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ABSTRACT

There is a consensus among economists that a carbon tax is the best approach for addressing the effects of CO2 emissions on the global climate. However, past international agreements on climate change instead specify caps on emissions (a quantity target) for each country. This paper explores several advantages of such use of quantity targets. For one, if a country were to impose a carbon tax at a rate high enough to correct for global externalities, this rate would far exceed the rate in that country's own self-interest. The result is an incentive to make use of other domestic government policies to encourage greater emissions, undercutting the intended abatement under a carbon tax. A quantity target instead by construction caps emissions. Second, the paper argues that a quantity target can better insure that global warming remains below two degrees Celsius, given the uncertainties faced regarding the response to any given carbon tax rate. Third, the set of quantity targets set for each country can more flexibly be adjusted to ensure that most countries benefit from participating in a global accord, while still allowing efficient patterns of abatement by giving countries credit for cross-border abatement efforts.

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Carbon Taxes:
Many Strengths but Key Weaknesses

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Global warming is an increasing threat to the quality of life throughout the planet. Over the last several decades, we have seen a steady increase in global average temperatures, in some locations already pushing the limits for human habitation as well as for the survival of other species of plants and animals. These increasing temperatures are leading to much more volatile weather patterns, with increasing chances of flooding, droughts, and violent storms. Melting of the ice caps in Antarctica and Greenland are raising ocean levels, gradually leading to the inundation of heavily populated coastal areas, and will likely affect key ocean currents such as the Gulf Stream.

There has been substantial research by scientists documenting the role of carbon dioxide (CO_2) in causing this global warming, work dating back at least to the 1950's.[1] More recent research by economists has gone to great effort to calculate the present value of the many social costs created per ton of current CO_2 emissions through their effect on global warming (a figure now referred to as the social cost of carbon, or SCC), work for which Nordhaus won a Nobel Prize.[2,3]

There seems to be a consensus among economists that the best way to induce emitters to take into account the social costs created by their current emissions of carbon dioxide and other greenhouse gasses is through the use of a "carbon" tax on emissions.[4] This tax rate should equal the SCC, thereby inducing emitters to take into account the present value of the costs their emissions impose on individuals throughout the globe, now and into the future, per ton of current emissions.[5]

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[1] As a UCSD faculty member, I should cite the path-breaking paper by Revelle and Suess (1957), a paper that was the first to recognize the role of the ocean in absorbing past emissions of CO_2, but then to forecast growing accumulation of CO_2 in the atmosphere (with the implied global warming) given that the global emissions rate already exceeded the absorption capacity of the oceans. The absorption of CO_2 in ocean waters leads to acidification of the ocean, threatening marine life, a further cost of these emissions beyond their implications for global warming.

[2] For one of his many contributions, see Nordhaus (1994).

[3] In the process, there have been many interesting issues debated in this literature, such as how best to handle uncertainty about the size of these costs (see, e.g., Weitzman (2009) and Cai, Judd, and Lontzek (2013)) and what discount rate to use for losses experienced by future cohorts (e.g., Stern (2007)).

[4] For a strong endorsement of the use of a carbon tax over other potential policies to achieve carbon abatement, see Nordhaus (2006).

[5] One debated issue is how best to use the revenue generated by a carbon tax. Goulder (2002) provides a survey describing the past literature on the efficiency advantages of using the revenue from a carbon tax to reduce other tax rates. There have also been arguments on equity grounds to use the revenue instead to compensate those

For an efficient pattern of abatement, the same tax rate should be used by all countries, and for all means of preventing global warming, including not only abatement of emissions of CO_2 and other greenhouse gasses but also sequestration of CO_2.

Economists have debated how best to reach agreement on such a tax rate among countries. The challenge is that each country faces an incentive to free ride, minimizing the tax rate it agrees to impose on its own citizens, while still benefiting from the abatement undertaken in other countries. Weitzman (2017a) argues that if countries need to agree jointly on one common carbon tax rate, then they appropriately need to trade off the costs such a tax imposes on their own citizens with the benefits these citizens receive from the resulting abatement in other countries through their use of the same tax rate. He forecasts that the chosen tax rate coming out of such a political process would be very close to the social cost of carbon.

Another major hurdle is the remaining incentive on countries to free ride by not enforcing such a tax, while still benefiting from the abatement done elsewhere. Here, Nordhaus (2015) recommends that countries supplement their agreement on a carbon tax rate with an agreement on a tariff rate to be imposed on imports from any country out of compliance with the agreed tax rate. He argues that reasonable tariff rates should be sufficient to induce compliance as long as the carbon tax rate is in the range of those implied by past estimates of the social cost of carbon.

In contrast to this consensus among economists on the use of a carbon tax to address the threats from global warming, the policies that have in fact been adopted under the United Nations Framework Convention on Climate Change, in particular including the Kyoto Protocol and the Paris Agreement, focus instead on getting countries to commit to some specified percent reduction in carbon emissions from a chosen base year.[6,7] While the Kyoto Protocol included some penalties for non-compliance, in practice non-complying countries simply withdrew from the agreement rather than pay such penalties. There were no agreed penalties under the Paris Agreement for lack of compliance, other than “name and shame”. Not surprisingly, then, Nordhaus (2019) finds no effect of these agreements on rates of abatement of CO_2 emissions.

Consistent with their longstanding support for a carbon tax, economists have expressed serious reservations about this policy focus on quantity targets for abatement rather than on the appropriate carbon tax rate. For example, Weitzman (2017b) argues that agreements are much harder to obtain when setting quantity emission targets for each country than when setting one common carbon tax rate, helping to explain the few

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harmed by global warming, or to compensate those bearing the incidence of the carbon tax. Most proposals, though, assume that the revenue would at least be retained within each country imposing such a tax.

[6] In the case of the Kyoto Protocol, countries negotiated over the percent reduction each of them would commit to, while in the Paris Agreement each country could independently decide what promises to make.

[7] Note that under these agreements, countries were allowed to buy credits towards their promised abatement through undertaking supplementary abatements in other countries, in principle assuring cost minimizing abatement from a global perspective.

participants in the Kyoto protocol and the lack of any negotiation on each country's quantity target in the Paris agreement. Nordhaus (2006) argues that there is no assurance that these quantity targets achieve the right level and timing of abatement, where the right level is one where the marginal gain from abatement equals the consensus value of the SCC. He argues that quantity targets also lead to a volatile price of carbon,[8] creating costly incentives (with no offsetting benefits) for firms to alter the timing of their emissions.

The aim of this paper, though, is to raise some concerns with having international agreements commit to a particular carbon tax rate rather than to some quantity targets, challenging this consensus among economists favoring use of a carbon tax.[9]

By design, a carbon tax rate equal to the SCC should achieve the optimal level of abatement from a global perspective, implying just offsetting gains and losses at the margin from additional emissions. When emissions increase in one country, residents elsewhere clearly lose due to the marginal exacerbation in global warming. Since each country's emissions decisions impose a negative externality on non-residents, incentives are distorted. At the optimal tax rate, residents in the emitting country must gain by an amount just equal to these total losses to non-residents, given that at the optimal tax rate there are zero net aggregate costs from marginal additional emissions.[10]

The first concern the paper focuses on is the incentives this gain from a marginal increase in emissions creates for the political choice in each country over a wide range of public policies other than the agreed carbon tax rate. To begin with, countries might try to offset such a high carbon tax with various forms of subsidies to energy production, such as a coal subsidy. Victor (2001) notes the wide range of possible taxes and subsidies affecting the energy production in any given country that can be used to offset a carbon tax, and advocates some attempt to combine these into an effective net carbon tax when judging compliance with an international agreement, to prevent such direct attempts to undermine a carbon tax.

The problem, though, is much broader. Given a carbon tax rate that far exceeds the rate that is in each country's own self-interest, any policies that as a side effect lead to increased emissions to that extent become more attractive.[11] Examples could include: tariff or non-tariff barriers on imports of goods whose domestic production would lead to

[8] Given a pre-specified quantity of permits, any fluctuations in demand or supply (due for example to the business cycle) are absorbed entirely through fluctuations in the price of these pollution permits.

[9] To focus on this issue, though, I will assume that countries have sufficient incentives to abide by whichever explicit commitments they have made under these international agreements, perhaps due to tariffs imposed on those out of compliance.

[10] In general, from each country's perspective, the difference between the marginal benefits and the marginal costs of extra emissions equals the carbon tax rate minus just the domestic externalities from extra emissions. When a country chooses this carbon tax rate to internalize domestic externalities, the difference equals zero. But when this tax rate is set based on some global agreement, the difference will be positive, and potentially very large.

[11] This is just an application of the theory of the second best.

high emissions, hurdles discouraging solar farm and wind turbine construction, tax provisions favoring heavily-emitting industries, favorable credit terms on loans to these high-emission industries (enabled for example through government repayment guarantees), or even just weak tax enforcement for a carbon tax.[12]

Even if some policies that lead to greater emissions end up being penalized under revised treaty provisions, there are too many policy options available for undercutting the impact of a carbon tax to become part of any feasible treaty. Side effects of the remaining policies, leading to increased emissions, could easily be sufficient to seriously undermine the effects of a carbon tax on abatement.

If instead a country commits to some quantity target for its emissions under an international agreement, the country would be left simply choosing the range of public policies that achieve this target at least cost to residents, as would be appropriate from an international perspective. There would be none of these second-best distortions to other policies that arise when a country commits instead to a high carbon-tax rate. This argument remains valid even if a country chooses to achieve this agreed target through use of a carbon tax.

To develop this argument, section 1 will lay out the traditional theory of the use of a carbon tax to correct for the negative externalities from emissions borne by just domestic residents. Under conventional assumptions, the tax rate in theory should lead to the efficient choice for the level of this activity from the country's perspective, eliminating any reason on second-best grounds to modify other policies due to any side effects they may have on the amount of this externality-generating activity.[13]

Section 2 then examines incentives when the carbon tax rate is set much higher, in order to reflect negative externalities experienced worldwide. Now, on second-best grounds, the net social benefits from all other domestic policies would include an extra term reflecting the effects of these policies on revenue from the carbon tax, relative to their effects on the net loss to domestic residents from extra emissions. This section then explores a variety of policies that would be particularly responsive to these distorted incentives.

Section 3 examines instead the implications of a commitment to a percent reduction in emissions as part of an international agreement. Here, by constraint, emissions are constrained by the commitments made in the international treaty, leaving other policies undistorted.

I turn next in section 4 to the implications of Weitzman's classic paper on "Prices vs. Quantities" (Weitzman (1974)), a paper directly relevant for the debate about the use of carbon taxes vs. quantity targets to best achieve CO_2 abatement. Weitzman's paper

[12] Nordhaus (2006) seems to recognize the problem, but argues that such indirect effects on emissions are too hard to take into account in any international agreement.

[13] Any equity effects of the carbon tax on the distribution of real net-of-tax income can be offset through adjustments to the income-tax schedule.

focuses on the inevitable uncertainty faced when trying to use either prices or quantity targets to best approximate the ex-post efficient outcome for abatement of CO_2 emissions. He finds that a quantity target dominates if the marginal benefits from extra abatement vary much more over possible levels of emissions than do the marginal costs of extra abatement, and conversely.

The international discussion on global warming has focused on the large potential disruptions to the climate if the rise in global temperatures due to accumulating CO_2 in the atmosphere exceeds two degrees Celsius. Implicit in this focus is a belief that the marginal benefits from abatement are substantial until there has been sufficient abatement that expected global temperatures are no higher than two degrees Celsius above past levels, even if marginal benefits could be much lower for yet further abatement. In contrast, given current technology the marginal costs of shifting from carbon fuels to renewable sources of power such as wind or solar power seems very low, over a broad range of degrees of abatement, at least given sufficient time to invest in renewables. The theory laid out in Weitzman (1974) then supports the use of quantity targets rather than use of a carbon tax to achieve the desired abatement of CO_2 emissions.

The theory in Weitzman (1974) also argues that this choice between using prices vs. quantities to achieve the desired abatement is more important the greater the uncertainty regarding the effects of any given carbon tax rate on equilibrium emissions.

Section 5 explores one possible source of poor forecasting of the effects of a carbon tax on equilibrium emissions. Forecasting these effects requires, at a minimum, information about the slopes of the demand and supply curves for fossil fuels. The supply curve for fossil fuels depends on both incentives for new exploration and incentives for use of known reserves. With a binding international agreement on CO_2 abatement, new exploration for fossil fuels should in theory stop entirely. Those owning known reserves, though, still have an economic incentive to fully exploit these known reserves as long as the market price they receive for fossil fuels exceeds the marginal cost of extracting these fossil fuels from the known reserves.

Together, these assumptions imply that emissions would drop only when a carbon tax rate is high enough to drive down the net-of-tax market price of fossil fuels below the marginal cost of extracting these reserves from the ground. For yet higher tax rates, the degree of abatement should be very sensitive to the tax rate, since given current technologies renewables are a very competitive alternative to fossil fuels. Assuring that the chosen tax rate is just sufficient to avoid global warming above two degrees Celsius will then be very tricky, given plausible uncertainties about supply and demand curves for fossil fuels.

Section 6 then discusses the implications of the analysis in section 5 for tax incidence. The model in section 5 forecasts that the incidence of a carbon tax will fall heavily on owners of fossil fuel reserves, regardless of the amount of emissions coming from the extraction of these fossil fuels per se from known reserves. Such a concentrated burden created from international abatement efforts inevitably hinders efforts to gain cooperation from countries (such as the U.S.) with a large fossil fuel industry, since these countries end up bearing a disproportionate fraction of the resulting costs.

When international agreements focus on the choice of a carbon tax rate, there is no available mechanism to ensure cooperation from countries that bear a disproportionate share of the burden. When countries instead agree on targets for a percent reduction in emissions, adjustment in these targets to reflect the relative burdens created by abatement efforts can be used to ensure broad participation in the agreements.

The paper then concludes in section 7 with a brief summary of the issues raised in the paper.

1. Theory of a carbon tax correcting externalities *within* a country

In laying out the theory of a carbon tax, I have simplified the model whenever I can, without losing the key insights that I would like to focus on. Much of the effort is there to ensure that the optimal carbon tax rate simply equals the marginal externality cost of emissions to residents in that country.[14]

Assume that each individual has some pretax income $Y = wz$ and faces an income tax schedule denoted by $T(Y)$. Here, w denotes a market-wide level of wage rates, while $z \equiv Y/w$ captures each individual's labor supply, skill level, and effort.[15]

An individual's utility is assumed to equal $U(Y/w, \mu(C); G)$. The first term captures the utility loss from the effort needed to earn pre-tax income of Y. The next term, $\mu(C)$, is a sub-utility function capturing the utility provided by the chosen consumption bundle, C,[16] while G is a vector of public services (including simply lump-sum transfers) provided by the government.

The individual's budget constraint is: $Y - T(Y) = pC$, where p is a vector of consumer prices. As a simplification, assume that this is a small open economy, implying that these consumer prices are set on the world market.

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[14] Without these assumptions, it is possible that the choice of a carbon tax rate would also be affected by equity considerations as well as by other efficiency considerations. For example, If the poor spend a higher fraction of their budget on fossil fuels, then to that extent a subsidy on fossil fuels could look attractive on equity grounds. If consumption of fossil fuels is a relative complement with household labor supply (e.g. cheaper fuel makes commuting to work easier) then to that extent a subsidy to fossil fuel consumption would be appropriate.
[15] One key simplifying assumption then is that general equilibrium impacts of policy changes on the level of market wage rates impact all individual incomes proportionately, eliminating one source of distributional considerations. If instead, a carbon tax changes relative wage rates, then as seen in Naito (1999) use of such a commodity tax can at the margin provide a less distorting form of redistribution than further use of the income tax.
[16] As shown in Atkinson and Stiglitz (1976), this choice of weak separability between the consumption bundle and leisure means that all consumption goods are equally substitutable with leisure, eliminating an efficiency reason for separate taxes on individual consumption goods.

Firms are assumed to be competitive and have constant returns to scale. The composition of domestic production simply depends on this vector of world prices, yielding an equilibrium domestic wage rate that allows firms to break even, given the domestic technologies.

The inputs to production are assumed to consist of labor and fossil fuels. With no sales taxes, the vector of output prices also equals p, labor costs can be summarized by the market price w, while the price of energy inputs equals $e + t$, where e is the price of fossil fuels set on the world market while t is the carbon tax rate. Aggregate domestic emissions from use of fossil fuels in production is denoted by E_d, while the sum of the z's, measuring aggregate labor inputs is denoted by Z. Given these assumptions, we then infer that $\frac{\partial w}{\partial t} = -E_d/Z$, a response that allows firms to continue to break even in response to any marginal increase in the carbon tax rate.

In choosing its tax and expenditure policies, the government is assumed to maximize a standard welfare measure, subject to its budget constraint:[17]

(1) $$\int U(Y/w, \mu(C); G) f(Y) dY + \gamma\left(\int T(Y) f(Y) dY - p_G G + tE_d\right)) - \gamma V_d(E)$$

To begin with, welfare depends on the sum of the utilities of those alive at that date.[18] Here, γ is the Langrangian on the government's budget constraint, while p_G is a vector measuring the costs of each type of government expenditure. $V_d(E)$ captures the social costs incurred by domestic residents due to global emissions (denoted by E) on future as well as current generations within the country.[19] Assume, in setting its own policies that the country takes as given the level of emissions in other countries, implying that $\frac{\partial E}{\partial E_d} = 1$.[20]

For a derivation of the equation characterizing the optimal income tax schedule, $T(Y)$, see for example Gruber and Saez (2002). This equation trades off the equity gains from shifting the tax burden to higher income individuals with the efficiency costs of distorting the reported Y for those individuals now facing a higher marginal tax rate.

Consider next the welfare effects of a marginal increase in t combined with an adjustment to the income tax schedule sufficient to compensate each income group for

[17] Here, $f(Y)$ denotes the density function for household income.
[18] For simplicity, we ignore possible intergenerational transfers by assuming a balanced budget each period. For a discussion of the role of intergenerational transfers in better matching benefits to costs from carbon taxes and carbon abatement, see Kotlikoff et al (2021).
[19] Note the simplifying assumption that emissions do not per se affect labor supply or consumption bundles. To simplify later results, we define these costs to be in units of γ.
[20] This particular Nash assumption is the simplest but certainly not the only possible assumption about how countries interact in this non-cooperative setting for emissions policies. Such an analysis of this non-cooperative game is not the focus of this paper.

the effects of an increase in t on Y, occurring through its effects on w.[21,22] In particular, to leave after-tax income unaffected by a marginal change in t, we find that the individual's income tax liabilities must change by: $dT(Y) = -E_d(1-T')(\frac{z}{Z})$, adding back to the individual's income enough to compensate for the fall in after-tax income resulting from the increased tax liabilities on emissions.[23] The revenue collected from the carbon tax minus the income tax revenue lost due to the fall in wages due to the carbon tax on net just offsets the financial cost of this adjustment to the income tax schedule.

The first-order condition for the optimal value of t (denoted by t_d) internalizing just domestic externalities then satisfies $(t_d - V_d')\frac{\partial E_d}{\partial t} = 0$, implying that the carbon tax rate simply equals the marginal damage to domestic residents from further use of fossil fuels: $t_d = V_d'$.

The first-order condition for the optimal amount on any specific type of government expenditure, denoted by G_k, equals:

$$\int U_{G_k} f(Y)dY = \gamma\left(p_{Gk} - \int T' \frac{\partial Y}{\partial G_k} f(Y)dy\right) - \gamma(t - V_d')\frac{\partial E_d}{\partial G_k} \tag{2}$$

Here, the sum of the welfare gains to individuals from these extra government expenditures are traded off not only with the marginal costs of these additional expenditures but also with the revenue gains or losses due to any resulting changes in individuals' reported income in response to these extra government expenditures. Labor supply could change to the degree that this particular form of government expenditure is either a complement or a substitute with leisure. Expenditures that are substitutes for leisure, leading to higher reported earnings, to that extent look more attractive.

Consider as an example government provision of free high-quality day care to children.[24] With high-quality day care available to parents, it becomes easier for parents to work, adding to their reported labor income and then adding to tax revenue. This is an example of the theory of the second-best, capturing welfare effects of any broader changes in taxable behavior that occur in response to a marginal policy change.

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[21] Känzig (2023), for example, documents using EU data that any increase in a carbon tax rate affects the poor relatively more than the rich, a distributional effect that can be offset by making the income tax schedule suitably more progressive. Since we have optimized over the income tax schedule, any marginal perturbations in this schedule have no welfare consequences.

[22] See Kaplow (2012) for a broader justification for this approach to welfare analysis, where any distributional impact of a policy change are offset through a simultaneous adjustment to the income tax schedule, enabling a focus on the policy's efficiency impact.

[23] Given our assumptions, consumer prices remain unchanged, equal to the world prices, implying that with this adjustment to income tax liabilities, household utility is unchanged as well.

[24] See Bergstrom and Blomquist (1996) for a formal analysis of this case.

Note, though, that the last term in equation (2), capturing the welfare effect of any impact of particular government expenditures on domestic emissions, E_d, drops out even though, in general, emissions will change. With the tax rate set so that $t = V_d'$, any change in E_d generates just offsetting benefits and costs to the society, yielding no net welfare impact. This will no longer be true when the carbon tax rate is set to internalize global rather than national externalities.

2. Theory of a carbon tax designed to correct *global* externalities

Consider now the implications of joining an international agreement which commits the country to impose some carbon tax rate t_g on CO_2, emissions but allows the country to retain the resulting tax revenue. Denote the global marginal social costs of carbon by $V_g' = \sum_c V_c'$. The aim is to set $t_g = V_g'$.[25]

Each country is assumed to be small relative to the global economy, implying that $V_g' \gg V_d'$. Contrary to the Kyoto Protocol or the Paris Agreement, assume that any non-compliance with this committed tax rate results in sufficient penalties that each country views this commitment to be a hard constraint. The question is how this commitment affects other policy choices.

To begin with, we find from equation (2) describing the first-order condition for any government policy G_k that any given policy G_k now becomes more attractive to the extent that it raises E_d, given that $t_g \gg V_d'$. Given how high some estimates are for the social cost of carbon (and the desired carbon tax rate), this incentive could well become a major factor in policy setting.

From a global perspective, extra domestic emissions cause harm to individuals living in other countries by an amount equal to $V_g' - V_d'$. Because policy decisions in any country d impose negative externalities on non-residents, policy incentives are distorted. By design under an optimal carbon tax rate, however, a marginal change in emissions results in no change in global welfare. The marginal loss to residents of other countries from extra emissions must then equal the gain from extra emissions accruing to the emitting country: $V_g' - V_d' = t_g - V_d'$. Regardless of the tax rate, the gain from extra emissions is proportional to $(t - V_d')$, where t measures the marginal benefits to a country from extra emissions,[26] while V_d' measures the costs that country bears from extra emissions.

[25] The value of V_g' depends on the current and expected future stocks of CO_2 in the atmosphere, and therefore depends on the history of past and projected future global emissions.

[26] While individuals are indifferent to a marginal change in their choice of emissions, by utility maximization, extra emissions generate a fiscal externality to other residents through their implications for government revenue.

The previous section did not consider any tax policies other than the income tax and a carbon tax.[27] Now, however, any tax changes that as a side effect lead to an increase in E_d to that extent become more attractive. For one, direct subsidies to carbon emissions such as those mentioned in Victor (2001) become attractive. More broadly, any tax changes that aid firms that are heavy emitters become more attractive, including policies such as depletion allowances, accelerated depreciation for particular categories of capital equipment used in industries with heavy emissions, or lack of oversight over transfer pricing by multinational firms linked to heavy emissions.[28]

Nontax policy changes that raise the tax base for the carbon tax also become more attractive. Which policies are affected depends on how the required carbon tax is designed under any international climate change treaty. Carbon taxes could be imposed, for example, on firms to the degree that they emit CO_2 in their production (as assumed in the prior discussion), on consumers to the degree that they purchase goods that generated emissions during their production or in their use, or on fossil fuel producers to the degree that the fuels they sell ultimately generate emissions.

To the degree that firms owe a carbon tax based on their own emissions, then equation (2a) supports greater use of policies that increase production in heavily-emitting firms, or emissions per unit of production by these firms. Examples would be tariff or non-tariff barriers protecting heavily-emitting firms against imports,[29] or policies increasing exports if instead these firms are net exporters.

Emitting industries could also be protected against domestic competition from firms that generate lower emissions, e.g. through policies that hinder the connection of solar farms or wind turbines to the electric grid or regulations that hinder use of nuclear power facilities.

Various policies could be used to grant heavily emitting firms cheaper access to land or to bank credit.[30] Environmental regulations on other pollutants linked to the same production processes could be relaxed.

To the degree that consumers owe tax on the use of fossil fuels linked for example to use of gasoline-powered cars or use of natural-gas-fired appliances, any policies that

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[27] Given the assumption of weak separability between consumption and leisure, these two taxes alone are sufficient to maximize social welfare when the carbon tax focuses on externalities within the country, as follows from the arguments in Atkinson and Stiglitz (1976).

[28] Statutory provisions that aid emitting firms would be reasonably obvious, but another approach would simply be weak enforcement of carbon taxes, for example poor monitoring of methane flaring or methane leakage in the oil industry.

[29] There is an obvious case for including a tariff in lieu of a carbon tax on imports from non-compliant countries in any international agreement on a carbon tax. But the incentive here is for protection from imports even from compliant countries.

[30] The cost of land for heavily-emitting firms could be reduced through using zoning regulations to limit competing use of the land, by charging below market fees for use of Federal land for fossil fuel extraction, or by not granting property rights to below-ground fossil fuel reserves to land owners (as is the law in Texas). Granting cheaper credit could occur through decisions by state banks or through Federal loan guarantees.

encourage these categories of expenditures now look more attractive. Examples could be reduced expenditures on public transit, only limited expenditures on charging stations for electric vehicles, or simply a reduced sales tax or VAT rate on these particular categories of expenditure.

If the tax base instead is on fossil fuel extraction and/or refining, as recommended in Metcalf and Weisbach (2009) to save on administrative costs, then countries face an incentive to increase their fossil fuel production, whether through various policies that would directly aid these industries, or protection for domestic producers from imports of fossil fuels.[31,32]

For each of the above policies that might be used to increase the carbon tax base, thereby leading to higher emissions and undermining the intent of the international treaty, a key question is whether the specific terms of the treaty coordinating policies on global warming can be designed to prevent such policy modifications that undermine abatement efforts. Nordhaus (2006) advocates the use of the IMF or some other neutral arbiter to measure "effective" carbon tax rates, including any other policy subsidies directly linked to emissions. In the above list, this perhaps covers weak enforcement of a carbon tax or a coal subsidy, but probably not any of the other listed policy modifications. The challenge, then, would be to define under a treaty some way to measure (and then to penalize) any deviation of each policy (due to second-best effects on the carbon tax base) from what would otherwise have been chosen, a seemingly impossible task. Regardless, the range of policies that might be used to undermine carbon taxes is really endless.

Recall that the net gain to a country from extra emissions equals the resulting net harm to non-residents under an optimal carbon tax rate. If a treaty required payments to non-residents sufficient to compensate these non-residents for the harm they experience from each extra unit of emissions from a treaty country,[33] then countries would no longer face such distorted incentives in their choices for other government policies.[34] However, countries with high emissions such as China or the U.S. would then find it much less attractive to agree to join such an international treaty.[35,36]

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[31] Metcalf and Weisbach (2009) recommended a tariff on imports of fossil fuels from countries not imposing comparable taxes on fossil fuel extraction. Here, though, the forecast is for tariffs on all fossil fuel imports.

[32] If the tax base instead equals domestic fossil fuel production minus net exports, then the tax base equals use of fossil fuels by domestic firms and households, leading to the incentives on government policies described previously.

[33] Such compensation for current emissions is a separate policy choice from proposals to provide compensation because of a history of emissions over past decades, an alternative that leaves current emissions incentives unaffected.

[34] In particular, the welfare effect of a marginal change in emissions in response to a policy change now equals $\left(t_g - V_d'(E) - (V_g' - V_d'(E)\right)\frac{\partial E_d}{\partial G_k} = 0.$

[35] Recall that the U.S. has twice withdrawn from these treaties, once under George W. Bush and once under Donald Trump, even without having had to make such compensation payments.

[36] Also, non-residents eligible for compensation would lose any incentive to avoid being harmed, no longer facing an incentive for example to move away from coastal cities subject to increased risk of flooding.

To explore this participation decision more formally, consider the offsetting gains and losses to a country from choosing to comply with an existing treaty specifying a particular carbon tax rate, taking as given the current set of countries in compliance with the treaty. One clear cost from compliance is the resulting requirement to raise the domestic carbon tax rate from t_d to t_g. The cost of doing so, denoted by L, equals $L(t_g) \equiv -\int_{t_d}^{t_g}(t - V_d')\frac{\partial E_d}{\partial t}dt$.[37] This is the area of a Harberger triangle capturing the efficiency loss from a domestic perspective of setting the carbon tax rate far above the level that the country would choose on its own.

The key benefit from complying is avoiding the penalty arising from tariffs imposed by the complying countries on all non-complying countries, minus any offsetting costs from being required to impose particular tariffs rates if this country chooses instead to comply. Denote the net penalty by Π. Here, the maximum treaty tax rate t_g that will still induce a country to comply with the treaty, denoted by t_g^{max}, satisfies: $L\left(t_g^{max}\right) = \Pi$.[38] If compliance requires as well transferring funds of some net amount equal to F to non-residents (less the funds now received to compensate for emissions elsewhere), however, then the participation constraint becomes $L\left(t_g^{max}\right) + F \leq \Pi$, leading to much lower feasible carbon tax rates in heavily-emitting countries that would still induce these countries to participate in the treaty.

3. Implications of quantity targets for the choice of other government policies

What happens to government incentives if, rather than committing to some carbon tax rate, countries instead commit to a quantity target, such as a given percent reduction in emissions relative to a given base year, to be achieved by a particular date.[39]

Equation (1) describing policy objectives would now include an extra term $\omega(E_d^c - E_d)$. This new term serves as a Lagrangian constraint limiting actual emissions from this particular country to the specified cap, denoted E_d^c. As a first pass, the government should then choose that set of policies that allows it to satisfy this constraint at least cost. The least cost approach to satisfying this constraint could well be use of a carbon tax on emissions,[40] though use of pollution permits or even subsidies to abatement

[37] By the envelope condition, any resulting marginal change in other government policies that might affect equilibrium emissions have no net welfare consequences and can be ignored here.
[38] Nordhaus (2015) argues that this is plausibly not a binding constraint when t_g equals his best estimates for V_g'.
[39] The treaty should also require countries to commit to imposing an adequate tariffs on imports from non-complying countries, both as a penalty for non-compliance but also as a means of imposing a presumptive carbon tax on imported goods to the extent that their production generated CO_2 emissions.
[40] The first-order condition for the optimal carbon tax rate now equals $(t - V_d' - \omega)\frac{\partial E_d}{\partial t} = 0$, implying that $\omega = t - V_d'$, where t equals the tax rate that limits emissions to E_d^c.

efforts could also work.   Now, though, there is no incentive to undermine the intended abatement, since doing so would raise emissions above the agreed cap.[41]

Note also that there would now be distorted incentives if there were any requirement to provide compensation to residents in other countries harmed by this country's emissions. The quantity target for emissions by design is intended to lead to the efficient amount of abatement, while requiring compensation payments in addition would lead to excessive abatement (marginal costs exceeding marginal benefits).

Governments do have an incentive to be lax in their measurement of total emissions, thereby weakening the constraint. However, current satellite technology seems able to measure CO2 emissions coming from a given broad geographical area, providing an available means of detecting (and then penalizing and thereby deterring) such evasion.

In contrast, such satellite technology is of only limited help in detecting any lack of enforcement of a carbon tax. Any given figure for total emissions detected by satellite could in principle still be consistent with a well enforced carbon tax, given the lack of compelling information about behavioral elasticities in response to such a tax. These differences in ease of enforcement again favor quantity caps over use of a carbon tax.

With use of a carbon tax, a country faced incentives to impose tariffs on imports of heavily polluting goods. What trade incentives exist when a country instead faces quantity targets on its carbon emissions? Any resulting behavioral responses have no direct effect on individual utilities, since the private sector is just indifferent to a marginal change in trade patterns by the envelope condition. But how is the public sector affected? We have already seen that any resulting marginal change in domestic emissions has no net effect on the public sector, since $(t - V' - \omega)\frac{\partial E_d}{\partial G_k} = 0$. In theory, any change in imports also affects emissions abroad. However, a small open economy cannot affect prices on the international market, and at fixed prices emissions abroad would not change. A small open country facing quantity constraints on its emissions then has no incentive to distort trade patterns, even in the presence of CO_2 externalities.

4. Prices vs. quantities

What do the arguments made in Weitzman's seminal paper on "Prices vs. Quantities" (Weitzman (1974)) have to say about the use of a carbon tax vs. quantity targets as the appropriate means for addressing the threat of global warming?   In a setting without any uncertainty, the choice should not matter, since there should be a one-to-one mapping between any carbon tax rate and quantity targets in the use of fossil fuels. Weitzman focused, though, on the inevitable uncertainty about the ultimate outcome. He then argued that the costs arising from the resulting misallocations that occur given

[41] Formally, the first-order condition for G_k now includes the term $(t - V_d' - \omega)\frac{\partial E_d}{\partial G_k}$, which equals zero at the optimal carbon tax rate, eliminating any distortions to the choice of other government policies.

uncertainty are smaller when policy specifies a quantity target *if* the slope of the curve representing the marginal benefits from additional abatements, as a function of the level of abatements, is steeper than the slope of the curve representing the marginal costs of additional abatements, and conversely.

Based on this reasoning, Nordhaus (2006) argued that global warming depends on the stock of atmospheric CO_2, a level that evolves slowly over time, implying that emissions during any given year have little impact on this stock, leading to a relatively flat marginal benefit curve for any particular abatement efforts. In contrast, the marginal cost curve in any given period could be relatively steep, given short-run constraints in shifting from fossil fuels to renewables, implying an advantage for use of a carbon tax over quantity targets.

But international agreements have in practice involved a commitment over many years. For example, the stated aim of the Paris Agreement, signed in 2016, was to limit global warming to two degrees Celsius, and based on this asked for an interim 50% reduction in emissions by 2030 and an ultimate target of no net emissions after 2050.

Over such a long time frame, the marginal benefits curve for abatement is likely to be quite steep, at least up to a level of abatement that limits global warming to under two degrees Celsius. The effects of warming beyond an increase in temperatures by two degrees Celsius are hard to forecast, given the lack of past experience. Scientists have been concerned that global warming beyond this level could potentially lead to dramatic and costly changes, coming for example from large scale melting of the Antarctic ice sheets, raising ocean levels and weakening the Gulf Stream.

In contrast, over this longer time horizon the marginal cost curve for shifting from fossil fuels to renewable sources of energy, should be relatively flat, given that the marginal costs of renewable sources of energy are closely comparable to (or even lower) than the marginal cost of energy from fossil fuels.[42] The slope would mainly reflect the costs of undertaking a speedier transition, say, to electric vehicles powered by electricity generated from wind, solar, and nuclear power.

With a relatively steep marginal benefit curve and a relatively flat marginal cost curve over the time frame used in past international agreements, the analysis in Weitzman (1974) implies that a quantity target dominates use of a carbon tax rate. Better to target a level of emissions that will keep global warming under two degrees Celsius than to risk that the response to any chosen carbon tax rate could be less strong than would be needed to achieve this outcome.

It is important to note, however, that Weitzman (1974) focuses on a static setting when comparing the implications of a given tax rate and a given quantity target under uncertainty. The subsequent literature, exemplified by Kaplow and Shavell (2002), considered a multi-period setting, in which a carbon tax rate can be adjusted frequently,

[42] Consistent with this, Metcalf and Stock (2023) estimate that the macroeconomic effects of carbon taxes that have been imposed within the European Union during the past thirty years have, if anything, been slightly positive.

either by formula or by administrative updates, to reflect new information about the benefits and costs of abatement efforts. Equivalently, a quantity target can also be updated based in part on any available new information regarding the marginal cost of abatement revealed by the market price of pollution permits.

Frequent policy updates lessen the concerns arising from uncertainty. In practice, though, there have been only two international agreements on climate change, the Kyoto agreement in 1992 and the Paris agreement in 2016. These agreements failed to set up any procedure for interim policy revisions, either through a formula or through setting up an agency with the authority to make these decisions. With such infrequent updating, the Weitzman (1974) analysis continues to carry weight.

5. Challenges in forecasting abatement when using carbon taxes

The analysis in Weitzman (1974) also argued that more is at stake in this choice between carbon taxes and quantity targets for abatement the greater the uncertainty in the response to any given carbon tax rate. The aim of this section is to suggest that this uncertainty can be large.

Let me lay out a stylized model forecasting the impact of a carbon tax on the use of fossil fuels, and therefore on carbon emissions.

In particular, denote the total stock of known reserves of fossil fuels by R, where these reserves represent those found based on past exploration efforts. Assume, though, that further exploration efforts stop in response to a binding international climate change agreement, given the expected fall in future demands for fossil fuels.[43] Assume that exploration costs have been the dominant cost in the supply of fossil fuels to the market. In particular, assume that the marginal cost of extraction from known reserves is low.[44, 45]

Any future sale of fossil fuels given serious abatement efforts must then come from known reserves. The question is how much of these known reserves will in fact be extracted and used, in the process generating additional CO_2 emissions. I assume that if all of these known reserves were ultimately used, then global warming would exceed two degrees Celsius. Limiting global warming to two degrees Celsius then requires that some known reserves be left in place, unused.

[43] While some exploration does currently occur, this likely reflects uncertainty about the degree of future compliance with existing abatement commitments (as exemplified by the U.S. withdrawal from the treaty under both the Bush and Trump administrations), as well as more temporary pressures arising from the war in Ukraine.
[44] This assumption seems very reasonable for open-pit mining of coal, and not a bad assumption for fracking to exploit natural gas reserves. Even the marginal costs for extracting fossil fuels from known reserves in the Arctic seems low, once the pipelines and drilling rigs are already in place.
[45] With competition among fossil fuel companies each having explored in the past for new reserves, the resulting profits from sale of those reserves that are newly discovered should in expectation be just sufficient to cover the costs of the past exploratory efforts needed to discover successfully reserves of this size and marginal cost of extraction.

Given the stylized assumptions I've made, the global supply curve for fossil fuels can be summarized by the solid line in Figure 1. Here, marginal costs of extraction are low until the total supply hits the known reserves, when the supply curve becomes vertical, at least until the price becomes high enough to encourage new exploration.

The Figure also includes a dashed line describing a typical global demand curve for fossil fuels, yielding an initial market-clearing price of e_b. This demand curve should be very elastic, given that renewables are now closely comparable in cost to fossil fuels.

As seen in this Figure, as long as the market price faced by suppliers remains above $e_b - t^*$, the equilibrium still involves ultimate sale of all known reserves. Tax rates below t^* generate no abatement in emissions, and no loss to consumers: The net market price faced by demanders remains equal to e_b. The incidence of the tax falls entirely on producers. To achieve a reduction in demand for fossil fuels by some desired fraction α%, the market price faced by demanders would need to rise to e_α, and the market price faced by suppliers would need to fall to $c_\alpha = e_\alpha - t_g$.

Figure 2 then graphs the amount of known reserves that end up being used as a function of the chosen carbon tax rate. If the chosen rate is below t^*, then all known reserves end up being used. The cautious approach of starting with a conservative tax rate would then accomplish nothing. Usage drops quickly though for higher tax rates. But with any uncertainty about the location of the demand and supply curves in Figure 1, it will be very hard to come close to any given desired degree of abatement.

6. How to achieve benefit taxation

Given the potentially dire consequences of uncontrolled global warming, the perceived benefits of abatement efforts far exceed the perceived costs, with the marginal benefits equal to the marginal costs at a carbon tax rate equal to the SCC. The challenge is to design a policy intervention that leaves all countries as net beneficiaries as well.

The challenge is that any particular approach to abatement can leave some countries worse off, even if the global benefits far exceed the global costs.

Even countries that benefit on net still inevitably contain residents who are net losers. Unless countries finance abatement efforts heavily with debt, for example, future residents would clearly be net beneficiaries from abatement efforts while current residents could easily end up being net losers.[46] Among current residents, the net burden could be particularly high on some groups, even if many others are net beneficiaries. For example, the value of shares in firms owning fossil fuel reserves or owning production technologies that are heavily dependent on fossil fuels inevitably fall,

[46] See Kotlikoff et al (2021) for further discussion.

so that individuals who own these shares or who have been working for these firms likely lose on net from abatement efforts.

Reaching a political consensus supporting abatement efforts could easily require providing some form of compensation to large net losers, to avoid a political stalemate. Bovenberg and Goulder (2001) for example argue that distributing at least some pollution permits without charge to firms that would otherwise be net losers from abatement efforts could well be sufficient to compensate shareholders for losses they would otherwise experience from abatement efforts. Compensation to workers in these industries is less discussed, though may also be an important step in achieving a political consensus favoring serious abatement efforts.

The arguments made in the previous section suggest that countries with large fossil fuel industries could easily end up being net losers from abatement efforts, given that the incidence of a carbon tax would likely fall heavily on owners of known fossil fuel reserves.[47] When quantity targets are used instead, one approach for compensating countries that are net losers is to accept less demanding quantity targets for these countries.[48,49] Bargaining over the allocation of quantity targets is a serious challenge, as emphasized in Weitzman (2017b),[50] and has proven to be hard enough that the Paris Agreement simply let countries choose their own targets. This approach did ensure virtually universal participation in the Paris Agreement, though it did not ensure desired global abatement rates. Coming up with clear guidelines for relative target rates of abatement, taking into account to begin with the size of the existing fossil fuel industry in each country, could serve as a valuable focal point in any future discussion attempting to coordinate the choice of quantity targets for each country.

7. Summary

Global warming, perhaps even more than the threats of nuclear war or another global pandemic, is the dominant international policy issue currently being faced by humanity. Economists have long supported the use of a carbon tax (with a tax rate set equal to our best estimate of the social cost of carbon) as the best means of providing efficient

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[47] That Canada dropped out of the Kyoto Protocol and the U.S. dropped out of both the Kyoto and Paris Protocols can likely be explained by the large size and the resulting political influence of their respective fossil fuel industries.
[48] This reallocation of quantity targets need not affect the overall efficiency of abatement efforts: Countries whose target abatements have been tightened through these adjustments can then buy credits towards their promised abatement through undertaking supplementary abatements in countries whose targets were loosened, providing a form of compensation to equalize relative burdens from participating in these international abatement efforts.
[49] With uniform carbon tax rates across countries, monetary transfers paid to countries (such as the U.S. and Canada) with large fossil fuel industries could in principle be used instead to induce such countries with large fossil fuel industries to join the treaty and comply with the treaty tax rate. These explicit "pay-offs", though, particularly those made to high-income countries such as the U.S. and Canada, may be a hard political sell in other countries.
[50] Countries differ not only in the size of their fossil fuel industry, but also in their economic growth rates, in the size of their energy-intensive industrial base, and in their per capita income (a figure likely closely linked to the monetary benefits to the country from global abatement efforts), complicating any efforts to come up with some guideline defining quantity targets that leave all countries as net beneficiaries from abatement efforts.

incentives for abatement, and yielding a single number (the carbon tax rate) that needs to be agreed on in international negotiations.

In contrast, past international negotiations have instead proposed quantity targets, specifying some desired percent reduction in the rate of global emissions by a specified date.[51] Economists, though, continue to push for a shift from an agreement on separate quantity targets for each country to an agreement on a common carbon tax rate.

The aim of this paper has been to raise several possible concerns about use of a carbon tax to address the threat of global warming that seem to have been omitted from past discussions among economists, concerns though that may explain the observed policy preference for quantity targets. For one, international negotiators may fear the many "games" that countries can play in order to undercut the effects of a high agreed carbon tax rate, games that become infeasible with an agreed cap on emissions. Negotiators, focused on assuring that global warming remains below two degrees Celsius, may shy away from a carbon tax given the uncertainty about whether any chosen rate will limit global warming as intended. In the selection of quantity targets for each country, there is enough flexibility to design the policy agreement to ensure cooperation from a broad set of countries, a flexibility lacking when choosing one carbon tax rate.

Largely ignored in this paper, though, as in most of the past literature, is the elephant in the room:[52] Unless countries face a sufficient penalty if they do not follow through on whatever commitments they make on abatement policies, whether through implementing an agreed carbon tax rate or instead through cutting their country's emissions by a specified percent, they have a strong incentive to free ride. A country would clearly prefer to avoid the costs of abating its own emissions, while continuing to enjoy the benefits from the abatements undertaken in other countries. Reaching a cooperative agreement in such a prisoner-dilemma setting is exceedingly hard.

Efforts to abate CO_2 emissions clearly will yield large net benefits from a global perspective. But international negotiations on abatement policies will continue to yield few benefits unless such abatement policies can be designed so that it is in most all country's self-interest to commit to these agreed policies.

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[51] Under the Kyoto Protocol, each country was then given its own target abatement rate, with the aim of achieving some overall target abatement rate. In the Paris Agreement, each country independently chose its own target abatement rate.

[52] The one important exception is Nordhaus (2015), who proposed that treaty countries commit not only to a carbon tax rate but also to common tariffs imposed on imports from non-complying countries as a form of penalty that might prove to be sufficient to induce compliance.

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Figure 1
Market equilibrium for fossil fuels

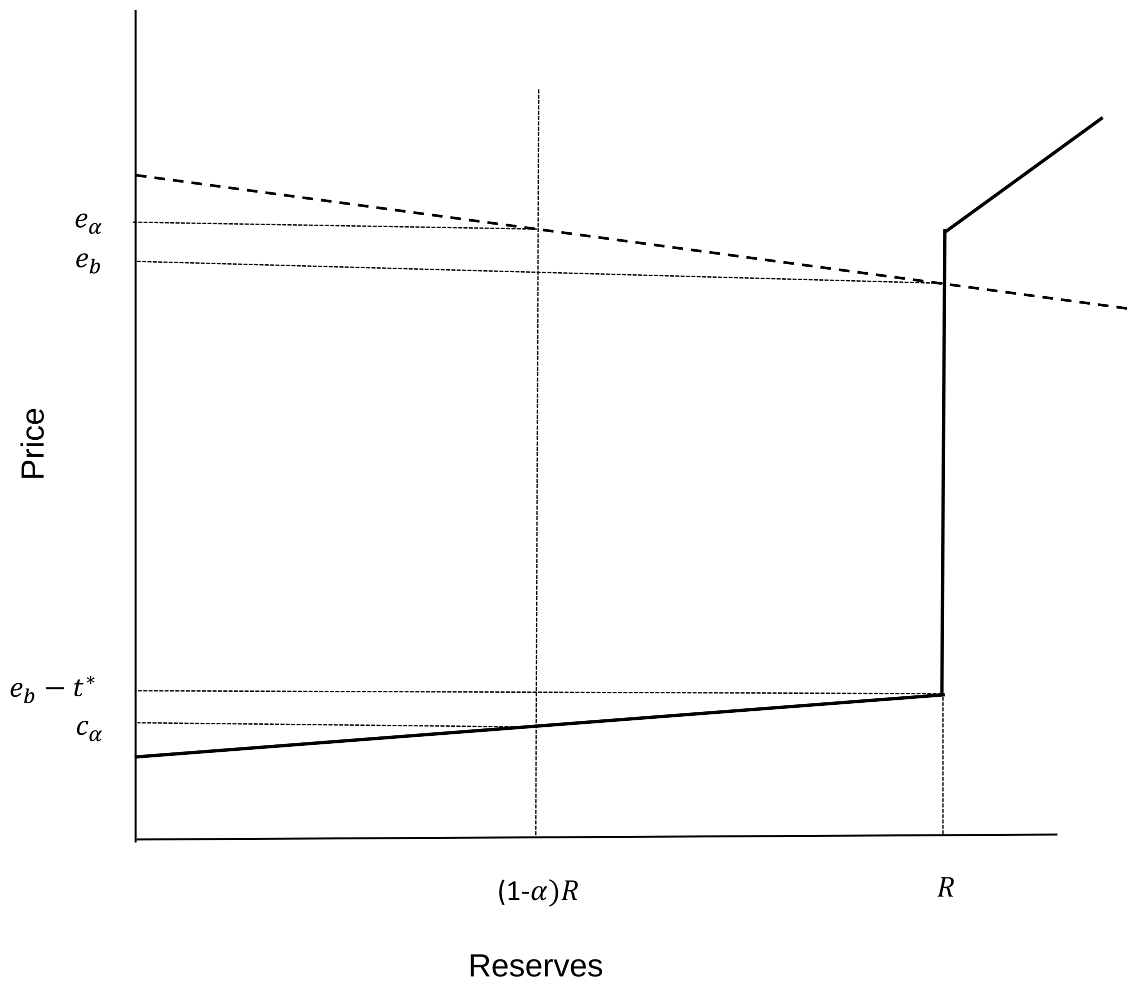

Figure 2
Tax rate and fossil fuel use