# POLICY INSTRUMENT CHOICE WITH COASEAN PROVISION OF PUBLIC GOODS

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## ABSTRACT

We examine the interplay between environmental policy instrument choice (i.e., prices vs. quantities) and private provision of public goods, which in this context we denote "Coasean provision." Coasean provision captures private provision of environmental public goods due to consumer preferences for environmentally friendly goods and services, incentives for corporate environmental management, environmental philanthropy, and even overlapping jurisdictions of policy. We show theoretically that even in a world of perfect certainty, the presence of Coasean provision distinctly affects instrument choice, based on both the efficiency criterion and distributional consequences. We also generalize the analysis to account for uncertainty using the classic Weitzman (1974) framework. Our findings suggest that the increasing prevalence of Coasean provision motivates a need to rethink the design of effective and efficient environmental policy instruments. This arises because policy instrument choice can have a significant impact on the environmental commitments of individuals, companies, and states, and vice-versa, with clear implications for overall economic welfare and policy preferences among polluters, citizens, and government revenue.

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# 1 Introduction

The study of externality problems and solutions provides the foundation for much of environmental economics and policy. The seminal work of A. C. Pigou (1932) developed the basic theory of externalities and proposed a solution by means of Pigouvian taxes. His contribution provides the first foray into what many now refer to as the centralized approaches to environmental policy.[1] An extensive literature has evolved to examine the advantages and disadvantages of various centralized policy instruments, including taxes and subsidies, direct standards, and systems of tradeable permits. There is, however, another stream of environmental economics that focuses on decentralized approaches to solving externality problems.[2] This literature has its foundation in the seminal contribution of Ronald Coase (1960). The basic idea is that if property rights are well-defined and there are no transaction costs, then parties can engage is decentralized bargaining to solve externality problems, thereby obviating the need for a centralized, top-down approach.[3]

This paper moves beyond the dichotomy between centralized and decentralized approaches to environmental policy to consider how the presence of incomplete Coasean bargaining affects the choice among centralized policy instruments. We assume two conditions as starting points for analysis. The first, which is quite standard, is that fully resolving some externality problems requires a centralized form of policy, and these are the environmental problems upon which we focus. Deryugina et al. (2020) provide a recent review of real-world applications of the Coase theorem to environmental problems and find examples that include polluters purchasing nearby lands, payments for ecosystem services, and land acquisitions to protect the supply of drinking water. Despite these selected examples, their conclusion echos that in most textbook treatments of Coasean solutions: bargaining is likely to efficiently resolve externality problems in a quite limited set of circumstances where the number of parties involved is exceedingly small, thus underscoring the need, at least in many applications, for centralized policies.

Our second starting point assumption is that implementing a centralized environmental policy alters the institutional setting in ways that can induce Coasean-type bargaining. When a policy is implemented in an otherwise unregulated setting, it establishes rights and responsibilities that can serve as *de facto* property rights, a mechanism for reducing

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[1] See Banzhaf (2020) for an interesting historical analysis of whether initial applications of Pigouvian taxes to pollution problems were driven by Pigou's original contribution or whether they emerged separately in other natural resource settings and were later attributed back.

[2] Some of this work is collectively referred to as free market environmentalism, and Anderson and Leal (2001) provide a general introduction.

[3] Mas-Colell et al. (1995) provide a textbook proof of the Coase theorem and show that additional assumptions are needed: no income effects, perfect information, rationality, and no endowment effects.

transaction costs, or both. We refer to the possibility for such policy-induced bargaining as Coasean provision. Whereas Coasean bargaining is often discussed in contexts where side-payments can support first-best, efficient outcomes, our notion of Coasean provision captures what are more generally suboptimal outcomes consistent with private provision of a public good (Cornes and Sandler 1985; Bergstrom, Blume, and Varian 1986). In other words, rather than assume away the conditions that give rise to free riding, we acknowledge that free riding occurs, yet consider the potential importance that Coasean provision of public goods may still have on policy instrument choice.

In practice, does such Coasean provision occur after policies are implemented? We argue that the possibility is more than a theoretical curiosity; it is increasingly at play, often at a large scale, across a range of environmental and natural resource concerns, including climate change, biodiversity conservation, pollution control, and fisheries management. For example, despite the fact that California has a cap and trade program on carbon dioxide emissions, we still observe California companies making unilateral commitments to privately reduce emissions. While land development is commonly regulated and taxed, we regularly see the private purchase of land for conservation purposes. And although fisheries are often regulated with catch limits, seafood supply chains are increasingly committing to procure only sustainably caught seafood. Underlying these examples, and many others, is Coasean provision of environmental public goods motivated by consumer preferences for environmentally friendly goods and services, incentives for corporate environmental management, and direct philanthropy—all of which occur under the backdrop of centralized policy.

Also consistent with our framework are environmental or natural resource policies that take place at different levels of governance or jurisdictions. There exists a literature on nested state and federal environmental regulations (Goulder and Stavins 2011; Goulder, Jacobsen, and van Benthem 2012; Levinson 2012), and our analysis illuminates ways in which policy interactions will depend on the policy instrument choice and level of stringency. For example, many states and cities in the United States have climate policies in place that are independent of, yet contribute to, emission targets at higher levels of government. And outside the United States, for example, the city of Copenhagen has made a public commitment to carbon neutrality, despite the fact that Denmark has a nation-wide carbon tax.[4] Moreover, there are circumstances where one country seeks environmental or natural resource protection in another country (e.g., developed countries seeking to prevent deforestation in developing countries) and our results show how the efficacy and efficiency of these efforts will depend

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[4] While a key question in the existing literature on policy interactions for climate change is "leakage," this is not the topic of concern here. Instead, our results are driven by the different incentives for private provision of pubic goods that policy instrument choice creates.

on characteristics of the environmental policies that a country has in place.

The fundamental question that we consider is how the presence of Coasean provision might affect policy instrument choice. We develop a theoretical model with an industry that benefits from pollution, citizens that experience the costs of pollution, and a government that may be concerned with raising revenue. A regulator chooses between policy instruments (an emissions tax or a cap-and-trade program) and determines the level policy stringency. Polluters respond by maximizing profits, but are also influenced financially by citizens, who may desire greater abatement than that targeted by the regulation. Any such privately provided abatement on the part of citizens amounts to Coasean provision, whereby citizens effectively pay polluters to emit less, participate in the cap-and-trade program by retiring permits, or both. Key questions are then: how does instrument choice affect Coasean provision, and conversely, how does the presence of Coasean provision affect instrument choice?

Few bells and whistles are required to generate novel and policy-relevant results. We consider both economic efficiency and distributional consequences and build on the canonical question of prices *vs.* quantities. While Weitzman (1974) focuses on the role of uncertainty in his seminal contribution, we start with a deterministic setup. Our first main finding is that the well-known symmetry between price and quantity instruments no longer applies in settings where Coasean provision is possible. An underlying reason is that taxes provide an implicit subsidy to Coasean provision at the expense of government revenue. Surprisingly, the same is not true of auctioned permits in a cap and trade program, even when the auction price and tax are equivalent. This implies, for example, that implementing the seemingly first-best price or quantity instrument (ignoring the potential for Coasean provision) is only efficient for the cap. Nevertheless, based on distributional consequences, both polluters and citizens prefer the tax even though it is less efficient. More generally, we show that the level of regulatory stringency affects the comparison between such myopically equivalent policies. While taxes are more efficient only when regulatory stringency is weak, both industry and citizens always prefer taxes, and government revenue is always lower with taxes than caps.

In the second part of the paper, we focus on comparisons between conditionally optimal policies, under both certainty and uncertainty. That is, we assume a regulator takes account of the possibility for Coasean provision and thereby seeks to compare policies where the level of stringency is chosen optimally for either the price or quantity instrument. In this case, with certainty, both instruments can implement the first-best level of pollution, and the level of overall efficiency is the same as that which would arise with a prohibition on Coasean provision. Moreover, while industry continues to prefer the tax, in which case government revenue is still lower, citizens now prefer the cap, which is set so that side payments to industry to reduce pollution do not take place. Accounting for uncertainty in this framework using the classic Weitzman (1974) approach produces further insights. In contrast to Weitzman (1974), which is a special case of our analysis, we find that uncertainty can affect the ex ante, optimally chosen level of a quantity instrument. The main effect of adding uncertainty to our model, however, is to show that, compared to the standard results, Coasean provision tends to favor prices over quantities, because Coasean provision plays a more prominent role in the former and helps to offset welfare losses from getting the policy "wrong" *ex post*.

Taken as a whole, our findings suggest that the increasing prevalence of Coasean provision in many settings calls for a rethinking of the standard framework for evaluating environmental policies. Policy instrument choice can have a significant impact on the environmental commitments of individuals, companies, and states, and vice-versa, with clear implications for economic welfare and policy preferences among polluters, citizens, and government revenue.

Although we are not aware of any other research that focuses on the same set of questions, there are a few related contributions upon which we build. The first is the so-called Buchanan-Stubblebine-Turvey Theorem, which considers how the simultaneous presence of a Pigouvian tax and Coasean bargaining will result in inefficiency (Buchanan and Stubblebine 1962; Turvey 1963). While the basic mechanism underlying that result is at play in our analysis, the framework here is more general because we do not assume the limiting case of only two agents. Baumol (1972) argued that the Buchanan-Stubblebine-Turvey setup is implausible in more realistic settings because Coasean bargaining becomes impossible with a large number of actors, where the transaction costs are simply too high. Instead, Baumol (1972) assumes no bargaining at all, which gives rise to the standard framework for comparing centralized policy instruments. Our analysis can thus be viewed as a haromonization of the "Coasean-bargaining-only" and "centralized-policy-only" approaches that is motivated by more contemporary, real-world observations about the presence of privately provided environmental public goods, even when existing policies are in place. Accordingly, our contribution falls in line with the recommendation of Banzhaf et al. (2013) for more research that seeks to bridge the useful insights of both Pigouvian and Coasean approaches to environmental management.[5] In doing so, we also provide a generalization of the canonical Weitzman (1974) framework for policy instrument choice under uncertainty.

In the next section, we describe the model setup, making explicit our definition of Coasean provision. Section 3 defines the policy instruments that we consider, along with the equi-

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[5] Another paper by MacKenzie and Ohndorf (2016) analyzes how the inefficiency brought about by the Buchanan-Stubblebine-Turvey Theorem can be offset by a reduction in the costs of establishing property rights, thereby providing a potential argument in favor of Pigouvian taxes. Their analysis does not, however, draw comparisons with other policy instruments, consider distributional concerns, or uncertainty.

librium conditions that emerge in the presence of Coasean provision. Section 4 considers instrument choice between myopically equivalent policies, where the aim is to illustrate how ignoring Coasean provision distorts standard conclusions about policy instrument choice. Section 5 focuses on a comparison of conditionally optimal instruments, showing both the efficiency and distributional consequences. Section 6 generalizes the analysis to account for uncertainty in the marginal benefits of pollution. Section 7 concludes with a summary and discussion.

# 2 Model Setup

We develop the simplest possible model that illustrates the key ideas. “Industry” has demand for pollution, which is a public bad and imposes costs on “citizens.” That is, industry benefits from pollution, and citizens benefit from abatement. The baseline model is static and deterministic, although we consider generalizations with uncertainty later in the paper. The aggregate level of pollution is denoted $Q$. Industry benefits according to a strictly increasing function $B(Q)$, and we assume the marginal benefits $MB(Q)$ are decreasing. The costly damages of pollution are given by a strictly increasing function $D(Q)$, and we assume the marginal damages $MD(Q)$ are increasing. The aggregate marginal damages are the sum of marginal damages across $j = 1, ..., N$ citizens such that we can write $MD(Q) = \sum_{j=1}^{N} MD_j(Q)$.[6]

We focus on the two classical policy instruments. One is a tax of rate $\tau$ applied to each unit of $Q$. The other is a cap $\Omega$ such that the quantity of pollution must satisfy $Q \leq \Omega$. When a cap is used, $\Omega$ permits are auctioned off at the highest bid price that clears the market. We assume, following standard approaches, that all revenue from either the tax or auctioned permits is retained by the government and used in socially beneficial ways. Standard analyses in environmental economics are based on the relation $\tau = MB(\Omega)$, which under certainty defines two equivalent instruments with respect to the implied level of $Q$, overall efficiency, and distributional consequences. One particular level of policy stringency, which is often the focal point of economic analysis, is that of the first-best, defined as the tax and quantity instruments that maximize efficiency by satisfying $\tau = MB(\Omega) = MD(\Omega)$.

The seminal contribution of Ronald Coase (1960) is often considered a reinterpretation of the preceding framework to analyze circumstances where neither of the policy instruments

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[6] Note that this adding up condition assumes that $Q$ is exogenously given and the not the result of private provision of abatement (i.e., less pollution) on the part of citizens, which is a topic that we discuss below and is central to the paper. The distinction here is that when $Q$ is exogenously given, citizens do not have to pay for its provision.

are needed to obtain the efficient, first-best outcome. The Coase Theorem holds that under certain conditions, negotiated bargaining will take place between the two sides (i.e., industry and citizens), and the optimal level of pollution will arise as a result of compensating side payments. An entire literature has emerged to add precision to the conditions that give rise to the Coase Theorem and its potential applications, but the most salient and policy relevant tend to be the establishment of clearly defined property rights and the need for zero transaction costs.[7]

While Coasean bargaining is often viewed as an alternative to other policy interventions (e.g., taxes and caps), our focus here is not on comparing centralized *vs.* decentralized approaches. Instead, we consider the efficiency and distributional implications of policy-induced, Coasean bargaining on the choice between centralized policy instruments. Our starting point is one where an environmental externality exists (creating an environmental public bad), which means that any preexisting Coasean bargaining (if it occurred at all) did not completely resolve the market inefficiency. In particular, the initial unregulated level of aggregate pollution satisfies $MB(Q_{max}) = 0$. Nevertheless, imposing a centralized, environmental policy alters the institutional setting such that policy-induced, Coasean bargaining might subsequently occur, for reasons that we now discuss related to both property rights and transaction costs.

While environmental policy instruments in the framework presented above are typically viewed as a way for governments to modify polluter incentives in more socially efficient ways, implementing a policy also plays another, perhaps overlooked, role. When a policy is implemented in an otherwise unregulated setting, it establishes the rights and responsibilities of industry and citizens, thereby acting as a *de facto* designator of property rights. That is, it delineates a property right to the polluting industry (e.g., each firm is allowed to pollute $X$ tons) and to the citizens (e.g., they are entitled to environmental quality of $Y$). Prior to implementation of such policies, it is often unclear whether industry has the right to pollute, citizens have the right to a clean environment, or some combination of both. In these cases, Coasean bargaining may be suppressed because of ambiguities about baseline conditions that establish who is supposed to compensate whom. Indeed, Coase (1960) himself addressed this possibility in his famous confectioner and doctor example. There, it was not until the court decided in favor of the doctor that property rights were clearly delineated and private bargaining could commence. Thus, at least in some cases, implementing an environmental policy may help set the stage for subsequent Coasean bargaining.

Implementing a centralized environmental policy can also reduce transaction costs, pro-

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[7] See Medema (2019) for a recent and comprehensive review of the literature related to the Coase Theorem in honor of its sixty year anniversary.

viding a second reason for policy-induced, Coasean bargaining. With emissions trading programs, for example, citizens have the ability to purchase and retire pollution rights from a centralized platform rather than needing to engage in costly negotiations with individual firms to reduce pollution.[8] Similarly, with individual transferable quotas for natural resource extraction (e.g., fishing or water rights), citizens sometimes have the ability to participate in these markets and promote conservation. In tandem with policies themselves, changes in technology and information provision can also promote Coasean bargaining after policy implementation. Whether or not explicitly intended for compliance purposes, changes in technology and data availability are dramatically reducing the cost of monitoring and verifying the stocks and flows of many environmental goods. For example, recent advances in satellite and sensor technology means that forests, fishing activity, air pollutants, and water are now monitored in real-time around the globe, enabling those seeking to privately provide greater environmental protection to do so in a more efficient and targeted manner.

We use the term "Coasean provision" to capture the idea of policy-induced, Coasean bargaining. Whereas Coasean bargaining is often discussed in contexts where negotiations can support first-best, efficient outcomes, our notion of Coasean provision captures what are more generally suboptimal outcomes consistent with private provision of public goods. From the citizens' perspective we are interested in the potentially market-revealed, marginal willingness to pay to avoid pollution. In the special case of a single citizen and no income effects, this is simply an alternative interpretation of the $MD(Q)$ function defined above.[9] More generally, because of free riding, the market demand for reducing pollution (i.e., abatement) will be based on the private marginal damages to individuals rather than the greater social marginal damages. We denote this function $PMD(Q)$, and it holds by definition that $PMD(Q) \leq MD(Q)$, with the difference including the free riding effect. We also assume that $PMD'(Q) > 0$. Later in the paper, we will employ a speicific case of Coasean provision in which $PMD(Q) = \beta MD(Q)$, where $0 \leq \beta \leq 1$.

As discussed in the introduction, many different factors can give rise to $PMD(Q)$, including preferences of wealthy individuals driven to environmental causes, corporate environmental management, or both. But to fix ideas it may be helpful to consider a fully micro-

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[8] Banzhaf (2010) makes this point as an explicit argument in favor of cap-and-trade programs. He argues in favor of such policies not only because of the reduction in transaction costs, but also because cap-and-trade programs help solve the additionality problem that may arise with Coasean provision. A recently formed organization, named Carbon Vault, is intended to capitalize on precisely this idea. Institutions and individuals seeking to reduce or offset emissions of carbon dioxide can purchase and retire cap-and-trade emission allowances from several different markets (see https://carbonvault.org/).

[9] It is necessary to assume no income effects in order for the marginal willingness to pay for abatement to be the same at all levels of $Q$ regardless of whether it is exogenously given or privately provided. Once could, of course, also think in terms of the marginal willingness to accept for pollution.

founded motivation. Assume citizens have quasilinear preferences of the form $U(x, Q) = x_j - f_i(Q_{max} - A)$, where $x_j$ is private consumption, and $A$ is the aggregate level of privately provided abatement among citizens. It follows that $A = \sum_{j=1}^{N} a_j$ and $Q = Q_{max} - A$. In this case, it is straightforward to verify that $MD(Q) = \sum_{j=1}^{N} f_j'(Q)$ and $PMD(Q) = \max\{f_1'(Q), ..., f_N'(Q)\}$.[10] The latter equation represents the potentially market-revealed, marginal willingness to pay to avoid pollution on the part of the citizens. It is the upper envelop of individual marginal damages, and it is equivalent to the market demand function for private provision of abatement, which is by definition a public good. That is, for any price of abatement $p$, the aggregate quantity demanded will satisfy $p = PMD(Q_{max} - A)$. An important feature of our setup, however, is that the demand becomes operational only after a centralized policy instrument is implemented.[11]

# 3 Instruments

We now consider how the potential for policy-induced, Coasean provision affects equilibrium outcomes with the classical policy instruments of either the pollution tax or cap. Our analysis in this section is positive (i.e., descriptive) and applies to any level of exogenously given policy stringency. In subsequent sections, we turn to normative and distributional concerns related to specific and endogenously chosen levels of stringency.

## 3.1 A Tax

Consider an exogenously set tax of $\tau$ on each unit of pollution. The standard result, without Coasean provision, is that pollution will continue up to the point where industry's marginal net benefits are zero, so the resulting level of pollution will satisfy $MB(\bar{Q}) - \tau = 0$, as shown in Figure 1. This, however, is no longer an equilibrium with $PMD(Q)$ defining the scope for Coasean provision. The logic is standard Coasean bargaining, but based on $PMD(Q)$ rather than the full social marginal damages. Once industry has responded to $\tau$ in the usual manner, reducing pollution to $\bar{Q}$, citizens have a private willingness to pay up to $PMD(\bar{Q})$ for the next unit of abatement, even after taking account of free riding. Then, because the private willingness to pay for more abatement exceeds the industry's willingness to accept all the way down to $\hat{Q}$, this is the level of pollution that becomes the equilibrium with Coasean

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[10] In the further special case of identical citizens, it would hold that $PMD(Q) = \beta MD(Q)$, where $\beta = 1/N$.

[11] As mentioned earlier, this does not mean that Coasean bargaining is not possible prior to policy implementation. It means that any pre-policy bargaining has already taken place and is accounted for in the aggregate marginal benefit and damage functions. Our focus here is on the implications of policy-induced, Coasean provision.

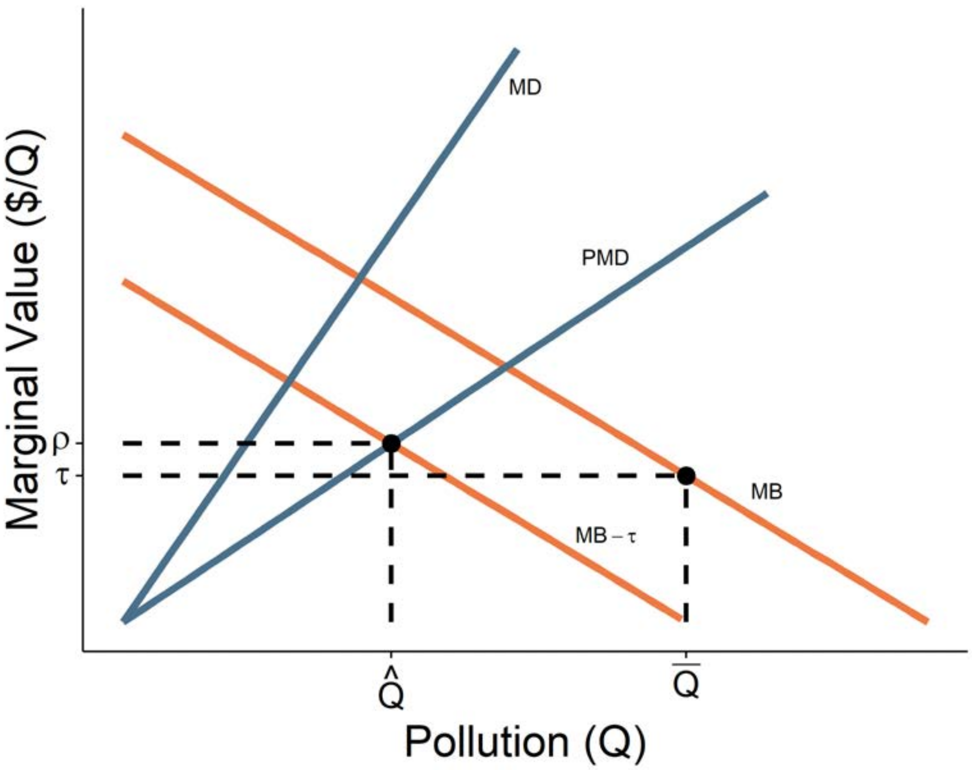

Figure 1: Marginal benefits and damages of pollution and equilibrium with Coasean provision and a tax of $\tau$.

provision. That is, under a tax of $\tau$, Coasean provision reduces pollution from $\bar{Q}$ all the way down to $\hat{Q}$.

Beyond gains from trade that underlie all Coasean solutions, what is the intuition for this somewhat surprising result that conflicts with standard approaches for teaching about pollution taxes? The answer is that imposing the tax provides an implicit subsidy by reducing industry's marginal benefit (i.e., demand) for pollution.[12] We illustrate this with the $MB(Q) - \tau$ curve in Figure 1. The effect is that any side payments that citizens are willing to pay to reduce pollution go even further because polluting firms can avoid paying the tax, in addition to collecting the side payments.

The special case of this setup with $N = 1$ is implicitly considered in Buchanan and Stubblebine (1962). While this case helps to illuminate the potential for Coasean bargaining to occur after implementing a tax, it overlooks a critical feature of the setup in a more general and realistic setting: abatement provides a public good, rather than reducing an

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[12] Consider a simple example. Suppose the price of gasoline is $3.20 per gallon and you drive exactly 227 miles in a week at that price. How much would you be willing to accept to drive one mile less? The answer is that you would accept any price above zero because it must be the case that the final mile earned you nothing in net benefit, else you would have driven more miles.

externality imposed on a single agent. This is important, for reasons we consider below, because with $N > 1$ the difference between private marginal willingness to pay and social marginal damages creates distinct welfare implications in the context of policy instrument choice.[13]

Finally, we turn to the side payments themselves. Does such private provision occur in practice in the context of a pollution tax? While our model is highly stylized, it is easy to find real-world examples capturing the same idea. Most municipalities have a landfill tax, yet major companies such as 3M, Coca-Cola, and Johnson & Johnson have recently announced commitments to a new recycling fund.[14] Moreover, as noted previously, the city of Copenhagen has made a public commitment to carbon neutrality despite Denmark having a national carbon tax, and similar arrangements are taking place in many other cities and countries.[15] In both cases, it is reasonable to assume that consumers (or citizens) have exerted market (in the first case) or political (in the second case) pressure to bring about these commitments. As with all Coasean bargaining, the magnitude of the side payments will depend on the outcome of a bargaining game. We nevertheless make the simplifying assumption here that side payments are based on a fixed price that clears all transactions. This implies a price of $\rho = MB(\hat{Q}) - \tau = PMD(\hat{Q})$, and the total transfer from citizens to industry would be $T = \rho(\bar{Q} - \hat{Q})$.[16]

## 3.2 A cap and trade

We now consider an exogenously given cap of $\Omega$ units of pollution that take the form of tradeable allowances. In the standard setup, without Coasean provision, the market clearing auction price would be equal to $MB(\Omega)$. Whether any subsequent Coasean provision would occur in this case hinges on whether citizens are willing to pay more than polluters are willing to accept. At the cap of $\Omega$, citizens' demand for abatement implies a marginal willingness to pay of $PMD(\Omega)$ for the first unit of additional abatement, and polluters are willing to accept $MB(\Omega)$. Thus, two cases emerge corresponding to whether the cap is sufficiently stringent or weak, where the threshold level of stringency that distinguishes the two cases satisfies $PMD(\tilde{Q}) = MB(\tilde{Q})$, as shown in Figure 2.

We begin with the case of a sufficiently stringent cap such that $\Omega^L \leq \tilde{Q}$. It is straight-

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[13] Moreover, even in the case of $N = 1$, the standard Coasean argument is support of efficiency will not hold if there are income effects. For example, if $Q$ is a strictly normal good, then $PMD(Q) < MD(Q)$ even for a single citizen.

[14] See https://www.closedlooppartners.com.

[15] See https://international.kk.dk/artikel/carbon-neutral-capital.

[16] While the figure illustrates a case where $\rho > \tau$, nothing rules the possibility for $\rho$ to be less than or equal to $\tau$.

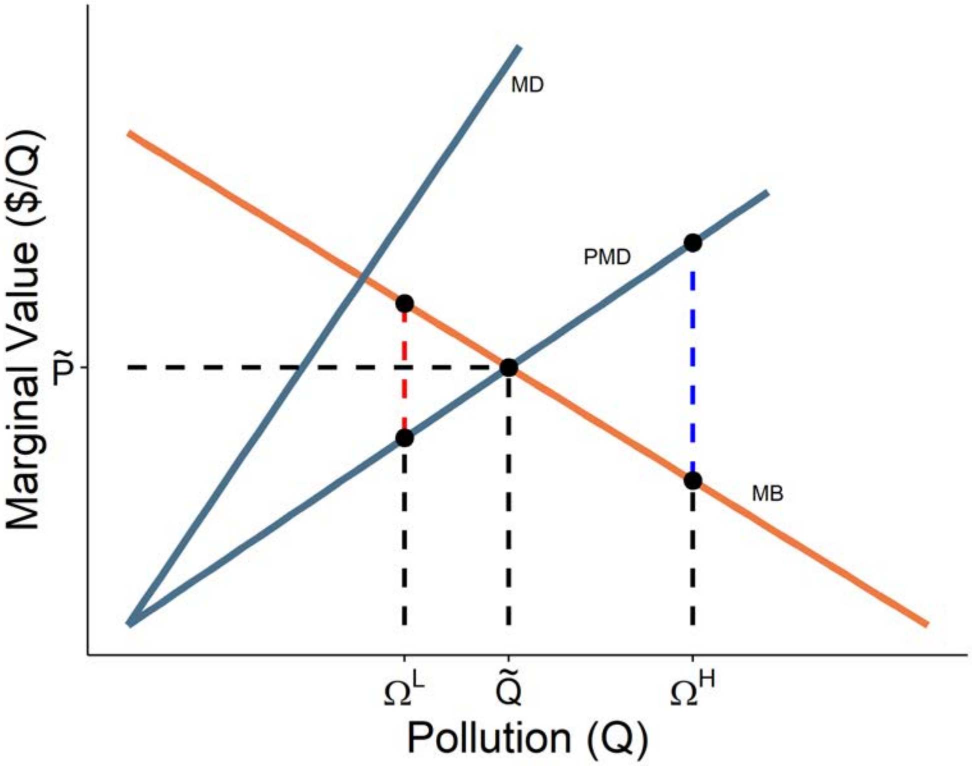

Figure 2: Marginal benefits and damages of pollution and equilibrium with Coasean provision and a cap and trade program defined by $\Omega$.

forward to see that Coasean provision will play no role in this case. The reason is that when polluters comply with the stringent cap, citizens are simply not willing to pay the permit price to achieve additional abatement. Their willingness to pay falls short by the red dashed line shown in Figure 2. It follows that the equilibrium level of pollution remains at $\Omega_L$, and the permit price is equal to $MB(\Omega^L)$, both of which are consistent with the standard textbook analysis of a cap-and-trade program.

The more interesting case is one with a sufficiently weak cap such that $\Omega^H > \tilde{Q}$. Coasean provision will play a role because, even after accounting for free riding, the citizens' demand for abatement indicates a marginal willingness to pay that exceeds $MB(\Omega_H)$. This is illustrated as the blue dashed line in Figure 2. In order to reveal this willingness to pay, we assume that citizens are able purchase permits, either directly from the initial allocation auction, or subsequently from firms themselves in a secondary market.[17]. This implies a combined industry and citizen inverse demand function for government issued permits that

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[17] Other papers have examined various aspects of citizen participation in cap-and-trade markets for air pollution, including questions about what it implies about efficiency of the cap (Israel 2007), the interaction with incentives for lobbying (Malueg and Yates 2006), and the potential for compounding inefficiencies due to market power (Eshel and Sexton 2009)

can be written as

$$p(\Omega) = \begin{cases} MB(\Omega) & \text{if } \Omega \leq \tilde{Q} \\ MB(\tilde{Q}) & \text{if } \Omega > \tilde{Q} \end{cases}.$$

With a sufficiently weak cap, it follows that the equilibrium permit price is $\tilde{P} = MB(\tilde{Q})$, and the equilibrium level of pollution is $\tilde{Q} < \Omega^H$, as depicted in Figure 2. An important observation for the moment is that equilibrium pollution is less than that targeted by the policy, as abatement of the amount $\Omega^H - \tilde{Q}$ occurs because of Coasean provision.[18]

# 4 Myopic Policies

We now turn to comparisons of instrument choice in the presence of potential Coasean provision. We begin with a comparison of tax and cap policies that satisfy $\tau^* = MB(\Omega^*) = MD(\Omega^*)$. We refer to these as myopically optimal (M-Optimal) policies because they represent the equivalent, first-best instruments that would be chosen if a regulator overlooked the possibility for Coasean provision; these are the textbook levels of stringency for environmental policy. We then generalize the comparative analysis to account for all myopically equivalent policies (i.e., not only the myopically first-best). In the next section, we define and evaluate conditionally optimal policies, where the regulator chooses the first-best tax or cap taking account of Coasean provision. In all cases, we consider overall efficiency based on standard welfare measures, and we analyze distributional consequences among industry, citizens, and government revenue.

## 4.1 M-Optimal Policies

It is straightforward to see that the welfare maximizing level of pollution will satisfy $MB(Q) = MD(Q)$ regardless of whether or not there is Coasean provision. Drawing on the results above, we know that in the presence of Coasean provision, the M-Optimal cap implements precisely this level of pollution, but the M-Optimal tax does not. This establishes the first result, which begins to show how the standard equivalence between price and quantity instruments breaks down in the presence of Coasean provision.

**Proposition 1** (Efficiency)**.** *When comparing M-Optimal policies, the cap $\Omega^*$ implements the first-best level of social welfare, but the tax $\tau^*$ does not.*

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[18] Note that we have implicitly assumed that with either a tax or cap, Coasean provision is a function of $PMD(Q)$, which itself does not depend on the instrument choice. This implies, for example, that any transaction costs associated with Coasean provision are the same with either the tax or cap. While this is the starting point assumption we make throughout, it is one that we discuss again later in the paper.

The basic intuition for this result is that with M-Optimal levels of policy stringency, Coasean provision does not occur with the cap, but it does with the tax because of the implicit subsidy it confers to bargaining. That is, Coasean provision under the M-Optimal tax leads to inefficiently low levels of pollution.

Turning now to the distributional consequences, we compare net benefits of the two instruments to industry and citizens, along with government revenue.[19] Standard results continue to apply for the cap. Industry net benefits are $B(\Omega^*) - MB(\Omega^*)\Omega^*$, where the second term is government revenue from the auctioned permits. The cost of pollution damages to citizens is simply $D(\Omega^*)$. With the tax, however, we know things differ. Industry net benefits are $B(\hat{Q}) - \tau^*\hat{Q} + T$, where the second term is government tax revenue, and the third is the transfer from citizens to industry (defined in Section 3.1). The cost to citizens in this case is equal to $D(\hat{Q}) + T$. Comparing these different magnitudes between policy instruments yields the following results:

**Proposition 2** (Distribution)**.** *When comparing M-Optimal policies, both industry and citizens prefer the tax $\tau^*$ to the cap $\Omega^*$, though government revenue is lower with the tax than the cap.*

*Proof.* With M-Optimal policies, $\tau^* = MB(\Omega^*)$, and it follows that $\hat{Q} \leq \Omega^*$, holding strictly for interior solutions. These two conditions imply immediately that government revenue is strictly lower with the tax, because $\tau^*\hat{Q} < MB(\Omega^*)\Omega^*$. Industry prefers the tax to the cap if and only if $B(\hat{Q}) - \tau^*\hat{Q} + T > B(\Omega^*) - MB(\Omega^*)\Omega^*$, which simplifies to $MB(\hat{Q})(\Omega^* - \hat{Q}) > B(\Omega^*) - B(\hat{Q})$, and this holds because $MB'(Q) < 0$. Finally, citizens prefer the tax to the cap if and only if $D(\hat{Q}) + T < D(\Omega^*)$, which is equivalent to $PMD(\hat{Q})(\Omega^* - \hat{Q}) < D(\Omega^*) - D(\hat{Q})$, and this holds because $PMD(Q) \leq MD(Q)$ for all $Q$ and $MD'(Q) > 0$. $\square$

A comparison between Propositions 1 and 2 illuminates a striking result: Although the tax is less efficient than the cap, it is always preferred by both industry and citizens. The reason is that imposing the tax, compared to the cap, effectively subsidizes mutually beneficial exchange between citizens and industry in the form of Coasean provision. The implicit subsidy arises because industry need not pay the pollution tax for units of abatement induced by citizen demand, and this explains why government revenue is lower with the tax than the cap. From a distributional standpoint, these results show that, in the presence of Coasean provision, the only argument in favor of the quantity instrument is greater government revenue. Indeed, the quantity instrument even has a greater level of pollution.

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[19] That is, we consider the different groups as a whole and not distributional consequences among agents within them.

## 4.2 M-Equivalent Policies

We now generalize our analysis to consider *any* level of policy stringency, where the comparison of instruments is based on taxes and caps that we refer to as myopically equivalent (M-Equivalent). That is, M-Equivalent policies must satisfy $\tau = MB(\Omega)$, where M-Optimal policies discussed in the previous subsection are a special case that accounts for marginal damages as well (i.e., the condition is also equal to $MD(\Omega)$). We find that the results differ in interesting and important ways at different levels of stringency.

We again organize our main results in two propositions that focus on efficiency and distribution. But first, because we have already established that at least some M-Equivalent policies do not implement the same level of equilibrium pollution, we need a definition of policy stringency to compare the tax and cap without relying on the same quantities of pollution. We have chosen to normalize stringency based on the level of the tax, such that stringency is defined as $S = \tau$, which implies that the correspondingly stringent M-Equivalent cap must satisfy $S = MB(\Omega)$.[20] This implies that $S$ denotes the level of the tax and the permit price that is consistent with an M-equivalent cap.

**Proposition 3** (Efficiency)**.** *When comparing M-Equivalent policies, there exists a particular level of stringency $\mathring{S}$ such that the two instruments produce the same level of welfare, which is less than efficient. Moreover, welfare with a tax is greater for all $S < \mathring{S}$, whereas welfare with a cap is greater for all $S > \mathring{S}$.*

*Proof.* The equilibrium condition for the tax defines an implict function $\hat{Q}(S)$ that is strictly decreasing. It follows that welfare with the tax, $W_\tau(S) = B(\hat{Q}(S)) - D(\hat{Q}(S))$, is a strictly concave function. To characterize the cap equilibrium, define a particular level of stringency $\tilde{S} = MB(\tilde{Q}) = PMD(\tilde{Q})$ so that we have the function

$$Q(S) = \begin{cases} \tilde{Q} & \text{if } S \leq \tilde{S} \\ Q : MB(Q) = S & \text{if } S > \tilde{S} \end{cases}.$$

This function, which defines the equilibrium level of pollution given a level of cap stringency, is weakly decreasing in $S$. Welfare with the cap, $W_c(S) = B(Q(S)) - D(Q(S))$, is therefore constant for $S \leq \tilde{S}$ and strictly concave for $S > \tilde{S}$. Welfare for the cap is maximized at $S^* = MB(Q) = MD(Q)$, which is first-best, and it is straightforward to verify that $W_c(S) > W_\tau(S)$ for all $S > S^*$, because the tax implements an even lower level of pollution

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[20] This choice of stringency measure is without loss of generality. One could alternatively define stringency based on the cap $\Omega$, derive the M-Equivalent tax, and prove all of the same results. One advantage of normalizing based on the tax is that a higher level of $S$ corresponds to greater stringency (i.e., less pollution).

that compounds what is already a (weakly) overly stringent policy. We also know that for all $S < S^{*}$, $W_{\tau}(S)$ is strictly concave and $W_{c}(S)$ is non-decreasing. Moreover, $W_{\tau}(0) = W_{c}(0)$ and $S = MB(Q_{max}) > S^{*}$. Together, these conditions imply that $W_{\tau}(S) = W_{c}(S)$ at one and only one level of stringency for $0 < S < Q_{max}$. This defines $\mathring{S}$, and it follows that $W_{\tau}(S) > (<) W_{c}(S)$ for all $S < (>) \mathring{S}$.[21] $\square$

Proposition 3 shows that the results of Proposition 2 do not hold for all M-Equivalent policies. While the cap is always more efficient (and first best) when comparing M-Optimal instruments, we find that the more efficient M-Equivalent instrument depends on the level of stringency. Underlying the result is the observation that a tax always induces a lower level of pollution than a M-Equivalent cap, and this explains why the tax is more efficient when the policy is sufficiently weak, whereas the cap is more efficient when the policy is sufficiently stringent.

While Proposition 3 provides guidance about which M-Equivalent policy will maximize welfare depending on the level of stringency, we now summarize the corresponding distributional consequences.

**Proposition 4** (Distribution)**.** *When comparing M-Equivalent policies for any level of stringency, both industry and citizens always prefer the tax to the cap, though government revenue is lower with the tax than the cap.*

*Proof.* This proof is a generalization of that for Proposition 2. With M-Equivalent policies $\tau = MB(\Omega) = S$, and it follows that $\hat{Q}(S) \leq Q(S) \leq \Omega$. Government revenue is lower with the tax, because in general $\tau\hat{Q}(S) < MB(Q(S))Q(S)$. Industry prefers the tax to the cap if and only if $B(\hat{Q}(S)) - \tau\hat{Q}(S) + T \geq B(Q(S)) - MB(Q(S))Q(S)$, which simplifies to $MB(Q(S))Q(S) - MB(\bar{Q}(S))\hat{Q}(S) \geq B(Q(S)) - B(\hat{Q}(S)$. To show that this inequality holds, we introduce another expression that is less than or equal to the left-hand side and greater than or equal to the right-hand side: $MB(Q(S))[Q(S) - \hat{Q}(S)]$. It is less than or equal to the left-hand side because we know that $\bar{Q}(S) \geq Q(S)$, and this implies that $MB(\bar{Q}(S)) \leq MB(Q(S))$. It is greater than or equal to the right-hand side because $MB'(Q) < 0$. Finally, citizens prefer the tax to the cap if and only if $D(\hat{Q}(S)) + T \leq D(Q(S)) + PMD(Q(S)[\bar{Q}(S) - Q(S)]$. Using the definition of $T$ and the fact that $\hat{Q}(S) \leq Q(S) \leq \bar{Q}(S)$, the condition in equivalent to $PMD(\hat{Q}(S))[Q(S) - \hat{Q}(S)] - K \leq D(Q(S)) - D(\hat{Q}(S))$, where $K = [PMD(Q(S) - PMD(\hat{Q}(S)][\bar{Q}(S) - Q(S)] \geq 0$, and the inequality holds because $PMD(Q) \leq MD(Q)$ for all $Q$ and $MD'(Q) > 0$. $\square$

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[21] Although discussed later in the paper, a graphical illustration of this proof is shown in Figure 3 for the special case of linear marginal benefits and damages of pollution.

Proposition 4 shows that the distributional results for M-Optimal policies (Proposition 2) generalize to all M-Equivalent policies. Thus, while the level of stringency affects whether the tax or cap is more efficient (Proposition 3), both industry and citizens always prefer the tax, which also produces a lower level of government revenue.

# 5 Conditionally Optimal Policies

The previous section considered exogenously set policies that aim to achieve the same level of pollution without recognizing the potential for Coasean provision. We referred to these as myopic polices. What happens if, instead, the regulator explicitly accounts for Coasean provision and chooses the policy stringency to maximize welfare? In this section we derive and compare conditionally optimal (C-Optimal) policies, where the level of stringency is chosen optimally for either the tax or cap. Additionally, we compare the efficiency and distributional results to the case where Coasean provision is not permitted to take place. This provides a useful benchmark for comparison and illuminates the trade-offs that regulators face over questions of whether to allow citizen participation in cap-and-trade programs, side payments to industry to reduce pollution with a tax, or both.

We know that regardless of instrument choice, the efficient level of pollution will satisfy $MB(Q^*) = MD(Q^*)$. We also established previously that the M-Optimal cap implements precisely this level of pollution as the equilibrium with $\Omega^* = Q^* = \Omega^+$, where we use the plus to denote C-Optimal policies. The M-Optimal tax at $\tau^* = MB(Q^*)$ is not first best, however, because the equilibrium condition is $MB(Q) - \tau = PMD(Q)$. This means that $\tau^*$ implements an inefficiently low level of pollution, that is, the tax is effectively too stringent. Nevertheless, lowering the tax to $\tau^+ = MD(Q^*) - PMD(Q^*)$ implements $Q^*$ as the equilibrium level of pollution and is therefore C-Optimal. Together, these results prove the following proposition.

**Proposition 5** (Efficiency)**.** *When comparing C-Optimal policies, both $\tau^+$ and $\Omega^+$ can implement the first-best level of social welfare, and it is the same level that arises through welfare maximization with a prohibition on Coasean provision.*

The intuition underlying Proposition 5 hinges on appropriately calibrating the C-Optimal tax. Rather than reflecting marginal damages at the optimal level of pollution, $\tau^+$ reflects marginal damages net of the citizens' private marginal willingness to pay for abatement. Anticipating the extent of Coasean provision, the regulator lowers the tax and lets citizens contribute to lowering pollution down to the optimal level. A further insight of Proposition 5 is that the level of maximized social welfare is not only invariant to the policy instrument,

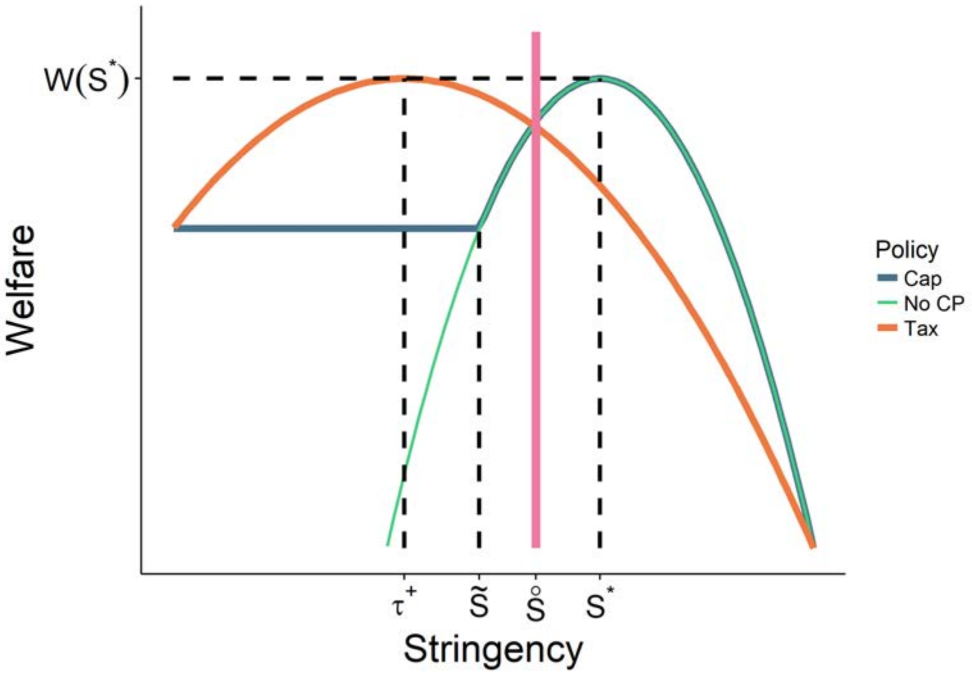

Figure 3: Welfare as a function of policy stringency for a tax and cap, and a policy scenario with no Coasean provision, in which case the tax and cap are equivalent. The figure is based on the simplifying assumption of linear benefit and damage functions, and the case where $PMD(Q) \leq MD(Q)$ holds strictly.

but also to whether Coasean provision is allowed to take place. In other words, if policies are implemented to maximize welfare, there is no overall welfare gain or loss that comes from permitting Coasean provision.

Figure 3 illustrates these results graphically, along with a summary of some previous results. Assuming linear benefit and damage functions, the figure plots welfare against policy stringency under three different regulatory scenarios: a tax or cap with Coasean provision, and no Coasean provision, in which case the tax and cap are equivalent. As a starting point, note that without Coasean provision, $S^*$ denotes the stringency of the equivalent tax and cap that maximizes welfare. This level of stringency is equal to the M-Optimal and C-Optimal cap with Coasean provision. A lower stringency of $\tau^+$ is required for the C-Optimal tax, which also implements the same level of maximized welfare.

Additional results about M-Equivalent policies that were proved earlier can be seen in the figure by recognizing that each point on the horizontal axis corresponds to a particular pair of M-Equivalent instruments. $\mathring{S}$ denotes the level of stringency identified in Proposition 3 where the M-Equivalent tax and cap implement the same level of welfare, and the tax is preferred on an efficiency basis at all lower levels of stringency, whereas the cap is preferred at all higher levels, including the M-Optimal levels at $S^*$. Moreover, note that welfare remains constant with the cap at all levels of stringency less than $\tilde{S}$, because with sufficiently low levels of stringency, citizens always engage in enough Coasean provision to bring pollution back to the point that satisfies $\tilde{S} = PMD(\tilde{Q}) = MB(\tilde{Q})$.

While the level of maximized welfare is invariant to the different policy scenarios, there are differences among them when it comes to the distributional consequences.

**Proposition 6** (Distribution)**.** *When comparing C-Optimal policies, industry prefers the tax $\tau^+$, consumers prefer the cap $\Omega^+$, and government revenue is lower with the tax than the cap. Moreover, the distributional consequences of cap $\Omega^+$ are the same as those that arises through a tax or cap set to maximize welfare with a prohibition on Coasean provision.*

*Proof.* With C-Optimal policies, the equilibrium level of pollution is the same and equal to $Q^*$ because $\tau^+ - PMD(\Omega^+) = MD(\Omega^+) = MB(Q^*)$. This implies that government revenue is lower with the tax because $\tau^+ Q^* \leq MB(Q^*)Q^*$. Industry prefers the tax to the cap if and only if $B(Q^*) - \tau^+ Q^* + T \geq B(Q^*) - MD(Q^*)Q^*$, and using the definition of $T$ and $\tau^+$, the inequality simplifies to $PMD(Q^*)\bar{Q} \geq 0$, which holds because $PMD(Q) \geq 0$ for all $Q$. Citizens prefer the cap to the tax if and only if $D(Q^*) \leq D(Q^*) + T$, which follows immediately because $T \geq 0$. Finally, because Coasean provision does not occur at $\Omega^+$, which implements the first-best level of pollution, its distributional consequences are the same as those for an equivalent tax or cap with a prohibition on Coasean provision. $\square$

Unlike the results in Propositions 2 and 4, we now see differences in the instrument preferences between industry and citizens. While the C-Optimal tax and cap both implement the same (and efficient) level of pollution, they differ in their implicit assignment of property rights. With the cap, industry must pay for all of its pollution. With the tax, citizens pay for what they are willing to provide, and the policy's level of stringency is set with this in mind. These differences explain why industry prefers the tax and citizens prefer the cap. Finally, government revenue is lower with the tax for two reasons: its rate is set lower in anticipation of Coasean provision, and a portion of the pollution reduction arises because of a transfer from citizens to industry rather than tax payments.

We again summarize results with a figure based on the assumption of linear marginal benefits and damages. Figure 4 illustrates the levels of pollution and distributional consequences for C-Optimal policies and all M-Equivalent policies. Characterized by their corresponding levels of stringency, the C-Optimal tax is $\tau^+$ and the C-Optimal cap is $S^* = MB(\Omega^+) > \tau^+$. They both implement the same level of pollution (panel A), and the preferences of industry and citizens can be seen by comparing the group-specific welfare between the policy scenarios (panels B and C). Also shown in Figure 4 is government revenue and comparisons to the

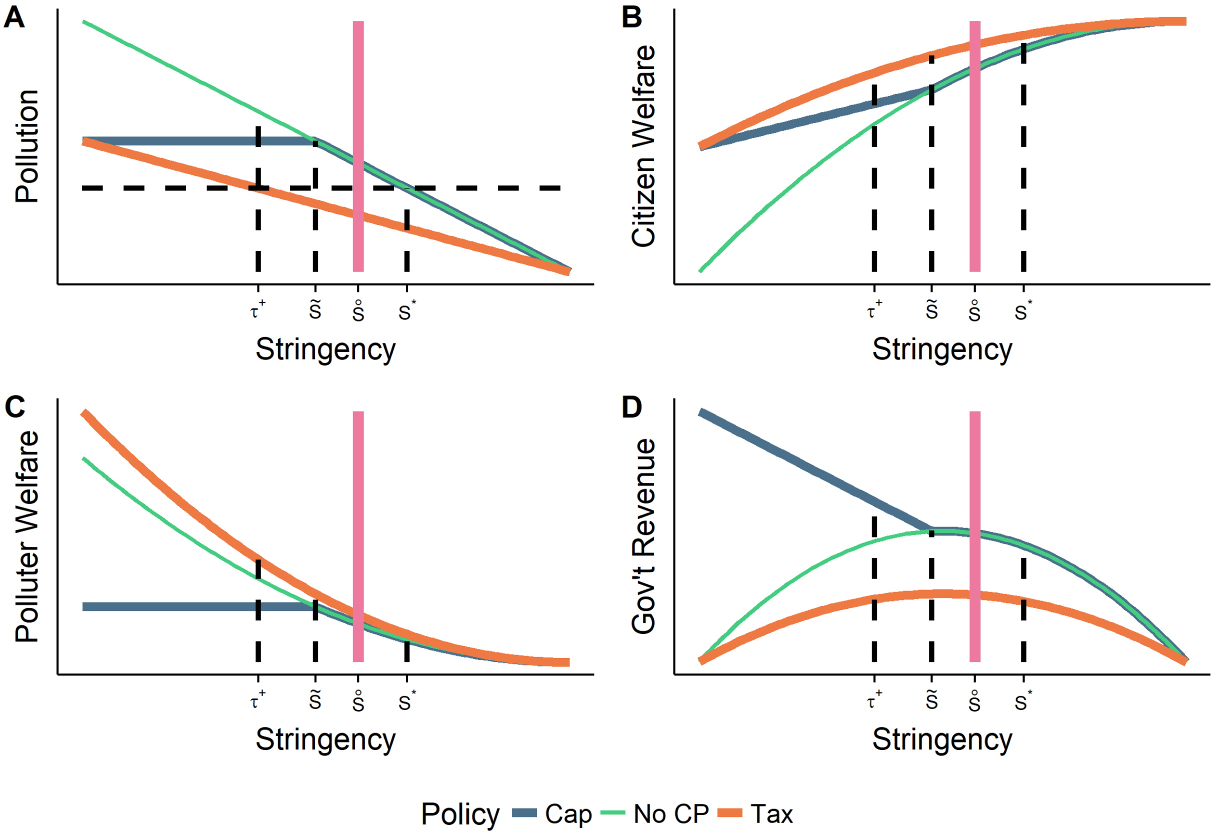

Figure 4: Pollution and distributional consequences of policy stringency for a tax and cap, and a policy scenario with no Coasean provision, in which case the tax and cap are equivalent. The figure is based on the simplifying assumption of linear benefit and damage functions, and the case where $PMD(Q) \leq MD(Q)$ holds strictly.

scenario where Coasean provision is not permitted. The figure makes clear how, with M-Equivalent policies, allowing Coasean provision usually makes industry and citizens (weakly) better off, as it allows for mutually beneficial exchange. The one exception is that for a sufficiently weak cap, where citizens keep both the permit price and the quantity purchased by industry constant. Moreover, with Coasean provision, the cap provides a mechanism for raising (weakly) more government revenue, whereas the tax raises strictly less. Finally, the different panels illustrate how the distributional consequences are the same for the C-Optimal cap and an optimally chosen tax or cap with a prohibition on Coasean provision.

## 6 Uncertainty

Our analysis of C-Optimal policies has thus far assumed the regulator has perfect knowledge about the benefits of pollution, the damages of pollution, and the scope for Coasean provision.

In this section, we show how incorporating uncertainty affects our conclusions about C-Optimal policies and the choice between them. Following Weitzman (1974), we assume that the source of the policymaker's uncertainty is the marginal benefits of pollution. Moreover, the policymaker seeks to maximize overall welfare with respect to choosing the stringency of C-Optimal policies and to choosing the more efficient of the two instruments.

Our approach adheres closely to the Weitzman (1974) setup, thereby showing our results as a generalization of those already familiar in the literature. Key simplifying assumptions are linear functional forms, where all parameters are positive. Expected marginal benefits of pollution are given by $MB(Q) = \alpha - \kappa Q$, and realized marginal benefits are $MB(Q) \pm \delta$, where $\delta$ captures the uncertainty. In the high state of the world, the marginal benefit is shifted up by $\delta$, which occurs with probability .5, and in the low state of the world, it is shifted down by $\delta$ with probability .5. The marginal damages of pollution are given by $MD(Q) = \gamma Q$. Allowing for Coasean provision, the demand for abatement is given by $PMD(Q) = \beta MD(Q)$, where $0 \leq \beta \leq 1$. The parameter $\beta$ therefore governs the scope for Coasean provision: $\beta = 0$ implies no scope, and $\beta = 1$ is consistent with one citizen and no income effects, which implicitly matches the standard Coasean assumption.

The central result of Weitzman (1974), using our notation, is that the welfare advantage of a tax compared to a cap is

$$\Delta^W = \delta^2 \left( \frac{\kappa - \gamma}{2\kappa^2} \right), \tag{1}$$

where the superscript $W$ stands for "Weitzman." The equation makes clear that taxes and caps deliver equivalent welfare in the absence of uncertainty (i.e., $\delta = 0$) or if the slopes of the marginal benefit and damage functions are the same (i.e., $\gamma = \kappa$). More generally, with uncertainty, taxes (or caps) are preferred if the marginal damage (benefit) function is flatter, that is, if $\kappa > (<)\gamma$.[22] Our aim in this section is to consider the ways in which this standard result changes in the presence of Coasean provision.

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[22] An implicit assumption of Weitzman (1974) is that the level of uncertainty is sufficiently small to insure that his welfare measures underlying equation (1) do not hit corner solutions. In particular, when solving for candidate, ex ante optimal policies, he implicitly assumes the deadweight loss triangles do not run into the vertical or horizontal axes. The condition can be written as

$$\delta \leq \alpha \min \left( \frac{\kappa}{2\gamma + \kappa}, \frac{\gamma}{2\kappa + \gamma} \right)$$

If $\kappa < (>)\gamma$, the condition implies that a tax (cap) optimized to the high state of the world weakly binds in the low state of the world. We will use this condition later in the paper as part of the proof to Proposition 8.

## 6.1 C-Optimal Policies With Uncertainty

Before comparing the instruments, we must first consider how introducing uncertainty affects the stringency of the C-Optimal tax and cap. In the standard Weitzman (1974) setup, with no Coasean provision, the levels of stringency for both the tax and cap that maximize expected welfare are invariant to the introduction and level of uncertainty.[23] In our setup, with Coasean provision, we show that this result continues to hold for the tax but not for the cap.

Two observations help to motivate our formal results. First, regarding taxes, we showed in the previous section that greater scope for Coasean provision results in a lowering of the the C-Optimal tax, because the planner anticipates Coasean provision and calibrates the tax to maintain the first-best level of pollution. Recall that the equilibrium condition is $\tau^+ = MD(Q^*) - PMD(Q^*)$. The same logic is preserved with uncertainty, and as we prove below, there is no effect of uncertainty on the C-Optimal tax. Second, we showed previously that the deterministic C-Optimal cap is unaffected by Coasean provision. We show below that this result continues to hold with uncertainty, provided that the scope for Coasean provision is modest (i.e., $\beta$ is sufficiently small). However, if $\beta$ is large enough, we find that Coasean provision will occur in the low state of the world but not the high, and this implies that the C-Optimal cap must be adjusted to account for uncertainty.

We begin by establishing the expected deadweight loss of any, arbitrary policy in the presence of Coasean provision.[24] Let $Q_i^*$ denote the welfare-maximizing level of pollution in state of the world $i \in \{L, H\}$, which is invariant to the policy instrument choice and whether or not Coasean provision takes place. These solutions are shown in the first row of Table 1. Now let $Q_{i\mathcal{P}}$ denote the equilibrium level of pollution in state of the world $i$ given the use of any, arbitrary tax or cap policy $\mathcal{P} \in \{\tau, \Omega\}$. These quantities and the equilibrium conditions that give rise to them are summarized in the other rows of Table 1. It follows that the difference between the first-best and equilibrium levels of pollution for either policy and state of the world can be written as $D_{i\mathcal{P}} \equiv |Q_i^* - Q_{i\mathcal{P}}|$. Then, conditional on policy $\mathcal{P}$, the deadweight loss in state $i$ is given by integrating between the marginal benefit and marginal damage curves, which is an area equal to $\frac{1}{2}D_{i\mathcal{P}}^2(\gamma + \kappa)$. Finally, recognizing that

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[23] Without Coasean provision, the policies that maximize expected welfare are a tax of $\tau^W = \frac{\alpha\gamma}{\gamma+\kappa}$ and a cap of $\Omega^W = \frac{\alpha}{\gamma+\kappa}$, and both implement the same level of pollution without uncertainty. These results implicitly rely on the assumption of no corner solutions as described in footnote 22.

[24] As will become clear, it is convenient to establish results based on minimizing deadweight loss rather than maximizing welfare. This is innocuous because deadweight loss of any policy in any state of the world (high or low) is just the loss in welfare under that policy relative to the first-best policy in that state of the world.

Table 1: Pollution levels under different policies in each states of the world.

| Variable | Low state ($i = L$) | High state ($i = H$) | Condition |
|---|---|---|---|
| $Q_i^*$ | $\frac{\alpha-\delta}{\gamma+\kappa}$ | $\frac{\alpha+\delta}{\gamma+\kappa}$ | $MB(Q) \pm \delta = MD(Q)$ |
| $Q_{i\tau}$ | $\frac{\alpha-\tau-\delta}{\beta\gamma+\kappa}$ | $\frac{\alpha-\tau+\delta}{\beta\gamma+\kappa}$ | $MB(Q) - \tau \pm \delta = PMD(Q)$ |
| $Q_{i\Omega}$ | $\min\left(\Omega, \frac{\alpha-\delta}{\beta\gamma+\kappa}\right)$ | $\min\left(\Omega, \frac{\alpha+\delta}{\beta\gamma+\kappa}\right)$ | $Q = \Omega$ or $MB(Q) \pm \delta = PMD(Q)$ |

state $i$ occurs with probability 0.5, expected deadweight loss under policy $\mathcal{P}$ is

$$E[DWL_{\mathcal{P}}] = \frac{\gamma + \kappa}{2}\left(D_{L\mathcal{P}}^2 + D_{H\mathcal{P}}^2\right), \tag{2}$$

which is a helpful expression for proving several of the subsequent results.

We require one more intermediate step. Lemma 1 below shows that the C-Optimal cap with uncertainty is always one of two possible solutions, depending on whether uncertainty is sufficiently large to trigger Coasean provision.

**Lemma 1.** *In the presence of uncertainty, the C-Optimal cap is either* $\Omega^+$ *or* $\Omega^{++} = \Omega^+ + \frac{\delta}{\gamma+\kappa}$*, where the latter is the efficient quantity of pollution conditional on the high state (i.e.,* $Q_H^*$*). If it is* $\Omega^+$*, there is no Coasean provision. If it is* $\Omega^{++}$*, there is Coasean provision in the low state only.*

*Proof.* We define a threshold cap set at $\Omega = \tilde{Q}_L \equiv \frac{\alpha-\delta}{\beta\gamma+\kappa}$, which solves $MB(\tilde{Q}_L) - \delta = \beta MD(\tilde{Q}_L)$ and is decreasing in the level of uncertainty. Any given pollution cap is either weakly smaller or larger than $\tilde{Q}_L$. First consider caps that are smaller, so $\Omega \leq \tilde{Q}_L$. Such caps would induce no Coasean provision in either the low or high states, so $Q_{H\Omega} = Q_{L\Omega} = \Omega$ and therefore $E[DWL_\Omega] = \frac{\gamma+\kappa}{2}\left(\left(\frac{\alpha-\delta}{\gamma+\kappa} - \Omega\right)^2 + \left(\frac{\alpha+\delta}{\gamma+\kappa} - \Omega\right)^2\right)$. Minimizing the expected deadweight loss thus requires setting the cap at $\Omega^+ = \frac{\alpha}{\gamma+\kappa}$, so any cap $\Omega \leq \tilde{Q}_L$ is welfare-dominated by $\Omega^+$. Now consider caps that are larger than the threshold, so $\Omega > \tilde{Q}_L$. Such caps would induce Coasean provision in the low state and therefore $Q_{L\Omega}$ is independent of $\Omega$. This implies further that $D_{L\Omega}$ is independent of $\Omega$ and minimizing Equation (2) is equivalent to minimizing $D_{H\Omega}^2$, which is solved by the cap $\Omega^{++} = \frac{\alpha+\delta}{\gamma+\kappa}$, so any cap $\Omega > \tilde{Q}_L$ is welfare-dominated by $\Omega^{++}$. Finally, at this solution, there is no Coasean provision in the high state because $Q_{H\Omega} = \Omega^{++}$. □

Invoking Lemma 1, our findings regarding the C-Optimal policies under uncertainty are summarized as follows:

**Proposition 7.** *In the presence of uncertainty, the optimal tax is equal to the C-Optimal tax without uncertainty,* $\tau^+$*. The optimal cap is equal to the C-Optimal cap without uncertainty,*

*$\Omega^+$, if $\beta \leq \beta_c(\delta)$, where $\beta_c(\delta)$ is a unique critical threshold that is decreasing in $\delta$. Otherwise, the optimal cap rises to $\Omega^{++}$.*

*Proof.* We begin with the tax. Using the definitions in Table 1, we can solve for $D_{L\tau} = A(\tau) - \delta B$ and $D_{H\tau} = A(\tau) + \delta B$, where $A(\tau) \equiv \frac{\alpha-\tau}{\beta\gamma+\kappa} - \frac{\alpha}{\gamma+\kappa}$ and $B \equiv \frac{1}{\beta\gamma+\kappa} - \frac{1}{\gamma+\kappa}$. Substiting these expressions into Equation (2) and rearranging yields $E[DWL_\tau] = A(\tau)^2 + (\delta B)^2$. Because $B$ is independent of $\tau$, minimizing the expected deadweight loss with respect to the tax is equivalent to minimizing $A(\tau)^2$, which yields $\tau^+ = \frac{\alpha\gamma(1-\beta)}{\gamma+\kappa} = MD(Q^*) - \beta MD(Q^*)$.

Turning to the cap, Lemma 1 establishes that the only two candidate solutions are $\Omega^+$ and $\Omega^{++}$, and it is sufficient for us the determine which has the lower deadweight loss. Substituting the candidate policies into Equation (2) yields

$$E[DWL_{\Omega^+}] = \frac{\delta^2}{2(\gamma+\kappa)} \tag{3}$$

$$E[DWL_{\Omega^{++}}] = \frac{(1-\beta)^2\gamma^2(\alpha-\delta)^2}{4(\beta\gamma+\kappa)^2(\gamma+\kappa)} \tag{4}$$

Setting these equations equal to each other and solving for $\beta$ yields a unique critical threshold:

$$\beta_c(\delta) = \frac{\alpha\gamma - \delta(\gamma + \kappa\sqrt{2})}{\gamma(\alpha + \delta(\sqrt{2}-1))}, \tag{5}$$

where we have made explicit the dependence of $\beta_c$ on uncertainty, $\delta$. We know the threshold is unique because the ratio $\frac{DWL_{\Omega+}}{DWL_{\Omega++}}$ is monotonically increasing in $\beta$ and thus crosses 1 only once. That $\beta_c(\delta)$ is decreasing in $\delta$ follows immediately from Equation (5). Because the ratio is less than (equal to, greater than) 1 for all $\beta < (=, >)\beta_c(\delta)$, it follows that when $\beta \leq \beta_c$ the C-Optimal cap is $\Omega^+$, and when $\beta \geq \beta_c$ the C-Optimal cap is $\Omega^{++}$. $\square$

Figure 5 illustrates different possibilities for the C-Optimal cap. $\Omega^+$ is the efficient level of pollution without uncertainty. $\Omega^{++}$ is the efficient level of pollution conditional on the high state of the world. The figure depicts values of $\beta$ and $\delta$ such that Coasean provision establishes a lower bound on pollution $\tilde{Q}_L > \Omega^+$ when the cap is set at $\Omega^{++}$.[25] The question, then, is: Which cap is preferred? The expected deadweight loss of choosing $\Omega^+$ is the standard Weitzman (1974) result and equal to area $(a+b)/2 = a$; shown in Figure 5 as the lower orange triangle. In contrast, the deadweight loss of choosing $\Omega^{++}$ is area $(a+c)/2$, because there is no deadweight loss in the high state. Hence the optimal cap is $\Omega^{++}$ if and only if area $a$ is greater than area $c$ (which is the case under the parameters shown in Figure

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[25] This is a necessary but not sufficient condition for $\Omega^{++}$ to be the C-Optimal cap.

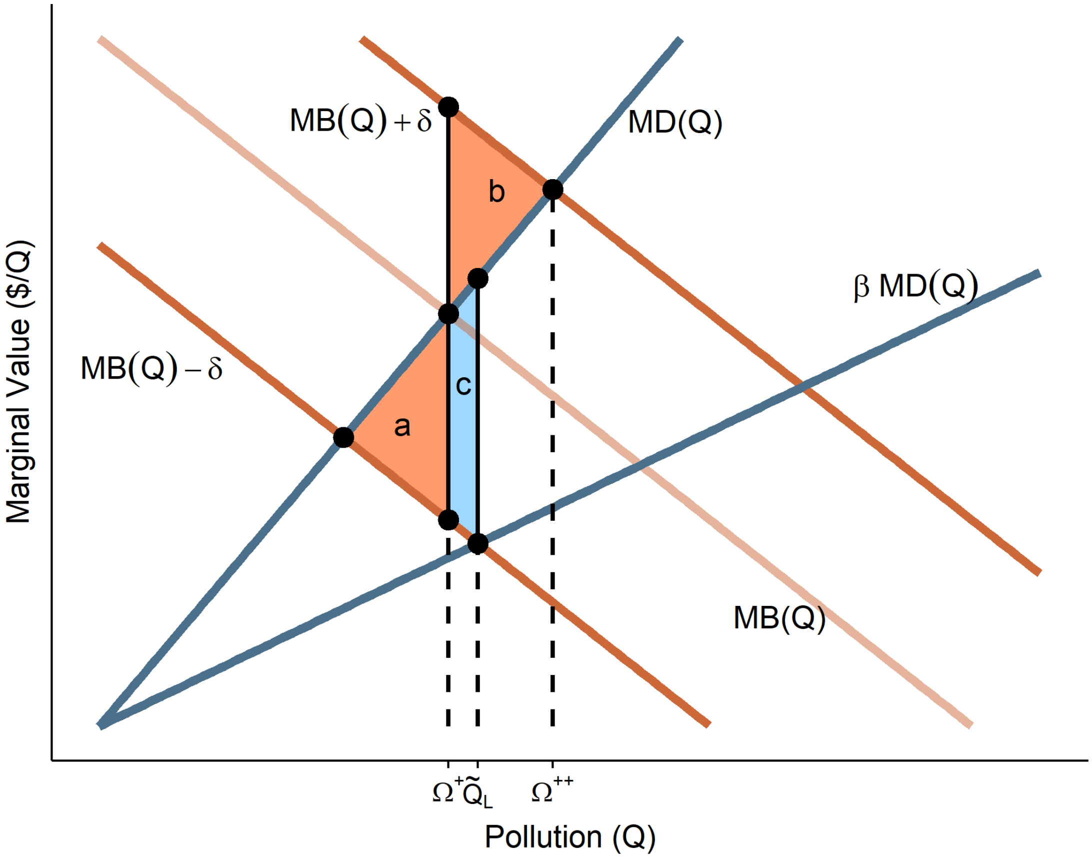

Figure 5: Graphical representation of caps $\Omega^{+}$ and $\Omega^{++}$ and their deadweight losses for an arbitrary value of $\beta$.

5), and this is more likely to occur with greater uncertainty ($\delta$) and greater scope for Coasean provision ($\beta$).

In sum, Proposition 7 reveals the effect of uncertainty on policy stringency. While it has no effect on the stringency of the tax, the same is true for the cap only if $\beta$ is sufficiently small. However, if the scope for Coasean provision is sufficiently large, then the optimal cap is slackened, knowing that Coasean provision will serve as a lower bound on the welfare loss in the low state of the world.[26]

## 6.2 Instrument Choice Under Uncertainty

Having established the C-Optimal policies under uncertainty in Proposition 7, we now consider the question of policy instrument choice: prices *vs.* quantities? Our approach continues

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[26] This result is in the same spirit as the optimal cap set by a regulator seeking to learn about $MB(Q)$ over time by overtly setting a slack cap and observing the resulting pollution level, see Costello and Karp (2004).

to rely on a comparison of expected deadweight losses, where the preferred instrument is the one with a lower expected loss.

Substituting the C-Optimal tax policy into equation (2) yields the expected deadweight loss under the C-Optimal tax:

$$E[DWL_{\tau^+}] = \frac{(1-\beta)^2\gamma^2\delta^2}{2(\beta\gamma+\kappa)^2(\gamma+\kappa)}. \tag{6}$$

With respect to the C-Optimal cap, we have already derived the expected deadweight losses for the two possible cases of $\Omega^+$ and $\Omega^{++}$ in equations (3) and (4), respectively. As shown in Proposition 7, these two cases also correspond with whether $\beta$ is less than or greater than $\beta_c(\delta)$. Subtracting equation (6) from equation (3) yields the welfare advantage of the tax over the cap when $\beta \leq \beta_c(\delta)$:

$$\Delta|_{\beta\leq\beta_c(\delta)} = \delta^2\left(\frac{2\beta\gamma+\kappa-\gamma}{2(\beta\gamma+\kappa)^2}\right) \tag{7}$$

Note that Weitzman's result in equation (1) is a special case of equation (7) when $\beta = 0$. Now, subtracting equation (6) from equation (4) yields the welfare advantage of the the tax over the cap when $\beta \geq \beta_c(\delta)$:

$$\Delta|_{\beta\geq\beta_c(\delta)} = \left(\frac{(1-\beta)^2\gamma^2}{4(\beta\gamma+\kappa)^2(\gamma+\kappa)}\right)\left((\alpha-\delta)^2-2\delta^2\right) \tag{8}$$

Using these deadweight loss expressions, our final proposition focuses on the question of instrument choice under uncertainty, given different levels of the scope for Coasean provision.

**Proposition 8.** *In the presence of uncertainty, expected welfare with the tax is greater than that for the the cap if and only if* $\beta > \beta^* \equiv \frac{\gamma-\kappa}{2\gamma}$.

*Proof.* It is sufficient to prove that for a given $\beta$, equations (7) and (8) are greater than zero if and only if $\beta > \beta^*$. Equation (7) evaluated at $\beta^*$ is equal to zero, and the expression is clearly positive or negative for all values of $\beta$ that are smaller or bigger, respectively. Turning to equation (8), note that the sign is the same as that of the second term in parentheses. It follows that equation (8) is positive if and only if $\delta < \frac{\alpha}{1+\sqrt{2}}$, which holds by the implicit assumption in Weitzman (1974) that we made explicit in footnote 22. In particular, it is straightforward to verify that $\alpha \min\left(\frac{\kappa}{2\gamma+\kappa}, \frac{\gamma}{2\kappa+\gamma}\right) < \frac{\alpha}{1+\sqrt{2}}$, and because the left-hand side is weakly greater than $\delta$, this completes the proof. □

The fundamental insight of Proposition 8 is that a greater $\beta$—i.e., scope for Coasean provision—tends to imply an advantage to taxes over caps. The reason is that greater $\beta$

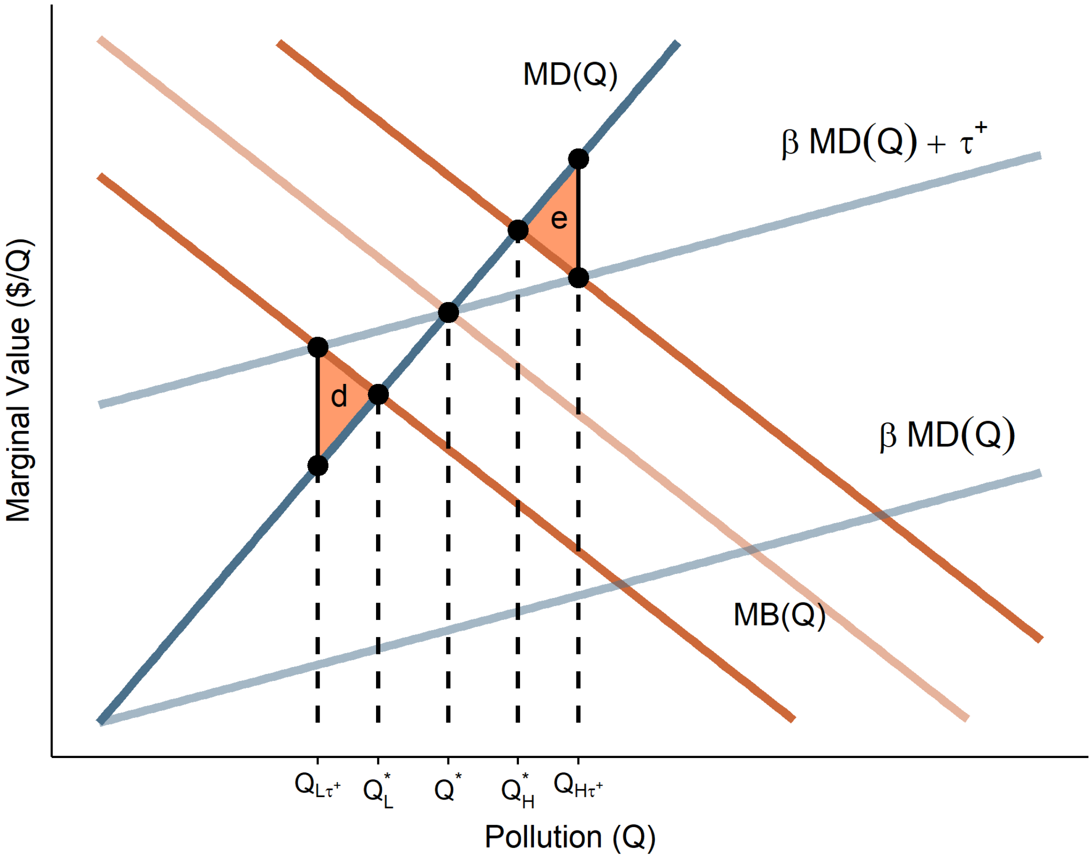

Figure 6: Expected deadweight loss with a tax, uncertainty, and Coasean provision is equal to $(d + e)/2$, which is decreasing in $\beta$.

lowers the tax-induced spread between equilibrium pollution levels in the low and high states of the world. Then, because these pollution levels are both closer to those that are ex-post optimal, expected welfare with the tax is greater for reasons that do not similarly affect the cap. Figure 6 illustrates the mechanism at work. While the efficient quantities of pollution in the low and high states ($Q^*_L$ and $Q^*_H$) are determined by $MB(Q) \pm \delta = MD(Q)$, the equilibrium quantities ($Q_{L\tau^+}$ and $Q_{H\tau^+}$) are determined by $MB(Q) \pm \delta = \beta MD(Q) + \tau^+$ (see Table 1). The deadweight loss in the low and high states are thus areas $d$ and $e$, respectively, with the expected deadweight loss equal to $(d + e)/2$. The figure makes clear how the expected deadweight loss with the tax is decreasing in $\beta$; for an increase in $\beta$ makes $\beta MD(Q) + \tau^+$ steeper while maintaining the same intersection with $MB(Q)$ at $Q^*$.[27] In the extreme case of $\beta = 1$, the deadweight loss is zero, and in the case of $\beta = 0$, we have the case considered in Weitzman (1974).

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[27] To see why the intersection is the same, recall that the tax is set such that $\tau^+ + \beta MD(Q^*) = MB(Q^*)$, so $d\tau^+/d\beta = -MD(Q^*)$ to maintain the result.

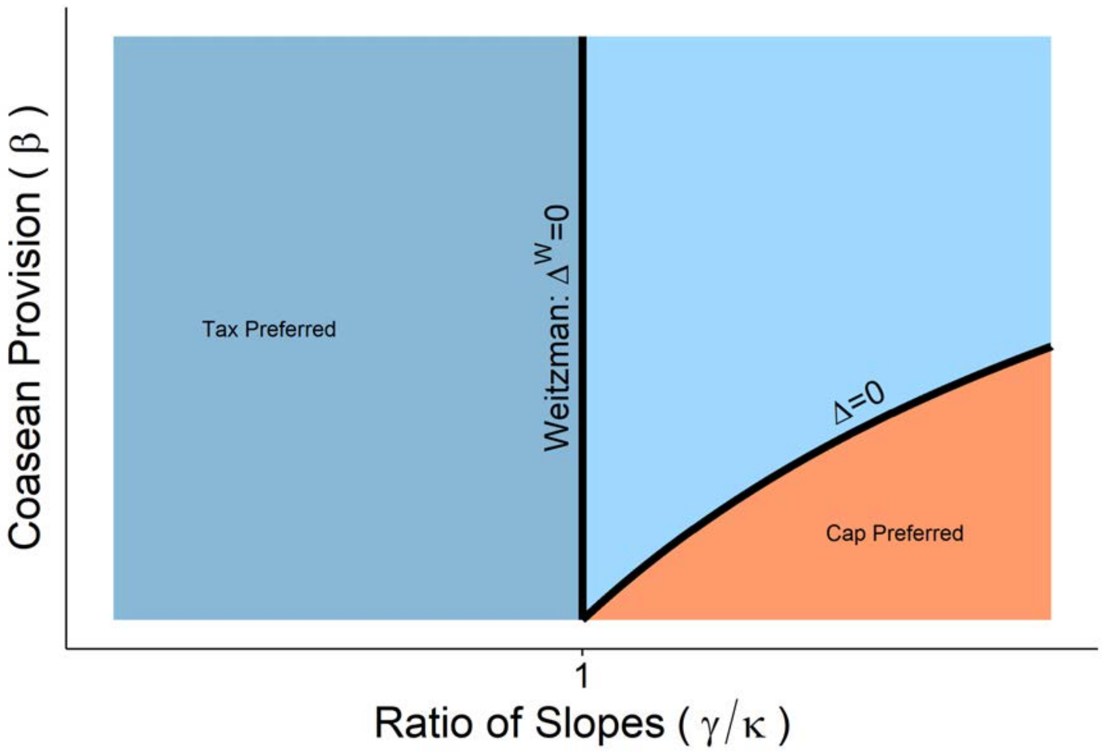

Figure 7: Parameter space over which the tax or cap delivers higher welfare. Blue areas indicate a preference for the tax; red area indicates a preference for the cap. Without Coasean provision the cap equals the tax when $\Delta^W = 0$.

Finally, it is useful to compare our results on instrument choice to the familiar baseline of Weitzman (1974). We can show that the presence of Coasean provision expands the parameter space over which taxes dominate caps under uncertainty. To see this, set equation (7) equal to zero and solve for the condition when taxes are strictly preferred to caps: $\frac{\kappa}{\gamma} > 1 - 2\beta$. Without Coasean provission (i.e., $\beta = 0$), we recover precisely Weitzman's result in equation (1). Moreover generally, if taxes are preferred in Weitzman's setup, they are always preferred with Coasean provision; however, certain caps that are preferred with Weitzman's setup are in fact dominated by taxes in the presence of Coasean provision. Figure 7 illustrates these results. The horizontal axis is the ratio $\frac{\gamma}{\kappa}$, and the vertical axis is $\beta$. Weitzman's result, applicable at $\beta = 0$, is that the taxes or caps are always preferred to the left or right of a ratio equal to one, respectively. With Coasean provision (i.e., $\beta > 0$), however, the dividing threshold is represented by the $\Delta = 0$ curve (satisfying $\frac{\kappa}{\gamma} = 1 - 2\beta$), which flips the region above from preferring caps to preferring taxes. Thus, Coasean provision expands the $\kappa$ and $\gamma$ parameter space over which taxes are preferred to caps, as indicated by the area in Figure 7 shaded in light blue.

In sum, the presence of uncertainty alters the deterministic findings of the previous sections about the relative efficiency of taxes *vs.* caps in the presence of Coasean provision. Without uncertainty, the C-Optimal tax and cap deliver the same, maximized level of welfare. With uncertainty, however, the expected welfare of the taxes *vs.* caps depends in part on the relative slopes of the marginal benefit and damage functions as shown in Weitzman (1974). What differs here is that the presence of, and greater scope for, Coasean provision tips the balance even further towards taxes.

# 7 Discussion and Conclusion

This analysis contributes to a new area of research that seeks to bridge useful insights from both Pigouvian and Coasean approaches to environmental and natural resource management (Banzhaf, Fitzgerald, and Schnier 2013). Rather than view the approaches as either/or substitutes, we consider settings where both simultaneously operate. Specifically, we examine how the existence of Coasean provision affects the canonical question of policy instrument choice: prices *vs.* quantities? While the analysis produces novel and policy-relevant results—calling for a rethinking of policy instrument choice in the presence of Coasean provision—it also raises questions that warrant further consideration. We briefly discuss three in particular before concluding the paper.

Is Coasean provision likely to be important in the real world? While our analysis is purely theoretical, it is motivated by the increasing prevalence of what can be reasonably deemed Coasean provision. Despite the existence of wide-ranging environmental and natural resource policies, the private provision of environmental public goods is on the rise. It occurs through direct philanthropy, corporate environmental management, and consumer preferences for environmentally friendly goods and services. We nevertheless recognize that for some environmental problems, the extent to which voluntary provision will have a significant impact can be limited. These might be considered relatively low-$\beta$ scenarios. But relatively high-$\beta$ scenarios consistent with our model certainly exist, as evidenced by the extent of provision observed above and beyond regulatory requirements. Examples include the large-scale impact of Walmart's sourcing of sustainably harvested seafood despite fisheries regulations, climate change policies at the state level that exceed federal requirements, and international efforts to promote conservation in other countries viewed as having insufficient protections.

What about alternative motives for Coasean provision? We have assumed throughout that Coasean provision is motivated by the benefit of providing a public good (i.e., abatement), where public and private provision are perfect substitutes. But the literature on privately provided public goods considers alternative motives that include signaling (Glazer and Konrad 1996), reputation (Harbaugh 1998), and warm-glow altruism (Andreoni 1989; Andreoni 1990). A key feature of these motives is that utility from provision comes from the act of giving rather than the incremental change to the level of the public good. While such motives may underlie Coasean provision in some circumstances, we leave it to future research to examine how different motivational assumptions may operate in this setting. One reason is that behavior motivated in this way is distinct from Coasean-type bargaining, because demand for reputation benefits and warm glow is effectively demand for a private good. We might, however, expect some of the differences between taxes and caps to be attenuated because the extent of Coasean provision would not depend on the direct effect of the policies on levels of pollution. This line of inquiry also adds a wrinkle to the analysis vis-à-vis welfare measures. In settings with both public and private provision, where the later is driven by warm glow, one must contend with an additional set of questions related to non-neutrality between the mechanisms of provision and whether warm-glow benefits should be included in welfare calculations (Chilton and Hutchinson 1999; van 't Veld 2020).

Asymmetries in transaction costs are also worthy of further inquiry. An implicit assumption throughout our analysis is that transaction costs associated with Coasean provision are invariant to the choice of policy instrument. But this assumption may be unrealistic in some settings. For example, cap-and-trade programs create centralized markets to facilitate transactions that may include citizens purchasing and retiring permits, in addition to trades among regulated firms. With taxes, however, how Coasean provision takes place may be less clear, perhaps relying on bilateral negotiations, and more susceptible to standard critiques about the limitations of Coasean bargaining. To the extent such differences do arise, extensions to the analysis are possible, where, for example, $\beta$ could differ depending on the policy instrument being employed. While this would alter the precise conditions that we derive, many of the qualitative findings about the potential importance of Coasean provision would remain. Moreover, given our distributional findings that industry benefits from taxes compared to caps, there is scope for industry to self organize in the case of the former to reduce transaction costs in ways that can facilitate Coasean provision and benefit the regulated industry as a group (Kotchen and Segerson 2019; Kotchen and Segerson 2020). Bundling goods and services with environmental contributions and the creation of "green" clubs provide possible examples (Kotchen 2013).

Finally, we conclude with a summary of the paper's main findings. At the most general level, we find that the presence of Coasean provision affects policy instrument choice. The effect is present whether the decision criterion is overall economic efficiency or the distributional consequences to different groups. In a world of certainty, if policies are set without regard to Coasean provision, then the standard equivalence between price and quantity instruments breaks down. It turns out that between the myopic, first-best instruments, caps are more efficient but, importantly, preferred by neither industry nor citizens. Caps do, however, raise more government revenue. More generally, between myopically equivalent policies, we find that caps are more efficient than taxes only when the level of policy stringency is sufficiently strong. When each of the policies is chosen optimally, they can both implement the first-best level of pollution, but the tax is lowered from the Pigouvian level in anticipation of Coasean provision. When introducing uncertainty, we generalize the classic Weitzman (1974) approach and find that Coasean provision tends to favor taxes over caps compared to the standard analysis.

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