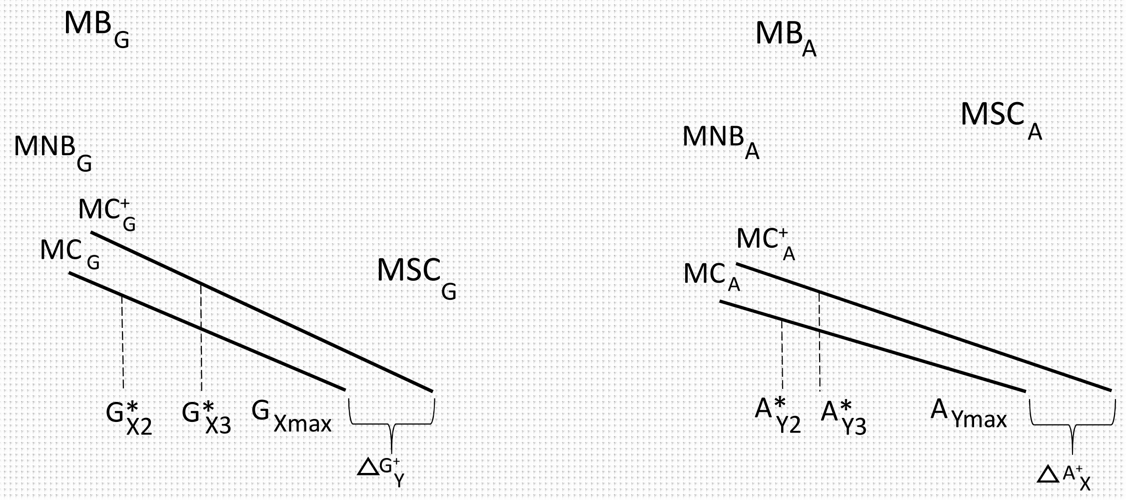
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Figure 4

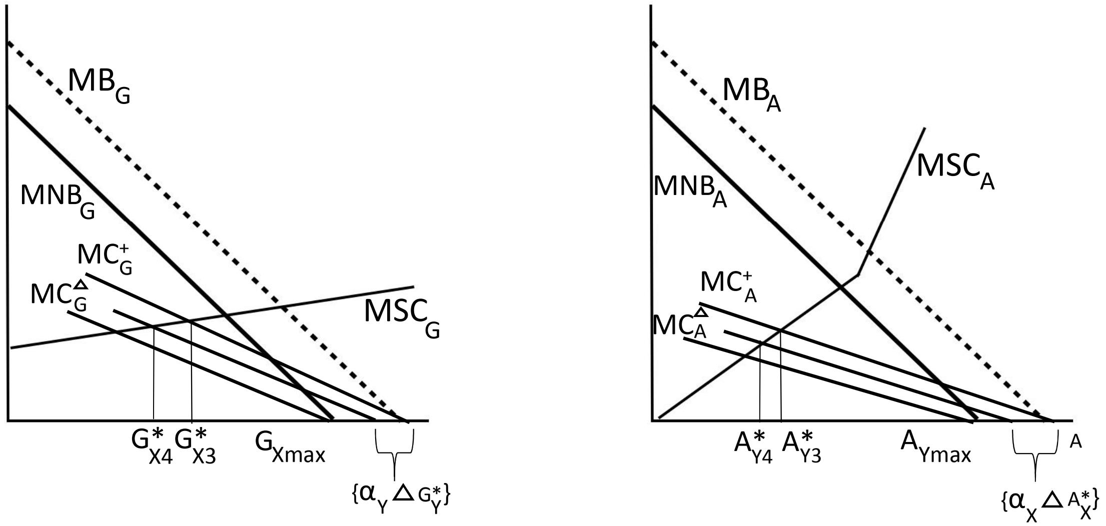
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Figure 5

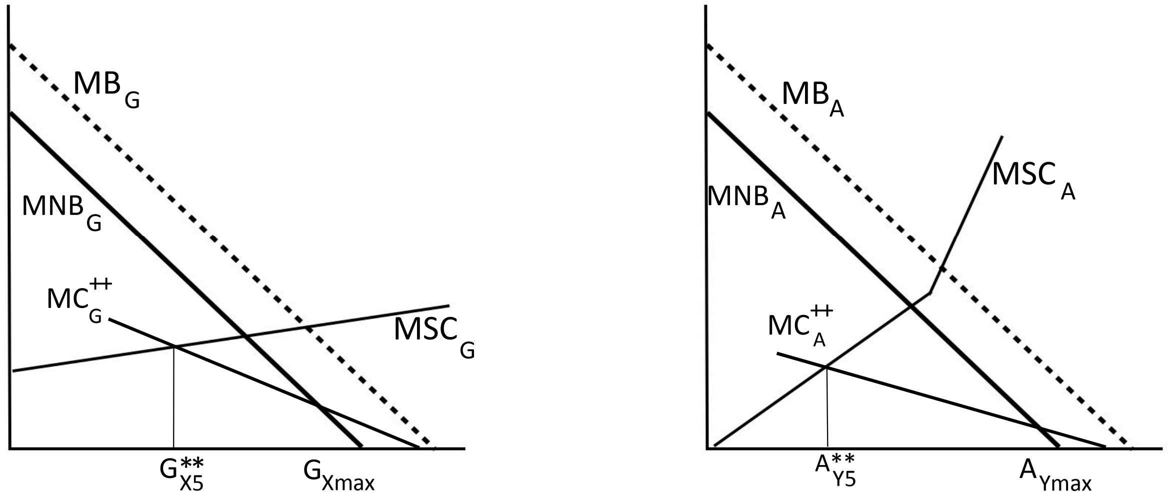

Figure 6