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Self-regulation, taxation and public voluntary environmental agreements

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Abstract

An increasingly popular instrument for solving environmental problems is the 'public voluntary agreement (VA),' in which government offers technical assistance and positive publicity to firms that reach certain environmental goals. Prior papers treat such agreements as a superior, low-cost instrument that can be used to preempt a threat of traditional, inefficient, regulation. We present a more general model in which public VAs may instead be weak tools used when political opposition makes environmental taxes infeasible. We explore the conditions under which taxes, public VAs, and unilateral industry actions are to be expected, and the welfare implications of the various instruments. Notably, we also show that welfare may be reduced by the introduction of public VAs.

Keywords: Self-regulation; Public voluntary agreements; Preemption

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1. Introduction

For many years environmental regulators have relied upon various forms of taxes, subsidies and command and control regulations to remedy environmental problems. Recently, however, a new tool has been added to the regulator's tool

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box, namely voluntary environmental agreements. Most voluntary agreements fall into one of three categories: unilateral agreements, public voluntary agreements, and negotiated agreements. Unilateral agreements refer to self-regulatory actions in which firms (usually belonging to an industry trade association) initiate a public pledge to improve their environmental performance. Under public voluntary agreements, participating firms agree to make good faith efforts to meet program goals established by the regulatory agency; in return, they may receive technical assistance and/or favorable publicity from the government. In a negotiated voluntary agreement, the regulator and a firm or industry group jointly set environmental goals and the means of achieving them; such agreements consequently tend to be heterogeneous in nature.

Because voluntary agreements have arisen quite recently, and because they have been developed by practitioners rather than academics, their properties are less well understood than those of the standard regulatory tools. A small but growing academic literature, both theoretical and empirical, has developed in which various aspects of voluntary agreements have been studied. However, the existing literature often fails to distinguish clearly between the different forms of voluntary agreements described above. The present paper develops a model of corporate and government behavior in which unilateral agreements, taxation, and public voluntary agreements can be considered in one unified framework. In so doing, we sharpen the discussion of voluntary agreements by distinguishing carefully between unilateral agreements and public voluntary agreements.

The literature on unilateral corporate voluntary environmental actions suggests that the preemption of stricter future regulations is a leading motivation for such actions.[1] This motivation has also been used to explain corporate participation in voluntary environmental agreements between corporations and environmental regulators.[2] In the case of public voluntary or negotiated agreements, the desire to preempt has also been ascribed to the environmental regulator, who may wish to preempt future regulations if voluntary actions represent a cheaper way of achieving environmental goals. While preemption may indeed explain the adoption of some voluntary agreements, it is not uncommon to find public voluntary environmental agreements in the *absence* of strong regulatory threats. In fact the US EPA notes ''Governments promote voluntary initiatives for a variety of reasons, including the pilot testing of new approaches and *the absence of legislative authority to establish mandatory programs*.''[3] If voluntary environmental agreements are not designed to preempt legislation, what then is motivating

[1]See Maxwell et al. (2000) and Lutz et al. (2000) for models in which industries or firms undertake unilateral actions aimed at preempting or weakening future regulations.

[2]See Segerson and Miceli (1998) and Hansen (1999) for models in which firms and regulators enter into voluntary agreements so as to preempt legislation dictating traditional regulations. We discuss these papers and their relation to the present paper in more detail in footnote 11.

[3]EPA (2001, p. 173), emphasis added.

firm and regulatory adoption of these agreements, and what are the impacts of such agreements on social welfare? This paper attempts to answer these questions.

We begin by reviewing the political history of the US Climate Change Action Plan (CCAP), which has spawned numerous public voluntary agreements. We find that the CCAP and its progeny arose in the absence of any serious regulatory threats. These programs offer participants a variety of modest benefits, including information about projects undertaken by other firms, and performance and cost data on energy efficiency products sold by a variety of vendors. The chief benefit to regulators appears to have been the improvement in the environmental performance of at least a portion of the industry when statutory authority for mandatory environmental standards did not exist.

We incorporate these insights into a three-stage game which features both the possibility of unilateral corporate voluntary efforts aimed at legislative preemption, and the possibility of a voluntary environmental agreement when legislative efforts fail. The model features a continuum of firms—differentiated according to their abatement costs—which produce a homogeneous good sold at a fixed price, and a welfare-maximizing environmental regulator. Firms have the option of adopting an environmental technology that eliminates all environmental externalities. In the first stage of the game, firms choose a level (possibly zero) of voluntary adoption. In the second stage of the game, after observing the unilateral adoptions by the industry, the regulator chooses whether to propose new legislation that would impose a pollution tax.[4] If the proposal is made, it is put to Congress and passes with some probability less than one. If legislation is successful, the regulator imposes a constrained welfare-maximizing pollution tax. Firms that did not choose voluntary abatement in stage one may now decide to adopt the technology and avoid paying the tax, or they may choose not to abate and thereby incur the tax. If legislative efforts fail, the regulator has the option of proposing a voluntary agreement, which is implemented by subsidizing firms' technology adoptions through the use of costly public funds. The level of subsidies is set so as to maximize social welfare.

Our model generates both positive and normative implications. We identify conditions under which industries will undertake self-regulation, and we identify which firms are most likely to participate in public voluntary programs. We also examine in detail the relative merits of taxation and voluntary agreements from the regulator's perspective; in particular, we show that the regulator is better off imposing a tax rather than a VA unless political opposition to the tax is high. The chief normative findings are surprising: public VAs can reduce welfare by increasing industry resistance to socially beneficial tax proposals and by reducing industry incentives to engage in welfare-enhancing self-regulation.

The following section discusses in some detail the political backdrop of many

[4] In order to economize on the number of agents in the model, we treat the regulator as a part of the executive branch of government and empower it to make tax proposals to the legislature.

US public voluntary agreements, setting the stage for the overview of our modeling approach, which is presented in Section 3. Our analysis of the model is conducted in two separate sections of the paper. Section 4 studies the regulator's choice between proposing a tax and proposing a public voluntary agreement. Section 5 examines the industry's decision regarding self-regulation, and how that affects the regulator's policy decisions. Section 6 concludes.

2. Politics and public voluntary agreements

In this section we provide details of the political backdrop to many US public voluntary environmental agreements (VAs) and review a related case study of corporate behavior developed by the International Academy of the Environment (IAE). Both of these serve to illustrate the use of public voluntary agreements in the absence of regulatory threats.[5] For a broader institutional analysis of the use of public voluntary agreements, see Maxwell and Lyon (2001).

2.1. Background to US public voluntary agreements

In her survey of US voluntary environmental agreements, Mazurek (1999) identifies nine unilateral agreements, 31 public voluntary schemes, and two negotiated agreements. Of the public voluntary schemes, the majority arose from the Clinton Administration's Climate Change Action Plan, which we examine in detail below. We argue that these schemes share several important features: (1) they can be implemented at little or no cost to at least some subset of firms; (2) they arose in an area in which the regulatory authorities did not have a statutory mandate to require any actions; and (3) the heterogeneity of the offenders would have made command and control regulation complex and costly for regulators to administer.[6]

Most of the climate change VAs aim to increase investments in energy efficiency. Energy efficiency has been supported by the US government, through a variety of programs, since the 1970s. Most of these emphasize the private benefits to firms and individuals of adopting energy-efficient equipment, and attempt to solve the 'market failures' that limit the spread of these technologies. The climate change VAs were begun under the Bush Administration after President Bush promised to be the 'environmental president.' Most of them, however, were

[5] The interested reader is encouraged to consult IAE (1998) for case details.

[6] Our characterization of these programs has been shaped by interviews with a number of current and former EPA officials: James Barnes, former Assistant Administrator; Bill Rosenberg, former Assistant Administrator for Air during the Bush Administration; Linda Fisher, former director, Office of Pesticides and Toxic Substances and Office of Pollution Prevention; and Skip Laitner, director, Office of Atmospheric Programs. We thank all of these individuals for their gracious cooperation.

promulgated as part of the Clinton Administration's efforts to achieve reductions in greenhouse gases after the 'Earth Summit' in Rio de Janeiro in June 1992.

In most cases, there does not appear to have been a substantial regulatory 'threat' driving the adoption of VAs. In our conversations with current and former EPA officials, none mentioned such threats as important to the creation of VAs, while all pointed out that VAs were typically used by EPA when the agency had no statutory authority to take formal regulatory actions. Global warming provides a particularly interesting case in point. The Bush Administration opposed strong actions to combat global warming, and was publicly derided by US environmental groups and by most other nations of the world for its refusal at the 'Earth Summit' to agree to a timetable with specific targets for reducing emissions of greenhouse gases. Senator Al Gore was among the Administration's harshest critics, and proposed a carbon tax to combat global warming.

After President Clinton was elected in November of 1992, one of his early actions was to announce support for stronger measures to prevent climate change. In the early months of 1993, his administration floated a variety of proposals to tax energy, including a carbon tax and a broader-based 'BTU tax' based on the energy content of fuels as measured in British Thermal Units. The political response was fast and powerful:

> ''A cadre of lobbyists began to plot the death of President Clinton's energy tax in December 1992—a month before Clinton took office and two months before he submitted the tax plan to Congress . . . Jerry Jasinowski, president of NAM [National Association of Manufacturers] . . . helped organize a group of 1400 lobbies, dubbed the American Energy Alliance. The NAM, the US Chamber of Commerce, and the American Petroleum Institute footed most of the bill . . . Behind the scenes, groups lobbied successfully for exemptions . . . By June, what had been a fair, across-the-board tax was riddled with loopholes . . . Lacking any clear popular support for the BTU tax, and facing defeat in the Senate, the White House threw in the towel and withdrew its proposal.''[7]

When the Administration presented its Climate Change Action Plan (CCAP) later in the year, the focus was shifted away from mandatory regulations to subsidies (including $200 million per year to stimulate the adoption of more energy-efficient technologies) and voluntary programs. The environmental community was not impressed. Alden Meyer, director of the program on climate change and energy at the Union of Concerned Scientists, argued that the plan placed too much emphasis on voluntary measures, ''with no prospect of hammers or sticks to bring us into compliance if those don't work.''[8]

[7] The quote is from Winer (1993).
[8] The quote is from Stevens (1993).

Released in October 1993, the President's Climate Change Action Plan (CCAP) embodied the Clinton Administration's commitment to reduce US greenhouse gas emissions to 1990 levels by the year 2000.[9] The plan was based on the premise that government and private enterprise could work together to achieve program goals without harming the economy. The plan involved four major government departments: the Department of Energy, the Environmental Protection Agency, the Department of Agriculture and the Department of Transportation.

The CCAP spawned many public voluntary programs including Green Lights, Climate Wise, Motor Challenge and Energy Star Buildings among many others.[10] IAE (1998) examines US corporation Johnson and Johnson's decisions to participate in several of the CCAP's public voluntary agreements, including each of those mentioned above. The report clearly indicates that the chief factors motivating Johnson and Johnson were the programs' implicit subsidies to participants.

According to IAE (1998), participation in these programs provided Johnson and Johnson with several benefits. To begin with, participants were provided with case studies detailing the cost savings of program participants. Second, the program administrators commissioned outside consulting firms to provide technical information aimed at aiding the development of a program action plan. The programs also offered seminars at which firms could exchange information about cost savings. Other benefits cited included access to question hotlines, free software, and access to databases of equipment suppliers and financing programs.

This section has attempted to make two key points that are developed more fully in the model of the succeeding sections. First, public voluntary agreements are often proposed in the absence of strong legislative threats; indeed, regulatory authorities often use such agreements precisely because they lack statutory authority to undertake more stringent measures. Second, companies join public voluntary agreements in order to obtain the (admittedly modest) benefits offered to participants by the government. Such agreements can thus be viewed as subsidies from government to firms, aimed at inducing environmentally friendly actions by the participating firms.

3. Model overview

Drawing on the insights into public voluntary agreements presented in Section 2, we develop a three-stage game played by a regulator and the firms in an

[9] This goal, of course, was not actually achieved.

[10] For details on these and the other programs introduced under the CCAP, see US Office of Global Change (1997).

industry. In order to distinguish between unilateral and public voluntary agreements, we allow the firms in stage 1 to decide whether or not to unilaterally adopt an environmental technology based on the decision's impact on expected industry profits. In stage 2, the regulator decides whether to propose an environmental tax, and sets its level, τ. In stage 3, if the regulator chooses not to propose a tax, or if the proposed tax is not passed by the legislature, the regulator may propose a public voluntary agreement involving a subsidy s, paid for by raising costly public funds.We purposely do not assume that voluntary actions are cheaper than actions mandated by law, as doing so would make it too easy to reach simplistic conclusions about the superiority of voluntary measures. We also assume away the possibility of 'win–win' solutions in which the adoption of environmentally friendly technology lowers cost; economic analysis is not needed to conclude that these actions are desirable, nor are subsidies required to induce adoption.[11]

The basic setup of our model is based on Lewis (1996). The industry consists of a group of domestic firms that supply an export product that sells at a fixed world price.[12] Firms, which are indexed by θ, differ according to their profitability and their fixed costs of adopting an environmental technology, which is assumed to eliminate all environmental costs associated with production. We assume θ is distributed over $[\underline{\theta}, \overline{\theta}]$ with cumulative density $F(\theta)$. (The simplest interpretation of θ is as an efficiency parameter.) Following Lewis, we assume that the regulator knows the density $F(\theta)$, but does not know the efficiency of any given firm.[13] We denote by $\pi(\theta)$ the gross profits of a firm of type θ, and we assume that $\pi'(\theta) > 0$, where the prime indicates the first derivative. Further, we assume that $\pi(\underline{\theta}) = 0$.

[11]Our model is related to the existing literature on regulatory preemption. Segerson and Miceli (1998) present a model in which environmental legislation will be passed with exogenous probability p unless the regulator preempts the legislation by offering a VA; they do not consider the possibility of unilateral action by the industry, and they assume a VA is always socially preferable to legislation. Hansen (1999) presents a model in which the regulator may be biased toward promoting the interests of the industry, and hence may propose a weak VA that preempts tougher regulations that would have been more socially desirable. Maxwell et al. (2000) present a model in which unilateral industry action can preempt tougher regulations, and show that preemption improves social welfare even when the legislature is driven by political pressure rather than welfare maximization. In contrast to these earlier papers, here we allow for unilateral preemptive action by the industry *as well as* the offering of a VA by the regulator, we model explicitly the welfare-maximizing design of both environmental taxation and a VA, and we prove that the VA is a weaker alternative to environmental taxation unless industry political resistance to a tax is strong.

[12]By assuming a competitive global market we leave out consideration of 'green consumers.' While this is clearly an interesting issue, we eschew it in order to keep our model tractable and because green consumers are arguably fairly unimportant in many markets, especially those for intermediate products. As Lyon and Maxwell (2001) discuss, the empirical support for the notion that green consumerism drives corporate environmental efforts is mixed at best.

[13]This assumption rules out the possibility of firm-specific subsidies. Such subsidies are not common in public voluntary agreements (see, e.g., EPA, 2001, Section 10).

Similarly, $c(\theta)$ is the fixed adoption cost of the environmental technology for a firm of type θ, and we assume $c'(\theta) < 0$.[14]

We assume each operating firm emits pollutants that impose an external cost on domestic consumers of $x > 0$. The net social welfare generated by firm θ prior to the adoption of the environmental technology is $\pi(\theta) - x$. Absent adoption of the environmental technology, the optimal size of the industry is the mass of firms indexed by $\theta \geq \theta^x$, where $\pi(\theta^x) - x = 0$.

In an unregulated equilibrium entry will occur until gross profits are driven to zero. This will cause excessive entry from a social viewpoint and the welfare-maximizing regulator will wish to act to prevent or remedy this outcome. This may be done by the imposition of a tax τ set equal to the social cost of pollution. (The cost of proposing and implementing the tax is assumed to be a fixed amount K.[15]) Any firm with costs $c(\theta) < \tau$ will undertake the environmental investment and avoid paying the tax. As Lewis (1996) points out, however, firms have a strong incentive to oppose the tax even if it is set at the optimal level. Let $\Delta(\tau)$ be the aggregate costs imposed on the industry by a tax, and $P(\Delta)$ be the probability that a tax will pass the legislature if it would impose aggregate costs of Δ. We assume $P(\Delta)$ is declining in Δ at an increasing rate. Like Lewis, we focus on the aggregate losses imposed on the industry, and abstract from issues of coalition formation within the industry; we thus implicitly assume the industry is able to coordinate its political actions through the use of tools such as a trade association or side payments.

In the absence of a tax, the regulator may propose a public voluntary agreement to encourage the adoption of the environmental technology. We assume the cost K of implementing the voluntary agreement is the same as the cost of implementing the tax, so as not to have our results hinge on exogenous differences in the cost of the two programs. As we have illustrated in Section 2, many public voluntary

[14]The idea is that firms with a high value of the efficiency parameter θ have high profits due to lower costs, and that their higher efficiency will also translate into lower costs of adopting the new technology. This is consistent with the observation that firms undertaking voluntary actions are often the larger, more profitable members of an industry.

[15]The literature offers multiple explanations for such political transaction costs. For example, Glazer and McMillan (1992) present a model in which a legislator who wishes to introduce a bill must bear the costs of investigating the matter carefully, conferring with interest groups, and enrolling like-minded legislators to support the bill. An alternative approach is to focus not on the costs borne by the legislator, but on the costs borne by his constituents who support the bill. This is the approach taken in the Chicago tradition of political economy pioneered by Stigler (1971), Peltzman (1976), and Becker (1983), who identify both the organizing costs faced by interest groups that wish to mobilize for effective political action, and the influence costs incurred by these groups once they have become organized. Both approaches generate a fixed cost of introducing a proposal for government action. We assume the cost of introducing a tax proposal is equal to that of introducing a VA, so as to avoid obtaining results that simply depend upon arbitrary differences in these costs.

agreements contain features which serve to subsidize the cost of corporate environmental actions. Thus, we follow Carraro and Siniscalco (1996) in modeling the public voluntary agreement as a subsidy, *s*, set optimally by the regulator, which is payable to any firm that adopts the environmental technology. Note that a public VA is a specialized form of subsidy, which can only be collected by firms that stay in business and participate in the VA program. Lewis models an optimal subsidy that is also collected by firms that reduce their emissions by exiting the industry. VA programs, however, are not optimal subsidies, since only firms that join the program can benefit from it.

We assume the subsidies paid by the regulatory authorities involve costly public funds.[16] In addition, we assume firms that adopted the environmental technology before the public voluntary agreement was established cannot be excluded from receiving the benefits of participating in the voluntary agreement, an assumption that is consistent with government practice in the public voluntary programs described in Section 2.[17]

To highlight the distinction between public voluntary agreements and unilateral industry self-regulation, we include a first stage of the game in which some subset of firms may unilaterally adopt the environmental technology. In so doing, we extend the work of Maxwell et al. (2000) by incorporating heterogeneous firms and the possibility of a public voluntary agreement offered by the regulator. As discussed above, we follow Lewis (1996) in treating the industry as working in concert in its political efforts; we extend that assumption to the coordination of self-regulatory activity as well.[18] Under this assumption, firms with the lowest technology adoption costs will be selected to enter the unilateral voluntary agreement. Thus, we denote by θ^{v} the firm with the highest technology adoption costs that joins the industry's unilateral voluntary efforts. Then all firms indexed by $\theta > \theta^{v}$ will also adopt the technology. Alternatively, the industry can choose not to take unilateral actions by setting $\theta^{v} = \bar{\theta}$.

The following section of the paper explores stages 2 and 3 of the game by examining in detail the regulator's choice between proposing a tax and proposing a VA. Following standard backward-induction logic, analysis of stage 1 of the game—the industry's choice of a unilateral level of technology adoption—is deferred until Section 5.

[16] An alternative approach would be to assume that the regulator has a budget constraint that limits the total amount that can be spent on subsidies under a VA. This would generate a Lagrange multiplier that would play a role similar to that of the cost of public funds. Since we do not believe our results would be substantially different either way, we have adopted a cost of public funds for simplicity.

[17] For example, under provisions of the Energy Star Buildings program, firms owning buildings which meet or surpass the program's minimum standards receive public recognition as soon as the firm joins the program.

[18] Maxwell et al. (2000) study the extent to which coordinated levels of self-regulation can be sustained as non-cooperative Nash equilibria.

4. The regulator's choice between taxation and a VA

In this section, we focus on the regulator's expected welfare when it proposes an environmental tax and when it proposes a public voluntary agreement (VA). We work backward through the game, beginning with the stage 3 decision regarding whether to offer a VA, then turning to the stage 2 decision regarding taxation. Note that the regulator only faces these policy choices in the event that the industry's unilateral actions are not sufficient to preempt government action. Furthermore, as we show in Section 5, the industry will either choose a preemptive level of unilateral action or none at all. Hence, throughout this section we assume the industry engages in no unilateral voluntary action, i.e. $\theta^{v} = \bar{\theta}$. As a reference point, we note that if government takes no action, social welfare is given by

$$W(\emptyset) = \int_{\underline{\theta}}^{\bar{\theta}} [\pi(\theta) - x]\, \mathrm{d}F(\theta), \tag{1}$$

where $\emptyset$ indicates the absence of government action.

4.1. Stage 3: the public voluntary agreement

Should legislative efforts fail, the regulator may incur a fixed cost K and create a public voluntary agreement consisting of a positive subsidy s, payable to firms which adopt the environmental technology. Recall that we assume the fixed cost of creating a VA is equal to the cost of proposing an environmental tax, in order to ensure our results are not simply driven by arbitrary differences in these costs. Define θ^{s} such that $c(\theta^{s}) = s$; then all firms of type $\theta \geq \theta^{s}$ adopt the technology. The subsidy is chosen to maximize social welfare.

If the regulator had complete information about the costs of each firm, he could tailor a subsidy $s(\theta) = c(\theta)$ to each individual firm that would be just great enough to induce that particular firm to adopt the new technology. Let θ^{sw} denote the highest-cost firm that the regulator chooses to subsidize. With costly public funds, the regulator determines θ^{sw} by setting $(1+\lambda)c(\theta^{\mathrm{sw}}) = x$. Thus, $\theta^{\mathrm{sw}} = c^{-1}(x/(1+\lambda))$.

Since our focus is on the case of incomplete information, we assume the regulator cannot identify the cost of an individual firm, and must set a single subsidy level that applies to all firms. The regulator's problem is then to choose s to maximize $W^{\mathrm{S}}(s) - K$, where

$$W^{\mathrm{S}}(s) = \int_{\underline{\theta}}^{\theta^{s}} [\pi(\theta) - x]\, \mathrm{d}F(\theta) + \int_{\theta^{s}}^{\bar{\theta}} [\pi(\theta) - c(\theta) + s]\, \mathrm{d}F(\theta) - [1 - F(\theta^{s})]s(1+\lambda), \tag{2}$$

where $\lambda > 0$ indicates that the funds used to subsidize adoption are costly.[19] The first term on the right-hand side of (2) indicates the net contribution to social welfare from firms operating in the industry that do not adopt the clean technology. The second term on the right-hand side denotes the net contribution to social welfare arising from program participants, who incur the costs of adopting the environmental technology and collect the subsidy payment. The final term captures the total costs of funding all program participants.

Since $c(\theta^s) = s$ we have

$$\frac{\mathrm{d}\theta^s}{\mathrm{d}s} = \frac{1}{c'(\theta^s)} < 0. \tag{3}$$

The first-order condition of the optimization problem (2) is

$$-\frac{\mathrm{d}\theta^s}{\mathrm{d}s}[x - c(\theta^s)]f(\theta^s) - \lambda[1 - F(\theta^s)] + \lambda s f(\theta^s)\frac{\mathrm{d}\theta^s}{\mathrm{d}s} = 0. \tag{4}$$

Using (3), the solution to first-order condition (4) yields

$$s^* = \frac{x}{1+\lambda} + \frac{\lambda}{1+\lambda}\left(\frac{c'(\theta^{s*})[1 - F(\theta^{s*})]}{f(\theta^{s*})}\right). \tag{5}$$

We use this result to establish the following lemma.

Lemma 1. *When the regulator offers a VA under conditions of incomplete information, too few firms will adopt the environmental technology, relative to the full information benchmark. In other words,* $\theta^{s*} > \theta^{sw}$.

Proof. Since $c'(\theta) < 0$, the term in parentheses in (5) is negative, so $s^* \equiv c(\theta^{s*}) < x/(1+\lambda)$. Then $\theta^{s*} > c^{-1}(x/(1+\lambda)) \equiv \theta^{sw}$. □

Because the regulator has incomplete cost information, the public VA captures the 'low hanging fruit' but is not powerful enough to reach the social optimum. At the margin, the regulator faces a tradeoff between inducing additional participation in the program and paying out additional subsidies to inframarginal firms that would participate in the program anyway. These factors are illustrated in Fig. 1. The benefit of a VA with subsidy level s is represented by the lightly shaded region

[19] A reasonable estimate of λ for the US economy is 0.3 (Laffont and Tirole, 1993, p. 38).

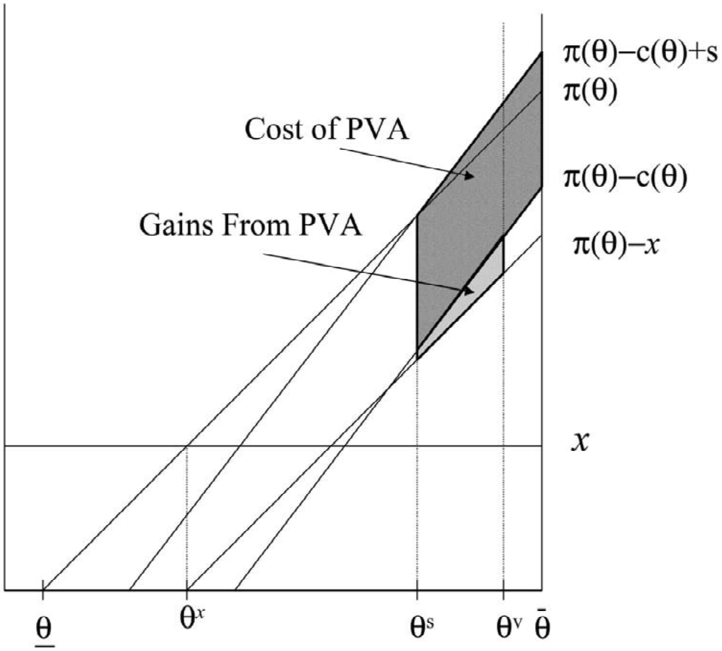

Fig. 1. Welfare gains and costs of a public VA.

between $\pi(\theta) - c(\theta)$ and $\pi(\theta) - x$, above θ^s. The cost of the program is shown by the darker shaded region, which represents the payment s made to all program participants, indexed by $\theta > \theta^s$.

As seen in Eq. (5), as s increases, additional participation is reflected in the term

$$f(\theta^s)\frac{\mathrm{d}\theta^s}{\mathrm{d}s} = f(\theta^s)/c'(\theta^s),$$

while additional payments increase in proportion to the share of participants already in the program, $[1 - F(\theta^s)]$. Combining these components, we see that as the cost of public funds rises, the optimal subsidy falls since $[c'(\theta^s)[1 - F(\theta^s)]/f(\theta^s)] < 0 < x$. Eventually the optimal subsidy will reach zero, thus eliminating the public voluntary program as a regulatory option. It is also evident that the subsidy will be smaller when the absolute value of $c'(\theta^s)$ is large, i.e., when adoption cost varies substantially across firms. In this case, an increase in the subsidy induces few additional firms to join the program, yet the rate at which program costs rise is unaffected; as a result, the subsidy program is less attractive. Overall, social welfare under a VA increases when the cost of public funds is low and the cost of technology adoption does not vary greatly across firms.

As the foregoing discussion indicates, in order for $s > 0$ to be optimal it is necessary that the absolute value of $c'(\theta^s)$ is small enough to ensure the right-hand side of (5) is positive; in other words, adoption cost must not vary too much across firms. We will assume this condition holds throughout the paper. In addition, if the regulator is to find it worthwhile to offer a VA, it is also necessary that the social benefits of the VA exceed the cost of creating the program. This requires that K be smaller than the net benefits of the adoptions induced by the VA. We will assume this condition holds throughout the remainder of this section, since otherwise a VA would never be offered. We will relax this latter assumption in Section 5, however, where we examine how changes in K affect the industry's incentives for self-regulation.

4.2. Stage 2: proposal of an environmental tax

In the second stage of the game, the regulator may propose an environmental tax which can be implemented at a cost K. As mentioned earlier, we assume this cost is equal to the cost of implementing a VA, so that arbitrary differences in these two costs do not drive any of our results. It is easy to see that any tax proposal will result in losses to the industry. As a result, industry will oppose even a first-best tax, and the optimal tax proposed by the regulator will be distorted away from its first-best level.

Industry losses from a tax occur in several different forms. Let θ^τ denote the firm that is just indifferent between paying the proposed tax and exiting the industry, i.e., $\pi(\theta^\tau) = \tau$, with

$$\frac{d\theta^\tau}{d\tau} = \frac{1}{\pi'(\theta^\tau)} > 0. \tag{6}$$

All firms indexed by $\theta \in [\underline{\theta}, \theta^\tau)$ will exit the industry and their profits will be lost. Denote by θ^a the firm that is just indifferent between paying the proposed tax and adopting the environmental technology, i.e., $c(\theta^a) = \tau$, with

$$\frac{d\theta^a}{d\tau} = \frac{1}{c'(\theta^a)} < 0. \tag{7}$$

All firms indexed by $\theta \in [\theta^\tau, \theta^a]$ will continue operations, but each firm will incur losses equal to the tax.[20] Firms indexed by $\theta \in [\theta^a, \bar{\theta}]$ will be induced to adopt the environmental technology at cost $c(\theta)$ rather than pay the tax. The sum of these enumerated losses constitutes the total direct costs borne by industry from the tax proposal. However, additional indirect losses are possible due to the loss of potential subsidies from a public voluntary agreement. Specifically, all firms indexed by $\theta \in [\theta^{s*}, \bar{\theta}]$ are eligible to receive the subsidy s^*, but will forego this

[20] Note that $\pi(\theta^a) - c(\theta^a) = \tau = \pi(\theta^\tau)$ so $\pi(\theta^a) > \pi(\theta^\tau)$. Since $\pi'(\theta) > 0$ it necessarily follows that $\theta^a > \theta^\tau$.

benefit if the tax is passed. These opportunity costs of a tax must also be taken into account. Thus, industry losses arising from the proposed tax may be written as

$$\Delta(\tau) = \int_{\underline{\theta}}^{\theta^{\tau}} \pi(\theta)\,\mathrm{d}F(\theta) + \int_{\theta^{\tau}}^{\theta^{a}} \tau\,\mathrm{d}F(\theta) + \int_{\theta^{a}}^{\theta^{s*}} c(\theta)\,\mathrm{d}F(\theta) + \int_{\theta^{s*}}^{\bar{\theta}} s\,\mathrm{d}F(\theta). \quad (8)$$

Differentiation of (8) readily confirms the intuition that industry losses are rising in the tax level.

Absent any political opposition, i.e. if $P(\Delta) = 1$, the regulator's objective is to maximize $W^{T}(\tau) - K$, where

$$W^{T}(\tau) = \int_{\theta^{\tau}}^{\theta^{a}} [\pi(\theta) - x + \gamma\tau]\,\mathrm{d}F(\theta) + \int_{\theta^{a}}^{\bar{\theta}} [\pi(\theta) - c(\theta)]\,\mathrm{d}F(\theta). \quad (9)$$

The first term on the right-hand side of (9) denotes the social value of firms remaining in the industry and paying the tax after its imposition. The term $\gamma\tau$ captures the benefit the regulator receives from environmental tax revenues. Note that the marginal benefit of tax revenues, γ, is not necessarily identical to the cost of public funds, λ,[21] and in practice may be quite small. The second term denotes the social value of firms that adopt the new technology. We assume that welfare is concave in τ.

The welfare gains from taxation, relative to government inaction, are shown in Fig. 2. The shaded region between $\underline{\theta}$ and $\theta^{\tau*}$ in the lower left part of the figure represents social gains from forcing inefficient firms to exit the industry. It is positive because profits are less than x on its range. The social gains from adoptions are represented by the shaded region in the right-hand side of the figure between θ^{a} and θ^{v}. Those gains represent the fact that the social cost of technology adoption, $c(\theta)$, is less than the social cost of pollution, x.

With full information, the regulator would be able to engage in perfect tax discrimination, charging each polluting firm a tailored tax $\tau(\theta)$ designed to extract the maximum profit possible, without inducing inefficient exit or technology adoption decisions. The lowest tax rate, τ^{L}, would apply to the least efficient firm that remains in the industry (rather than exiting to avoid the tax); let this firm be indexed by θ^{L}. Social welfare maximization requires that $\pi(\theta^{L}) - x + \gamma\tau^{L} = 0$, implying that $\tau^{L} = x/(1+\gamma)$. Now define θ^{M} such that $\pi(\theta^{M}) - c(\theta^{M}) = 0$. For all firms indexed by $\theta \in (\theta^{L}, \theta^{M})$, the regulator simply sets $\tau(\theta) = \pi(\theta)$, thereby extracting all 'excess' profits. For firms with $\theta > \theta^{M}$, however, it is cheaper to adopt the new technology than to hand over all profits to the regulator, so the tax is

[21] For example, Bovenberg and Goulder (1996) show that the benefits of an environmental tax are much lower if revenues are recycled through lump-sum rebates than if the revenues are used to reduce marginal income tax rates.

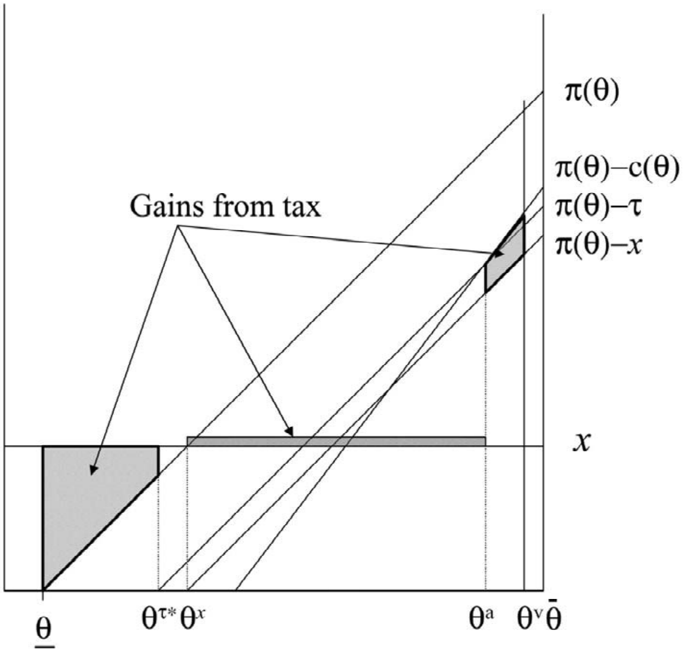

Fig. 2. Welfare gains from taxation.

constrained to be no greater than $c(\theta)$. Hence, the welfare-maximizing tax is $\tau(\theta)=c(\theta)$ for all firms with $\theta>\theta^{\mathrm{M}}$ that choose to pollute and pay the tax rather than adopting the new technology. Finally, the regulator must also target the least efficient firm that is to adopt the new technology rather than pollute and pay the tax; let this firm be indexed by θ^{H}. Social welfare maximization requires that $\pi(\theta^{\mathrm{H}})-x+\gamma\tau^{\mathrm{H}}=\pi(\theta^{\mathrm{H}})-c(\theta^{\mathrm{H}})$. This firm will make its decision based on whether it is cheaper to adopt the technology or pay the tax; hence, the identity of this firm is determined by $c(\theta^{\mathrm{H}})=\tau^{\mathrm{H}}$. It is then easy to see that $\tau^{\mathrm{H}}=x/(1+\gamma)$. Firms with $\theta>\theta^{\mathrm{H}}$ adopt the technology and do not pay the tax. Thus, while the tax rates for θ^{L} and θ^{H} are equal, for inframarginal firms the tax is raised above this level to extract as much profit as possible.

With incomplete information, of course, the regulator must set a single tax rate for all firms. In this case, the regulator simply maximizes $W^{\mathrm{T}}(\tau)-K$, the optimization of which yields

$$\frac{\partial W^{\mathrm{T}}(\tau)}{\partial\tau}=\frac{\partial\theta^{\mathrm{a}}}{\partial\tau}[\pi(\theta^{\mathrm{a}})-x+\gamma\tau]f(\theta^{\mathrm{a}})-\frac{\partial\theta^{\tau}}{\partial\tau}[\pi(\theta^{\tau})-x+\gamma\tau]f(\theta^{\tau}) +\int_{\theta^{\tau}}^{\theta^{\mathrm{a}}}\gamma\,\mathrm{d}F(\theta)-\frac{\partial\theta^{\mathrm{a}}}{\partial\tau}[\pi(\theta^{\mathrm{a}})-c(\theta^{\mathrm{a}})]f(\theta^{\mathrm{a}})=0.$$

Using (6) and (7) and the facts that $\pi(\theta^\tau) = \tau$ and $c(\theta^a) = \tau$ we obtain

$$\tau^N = \frac{x}{1+\gamma} - \frac{\gamma}{1+\gamma}\left[\frac{F(\theta^a) - F(\theta^\tau)}{[f(\theta^a)/c'(\theta^a)] - [f(\theta^\tau)/\pi'(\theta^\tau)]}\right]. \quad (10)$$

The first term in (10) is simply equal to $\tau^L = \tau^H$. The second term (which is positive) reflects the fact that the regulator has incentives to increase the tax to obtain greater tax revenues from the tax base of inframarginal firms, who are a fraction $F(\theta^a) - F(\theta^\tau)$ of the total set of firms. However, note the presence of the expression $f(\theta^a)/c'(\theta^a) - f(\theta^\tau)/\pi'(\theta^\tau)$ in the denominator of the second term. This expression reflects the net change in the size of the tax base as the tax rises. Its presence in the second term shows that the regulator trades off the benefits of taxing the base more heavily against the costs of decreasing the size of the base. On balance, however, the regulator raises the tax rate above the socially optimal marginal tax rate because incomplete information makes tax discrimination impossible. We can thus state the following lemma.

Lemma 2. *When the regulator possesses incomplete information, the socially optimal tax rate exceeds the optimal marginal tax rate under complete information. As a result, too many firms exit the industry, relative to the full information benchmark.*

Proof. Because $c'(\theta) < 0$ and $\pi'(\theta) > 0$, the term in brackets in (10) is negative. Hence, $\tau^N > x/(1+\gamma)$. □

In Lemmas 1 and 2, we have shown that even when political opposition is not an issue, both the VA and the tax are distorted away from the full information level due to the regulator's incomplete information about firms' profits and adoption costs. The following proposition extends the analysis by characterizing the relative performance of the two instruments in the case where there is no political resistance.

Proposition 3. *When regulators do not face political opposition from industry, i.e. when $P(\Delta) = 1$, the optimal pollution tax generates greater social benefits than does the optimal public voluntary agreement.*

Proof. We begin by comparing the optimal VA and the optimal tax when $\lambda = \gamma = 0$, in which case $s^* = \tau^* = x$. We then consider how the comparison changes when $\lambda > 0$ and $\gamma > 0$.

Define $\hat{\theta} = c^{-1}(x)$. Then when $\lambda = \gamma = 0$ and $s^* = \tau^* = x$, social welfare under the VA is

$$W^{S}(s^{*}=x)=\int_{\underline{\theta}}^{\hat{\theta}}[\pi(\theta)-x]\,dF(\theta)+\int_{\hat{\theta}}^{\bar{\theta}}[\pi(\theta)-c(\theta)]\,dF(\theta),$$

and social welfare under the tax is

$$W^{T}(\tau^{*}=x)=\int_{\theta^{\tau}}^{\hat{\theta}}[\pi(\theta)-x]\,dF(\theta)+\int_{\hat{\theta}}^{\bar{\theta}}[\pi(\theta)-c(\theta)]\,dF(\theta).$$

The only difference between these two expressions is that the tax induces exit by firms with $\theta\in[\underline{\theta},\theta^{\tau}]$. These exits are socially beneficial, since these firms had profits that were less than the social cost of their emissions. Hence, $W^{T}(\tau^{*}=x)>W^{S}(s^{*}=x)$.

Now consider what happens when $\lambda>0$ and $\gamma>0$. Let us abuse notation slightly by writing $W^{T}(\tau,\gamma)$ and $W^{S}(s,\lambda)$ to indicate explicitly the dependence of welfare on γ and λ under a tax and VA, respectively. In terms of this notation, the foregoing paragraph proved that $W^{T}(\tau^{*},0)>W^{S}(s^{*},0)$. Recalling that the regulator sets τ optimally for a given γ, and sets s optimally for a given λ, denote by τ_i^{*} the optimal tax when $\gamma=\gamma_i$, and denote by s_i^{*} the optimal subsidy when $\lambda=\lambda_i$. It is easy to see from Eq. (9) that $\partial W^{T}/\partial\gamma>0$. Then for $\gamma_1>\gamma_0$ it is immediate that $W^{T}(\tau_1^{*},\gamma_1)>W^{T}(\tau_0^{*},\gamma_1)>W^{T}(\tau_0^{*},\gamma_0)$. Hence, social welfare under an environmental tax is greater the larger is γ. In similar fashion, it is easy to see from (2) that $\partial W^{S}/\partial\lambda<0$. Then for $\lambda_1>\lambda_0$, it is immediate that $W^{S}(s_1,\lambda_1)<W^{S}(s_1^{*},\lambda_0)<W^{S}(s_0^{*},\lambda_0)$. Hence, social welfare under a VA is smaller the larger is λ. Pulling these observations together, we have shown that when the regulator does not face political resistance from industry, $W^{T}(\tau^{*},\gamma)>W^{S}(s^{*},\lambda)$ for all $\gamma>0$ and $\lambda>0$. □

Proposition 3 shows that the tax is inherently a more powerful instrument than the VA. As mentioned above, the fundamental limitation of the VA is that it cannot subsidize firms to exit the industry; firms must stay in business in order to collect any benefits from the VA program. Thus, a VA should not be confused with an optimal subsidy program.

In reality, of course, political opposition is important: firms will oppose a tax since from (8) industry losses $\Delta(\tau)$ are positive for any positive tax. This fact alters the regulator's objective function. Specifically, the regulator will optimize the expected benefits of the tax, given that legislation favoring the tax will only pass with probability $P(\Delta)<1$. Thus, in setting the tax the regulator solves the following optimization problem:

$$\max_{\tau}\ \bar{W}(\tau)=P(\Delta)W^{T}(\tau)+[1-P(\Delta)]W^{S}(s^{*}), \tag{11}$$

where s^* is the optimal subsidy to be imposed if the tax does not pass. Substituting (9) into (11) and optimizing we obtain

$$\frac{\partial \bar{W}(\tau)}{\partial \tau} = P(\Delta)\left\{[\tau(1+\gamma)-x]\left[\frac{f(\theta^{a})}{c'(\theta^{a})} - \frac{f(\theta^{\tau})}{\pi'(\theta^{\tau})}\right] + \gamma[F(\theta^{a}) - F(\theta^{\tau})]\right\} + P'(\Delta)\frac{\partial \Delta}{\partial \tau}[W^{T}(\tau) - W^{S}(s^*)] = 0.$$

Solving for τ yields

$$\tau^* = \frac{x}{1+\gamma} - \frac{\gamma}{1+\gamma}\frac{[F(\theta^{a}) - F(\theta^{\tau})]}{[f(\theta^{a})/c'(\theta^{a})] - [f(\theta^{\tau})/\pi'(\theta^{\tau})]} - \frac{1}{1+\gamma}\frac{[W^{T}(\tau^*) - W^{S}(s^*)]}{[f(\theta^{a})/c'(\theta^{a})] - [f(\theta^{\tau})/\pi'(\theta^{\tau})]}\left(\frac{P'(\Delta)}{P(\Delta)}\frac{\partial \Delta}{\partial \tau}\right). \tag{12}$$

Recalling that $\partial \Delta/\partial \tau > 0$, a comparison of this result to (10) shows that political resistance weakens the tax, relative to τ^{N}, since $W^{T}(\tau^*) > W^{S}(s^*)$. The reason is simple: since the tax is socially beneficial, the regulator lowers the proposed tax so as to increase its chances of passage. As a result, $\tau^* < \tau^{N}$.

The extent of the distortion away from τ^{N} depends on two new factors that appear in the third term of (12): the elasticity of political resistance with respect to taxation, and the net benefit of taxation compared to the VA. The tax elasticity of political resistance is the percentage change in resistance divided by the percentage change in tax, i.e.

$$\eta \equiv \frac{-P'(\Delta)}{P(\Delta)}\frac{\partial \Delta}{\partial \tau}\tau > 0.$$

Using this definition, we see that the final term in (12) can be rewritten as $(-\eta/\tau)$. Thus, the political distortion in the tax is greater when η is high, i.e. when the political resistance to a marginal tax increase is strong. As can be seen in the definition of η, the tax elasticity is greater when $P'(\Delta)$ is large; the probability of passing a tax, $P(\Delta)$, is small; and when losses rise rapidly with the tax rate, i.e. when $\partial \Delta(\tau^*)/\partial \tau$ is large, either because many inefficient firms would be forced to exit, because many moderately efficient firms would resist paying the tax, and/or because many efficient firms would be forced to adopt the costly new technology. In any case, the higher is the tax elasticity of political resistance, the more the regulator distorts downward the proposed tax.

The second factor causing political tax distortion is that the more the regulator wants the tax, i.e., the greater is $[W^{T}(\tau^*) - W^{S}(s^*)]$, the more the regulator weakens the tax proposal to increase its chances of passage.

We record these observations in the following lemma.

Lemma 4. *Political distortion causes the regulator to weaken its tax proposal, i.e.*

$\tau^* < \tau^N$. The distortion increases with the tax elasticity of political pressure and with the net benefit of taxation compared to the VA.

We have shown that both the VA and the tax depart from the marginal social cost of pollution due to the distortionary effects of raising tax monies and/or political resistance to taxation. Whether the tax produces better results than the VA in practice depends upon a number of parameters. The key parameters affecting each of these instruments have been discussed above. In particular, welfare under a public voluntary agreement improves when the cost of public funds is low and the cost of adoption is low and does not vary greatly across firms. Welfare under a pollution tax improves when the tax elasticity of political resistance is low, and when innate efficiency does not vary greatly across firms. In light of the result established in Lemma 4, it is easy to see the following corollary to Proposition 3.

Corollary 5. *Taxation is a preferable regulatory instrument to a public voluntary agreement unless political opposition* $[1 - P(\Delta)]$ *is high.*

Because taxation works at both the upper and lower end of the efficiency distribution of firms, it is inherently a more powerful instrument than a public VA. As a result, it is preferred to a VA unless the political forces opposing taxation are strong. Indeed, the only reason the regulator might not propose a tax is that making the proposal requires a fixed cost of K, which is not justified if the probability of success is too small. As discussed in Section 2, the Climate Change Action Program appears to be a case where the costs of technology adoption for many firms were relatively low, but where the political resistance to a tax was high because some firms would have been forced out of business and a broad base of firms would have had to pay higher taxes. Thus the public VA proved to be the only feasible policy, even though an energy tax would have been a more potent tool.

As mentioned at the outset of the paper, voluntary programs—despite their inherent weaknesses—are becoming more popular. This is even more evident in Europe than in the US. As OECD (1999) notes: ‘‘Despite considerable institutional diversity among European Union member states, an overall pattern of VA use can be identified.’’ It is interesting, therefore, to examine how welfare is affected when the regulator has the possibility of offering a public VA after legislative efforts fail. As the following proposition notes, the option of offering a VA may diminish social welfare, and legislatures might wish to commit *not* to use public VAs to achieve some environmental policy goals.

Proposition 6. *If the tax elasticity of political resistance is high, social welfare may be lower when the regulator has the option of offering a public VA.*

Proof. Consider a reference case in which government either taxes or takes no action. Expected social welfare is

$$\bar{W}^{\mathrm{NVA}}(\tau) = P(\Delta)[W^{\mathrm{T}}(\tau) - K] + [1 - P(\Delta)]W(\emptyset).$$

To this reference case compare a case in which the regulator can offer a VA if a tax proposal fails, the expected welfare of which is

$$\bar{W}^{\mathrm{VA}}(\tau) = P(\Delta)[W^{\mathrm{T}}(\tau) - K] + [1 - P(\Delta)][W^{\mathrm{S}}(s^*) - K].$$

The benefit of the latter case is that offering a VA ex post is preferable to no government action, i.e. $W^{\mathrm{S}}(s^*) - K > W(\emptyset)$. The cost is that industry losses from a tax—relative to the subsidy offered under a VA—are greater in the latter case, as can be seen in (8). As a result, political resistance is greater in the latter case, and $P(\Delta)$ is smaller. If the tax elasticity η is high enough, the reduced probability of passing tax legislation more than offsets the ex post gains from being able to offer a VA. In that case, welfare would be higher if the regulator did not have the option of offering the VA ex post. □

The intuition behind Proposition 6 is simple: if firms know a VA will be offered after a tax fails, they have more incentive to oppose the tax so they can collect the subsidy that is offered under the VA. If the tax elasticity of political opposition is high, offering the VA can produce a significant increase in political resistance to the tax, and greatly reduce the chance that the tax proposal will be passed. If the social benefits of the tax are substantially greater than the benefits of the VA, then this increased political resistance dominates the benefits of the VA, and expected welfare is higher when the possibility of a VA is eliminated. Note that as K (the cost of crafting a tax proposal or offering a VA) rises, the benefits of the VA fall, while the total subsidy payments under the VA program remain unchanged. Hence, the option of offering a VA is less socially valuable the larger is K. Indeed, Proposition 3 shows it is possible that social welfare would be higher if public VAs had never come into existence. Whether a legislature could credibly commit *not* to offer a VA is questionable, since governments are not known for their commitment abilities. Nevertheless, our results suggest a more cautious approach to the use of public VAs than has been espoused by some.[22]

[22] For example, IAE (1998) highlights the benefits voluntary programs appear to offer and urges serious consideration of expanding their use in the future. Segerson and Miceli (1998) assume VAs are more efficient than traditional regulation, which leads naturally to the conclusion that policymakers should use them. Our results suggest policymakers should also be cognizant of the opportunity costs of making such programs available.

5. Industry self-regulation

The previous section studied stages 2 and 3 of the game, involving the regulator's decision regarding which policy instrument to wield. This section studies the first stage of the game, in which the industry decides whether and to what extent it will unilaterally adopt the environmental technology, taking into account how its decision will affect the likelihood and level of the tax, as well as the likelihood of the public voluntary program. Thus we must examine not only the impact of unilateral activities on industry profitability, but also on the regulator's response. Because the technical analysis of these effects is involved, and somewhat tedious, the formal analysis is relegated to Appendix A. Here we provide the intuition behind the results in a less formal fashion. We examine whether the industry will undertake unilateral self-regulation, and the welfare consequences if self-regulation occurs. We also study how offering a public VA affects incentives for industry self-regulation.

This section of the paper extends the analysis of Maxwell et al. (2000) in two main ways. First, we allow for uncertainty regarding the passage of new legislation if no self-regulation occurs. Second, we allow the regulator to employ a VA if legislation does not pass. Thus, we distinguish sharply between unilateral action by industry and a public voluntary agreement offered by the government, something that has not been done in previous formal models. In addition, this paper focuses on the imposition of a tax instead of the regulatory standards considered in the earlier paper.

To begin with, we change our notation to make all of our expressions for welfare contingent upon the level of unilateral adoption by industry. As discussed earlier, we imagine the industry working in concert in its preemption efforts. Under this assumption, the firms with the lowest technology adoption costs will enter the unilateral voluntary agreement, since this set of firms can achieve preemption at the lowest total cost to the industry. Thus, we denote by θ^{v} the firm with the highest technology adoption costs that joins the industry's unilateral voluntary efforts. Then all firms indexed by $\theta > \theta^{v}$ will also adopt the technology. If the industry opts to take no unilateral actions, it simply sets $\theta^{v} = \bar{\theta}$. Throughout this section we will write $W^{\mathrm{T}}(\tau, \theta^{v})$ to indicate social welfare under a tax, $W^{\mathrm{S}}(s^{*}, \theta^{v})$ for social welfare under the optimal VA, and $\bar{W}(\tau, \theta^{v})$ for expected social welfare when the regulator proposes a tax of τ.

More formally, the general expression for welfare when the government takes no action is

$$W(\emptyset, \theta^{\mathrm{v}}) = \int_{\underline{\theta}}^{\theta^{\mathrm{v}}} [\pi(\theta) - x]\, \mathrm{d}F(\theta) + \int_{\theta^{\mathrm{v}}}^{\bar{\theta}} [\pi(\theta) - c(\theta)]\, \mathrm{d}F(\theta), \tag{13}$$

where all firms indexed by $\theta \geq \theta^{v}$ voluntarily adopt the pollution technology. If a public voluntary agreement is offered after some firms have undertaken voluntary adoptions, social welfare is given by[23]

$$W^{\mathrm{S}}(s^*, \theta^{\mathrm{v}}) = \int_{\underline{\theta}}^{\theta^{s*}} [\pi(\theta) - x]\, \mathrm{d}F(\theta) + \int_{\theta^{s*}}^{\theta^{\mathrm{v}}} [\pi(\theta) - c(\theta) + s^*]\, \mathrm{d}F(\theta) + \int_{\theta^{\mathrm{v}}}^{\bar{\theta}} [\pi(\theta) - c(\theta) + s^*]\, \mathrm{d}F(\theta) - [1 - F(\theta^{s*})]s^*(1 + \lambda). \quad (14)$$

If the legislature passes the tax proposal following the voluntary technology adoptions of some firms, social welfare is given by

$$W^{\mathrm{T}}(\tau^*, \theta^{\mathrm{v}}) = \int_{\theta^{\tau*}}^{\min\{\theta^{\mathrm{v}},\, \theta^{\mathrm{a}}\}} [\pi(\theta) - x + \gamma\tau^*]\, \mathrm{d}F(\theta) + \int_{\min\{\theta^{\mathrm{v}},\, \theta^{\mathrm{a}}\}}^{\bar{\theta}} [\pi(\theta) - c(\theta)]\, \mathrm{d}F(\theta). \quad (15)$$

Finally, subsequent to some voluntary technology adoption, the expected level of welfare from proposing the optimal tax is

$$\bar{W}(\tau^*, \theta^{\mathrm{v}}) = P(\Delta)W^{\mathrm{T}}(\tau^*, \theta^{\mathrm{v}}) + [1 - P(\Delta)]W^{\mathrm{S}}(s^*, \theta^{\mathrm{v}}) \quad (16)$$

if the level of voluntary adoption has not preempted the public voluntary agreement, and is

$$\bar{W}(\tau^*, \theta^{\mathrm{v}}) = P(\Delta)W^{\mathrm{T}}(\tau^*, \theta^{\mathrm{v}}) + [1 - P(\Delta)]W(\emptyset, \theta^{\mathrm{v}}) \quad (17)$$

otherwise, where the general expression for $\Delta(\tau)$ is given by

[23]The reader will note that the second and third terms on the right-hand side of (14) could be combined so as to eliminate the dependence of the expression on θ^{v}. We keep the two terms independent for notational consistency. All other welfare functions are dependent on θ^{v} and are presented as $W(\cdot, \theta^{v})$.

$$\Delta(\tau) = \int_{\underline{\theta}}^{\theta^{\tau}} \pi(\theta)\, \mathrm{d}F(\theta) + \int_{\theta^{\tau}}^{\min\{\theta^{a},\, \theta^{v}\}} \tau\, \mathrm{d}F(\theta)$$
$$+ \Phi(\theta^{-s}, \theta^{v})\left(\Phi(\theta^{a}, \theta^{v}) \int_{\theta^{a}}^{\min\{\theta^{s*},\, \theta^{v}\}} c(\theta)\, \mathrm{d}F(\theta) + \int_{\theta^{s*}}^{\bar{\theta}} s\, \mathrm{d}F(\theta) \right)$$
$$+ \Phi(\theta^{v}, \theta^{-s})\left(\Phi(\theta^{a}, \theta^{v}) \int_{\theta^{a}}^{\theta^{v}} c(\theta)\, \mathrm{d}F(\theta) \right), \tag{18}$$

where $\Phi(x, y)$ is an indicator variable taking on the value 1 if $x < y$, and 0 otherwise.

For purposes of this section, we assume that if there is no unilateral action by the industry, then the regulator prefers to propose a tax rather than institute a public VA. If this were not so, then the industry would have no motive for taking unilateral action. As we show below, unilateral action is unprofitable for the industry unless it serves to preempt government action. While preempting a tax is desirable for the industry, preempting a government handout is not. Hence, if the public VA is preferred by the regulator when $\theta^{v} = \bar{\theta}$, then the industry will take no self-regulatory action.

We turn next to the impact of self-regulation on the regulator's benefits of offering a public voluntary agreement. The benefits of a VA, relative to doing nothing, are

$$W(s^{*}, \theta^{v}) - W(\emptyset, \theta^{v}) = \int_{\theta^{s*}}^{\theta^{v}} [x - c(\theta)]\, \mathrm{d}F(\theta) - \lambda s^{*}[1 - F(\theta^{s*})] - K. \tag{19}$$

Note that if enough firms undertake unilateral action in stage 1, then the regulator does not propose a VA. Denote by θ^{-s} the critical value of θ^{v} at which the regulator will forego the public voluntary program. Then $\theta^{-s} > \theta^{s*}$ is the value of θ^{v} that sets (19) to zero:

$$\int_{\theta^{s*}}^{\theta^{-s}} [x - c(\theta)]\, \mathrm{d}F(\theta) = \lambda s^{*}[1 - F(\theta^{s*})] + K. \tag{20}$$

The left-hand side of (20) represents the benefits of the VA, as reflected in the difference between the social damage caused by pollution, x, and the social cost of the abatement technology, $c(\theta)$, integrated over the range of firms who did not adopt the technology at stage 1, but were induced by the VA to adopt. The right-hand side of (20) represents the cost of the VA, as measured by the cost of public funds required to provide a subsidy to all firms with $\theta > \theta^{s}$, along with the fixed cost K of creating the program. Clearly the regulator will find it optimal to propose the public voluntary program only as long as $\theta^{v} > \theta^{-s}$. Note that even if $K = 0$, it is possible for unilateral voluntary efforts to preempt public voluntary agreements.

It is also important to note that the optimal subsidy is independent of the number of firms that engage in the unilateral voluntary agreement (i.e., independent of θ^{v}). The regulator sets s by maximizing (19), but it is clear by inspection that θ^{v} has no impact upon the marginal effect of an increase in s. Hence, as long as the regulator decides to offer the VA at all (i.e., as long as $\theta^{v} > \theta^{-s}$), $s*$ is not a function of θ^{v}.[24] We thus obtain the following lemma.

Lemma 7. *The regulatory benefits arising from a public voluntary agreement are strictly decreasing in the number of voluntary adoptions* (*hence, increasing in* θ^{v}) *and reach zero at* $\theta^{v} = \theta^{-s}$.

Proof. From Eq. (19), it is easy to see that the net benefit of the VA is increasing with θ^{v} so long as $x - c(\theta) > 0$ for all $\theta \in [\theta^{s*}, \theta^{v}]$. Since $c'(\theta) < 0$, it is sufficient to show that $x - c(\theta^{-s}) > 0$. As shown above, we know $\theta^{-s} > \theta^{s*}$. Furthermore, Lemma 1 shows that $\theta^{s*} > \theta^{sw} \equiv c^{-1}(w/(1+\lambda))$. Since $c'(\theta) < 0$, we know that $c^{-1}(\cdot) < 0$ as well. Since $x/(1+\lambda) < x$, we then have $c^{-1}(x/(1+\lambda)) \equiv \theta^{sw} > c^{-1}(x) \equiv x$. Hence $\theta^{-s} > \theta^{s*} > \theta^{sw} > \theta^{x}$, and $c(\theta^{-s}) < x$. □

Lemma 7 shows that unilateral voluntary activity on the part of the industry (which reduces θ^{v}) will not enhance the likelihood that the regulator will provide the public voluntary program.[25] Nor do these efforts affect the level of the subsidy. Furthermore, as long as voluntary activities do not preempt the public voluntary agreement, firms will receive the same compensation no matter the timing of the adoption. Clearly, then, incentives for unilateral voluntary action exist only because of the threat of taxation. Put another way, if $P(\Delta) = 0$ the industry has no incentive to engage in voluntary activity.

Next we examine industry incentives to engage in unilateral voluntary activities when faced with both the possibility of a tax and the possibility of a subsequent public voluntary agreement. To examine the impact of unilateral initiatives on the possibility of a tax we examine the net benefits to the regulator of offering the tax, relative to its next best option. These net benefits are

$$\overline{NW}(\tau*, \theta^{v}) = \begin{cases} \bar{W}(\tau*, \theta^{v}) - W^{S}(s*, \theta^{v}), & \text{for } \theta^{v} \geq \theta^{-s}, \\ \bar{W}(\tau*, \theta^{v}) - W(\emptyset, \theta^{v}) - K, & \text{for } \theta^{v} < \theta^{-s}. \end{cases} \tag{21}$$

[24] Note that optimization of (19) yields the same $s*$ as optimization of (2).

[25] This could change in a model with asymmetric information about the distribution of firms' costs. If the regulator is poorly informed regarding the potential costs of technology adoption, then unilateral adoptions could signal that a VA program would be cost-effective, and might encourage the regulator to offer such a program. For a related model, see Denicolo (2000).

Eq. (21) reflects the fact that as long as unilateral voluntary efforts do not preempt the public voluntary agreement, the relevant alternative to the tax is the stage 3 agreement. However, if industry unilateral efforts do preempt the public voluntary agreement, then the relevant regulatory alternative is one of inaction. Note that both the tax proposal and the VA require the regulator to incur the cost K, so this cost cancels out when one is subtracted from the other. Thus, the fixed cost K appears only in the lower part of (21), since inaction requires no fixed costs.

We have seen that industry has no incentive to engage in unilateral voluntary actions absent a tax. Thus, two possible motivations for unilateral voluntary actions exist. First, unilateral actions that do not preempt the tax might nevertheless raise expected industry profits above those associated with no unilateral voluntary agreement, perhaps by weakening the tax that is eventually proposed. Second, unilateral action might preempt the tax and industry profits following preemption may exceed the expected profits associated with no unilateral voluntary agreement.

We show in Appendix A that for sufficiently small γ, $\theta^{-\tau} < \theta^{-s}$, i.e., unilateral abatement will preempt the public VA before it preempts the tax. In addition, Appendix A also contains a proof that expected industry profits are increasing in θ^{v} for all $\theta^{v} \in [\theta^{-\tau}, \bar{\theta}]$. Consequently, the industry will never engage in unilateral voluntary actions that do not lead to the preemption of the proposed tax.[26] However, it is easy to see that preemption is possible for large enough K. Consider a K large enough that the regulator is almost indifferent between proposing a tax and not; in this case, a small amount of voluntary adoption will reduce the incremental benefit of taxation enough to preempt tax legislation. Denote by $\theta^{-\tau}$ the level of θ^{v} such that $\overline{NW}(\tau^{*}, \theta^{-\tau}) = 0$. Note that $\partial\theta^{-\tau}/\partial K > 0$, indicating that large K implies that preemption is possible with a smaller amount of unilateral action. While it is clear that for sufficiently large K voluntary actions will preempt the tax proposal, we must also consider whether preemption is profitable for the industry. In Appendix A we prove the following proposition, which establishes conditions under which feasible preemption is also profitable.

Proposition 8. *If preemption is feasible, it is also profitable for large enough K.*

This result extends that of Maxwell et al. (2000), who show that preemption is profitable in a setting where there is no possibility of a public voluntary agreement. The relationship between K and the extent of unilateral action is shown in Fig. 3. At high levels of K, legislation is effectively 'blockaded' due to the excessive fixed cost of implementing it. As K falls, a point is reached where a small amount of unilateral action is sufficient to preempt a tax, and industry finds this action profitable. As K falls further, proposing the tax becomes more attractive, so the

[26] This result parallels that of Maxwell et al. (2000), who show that unilateral action that fails to preempt is unprofitable in a setting without the possibility of a public voluntary agreement.

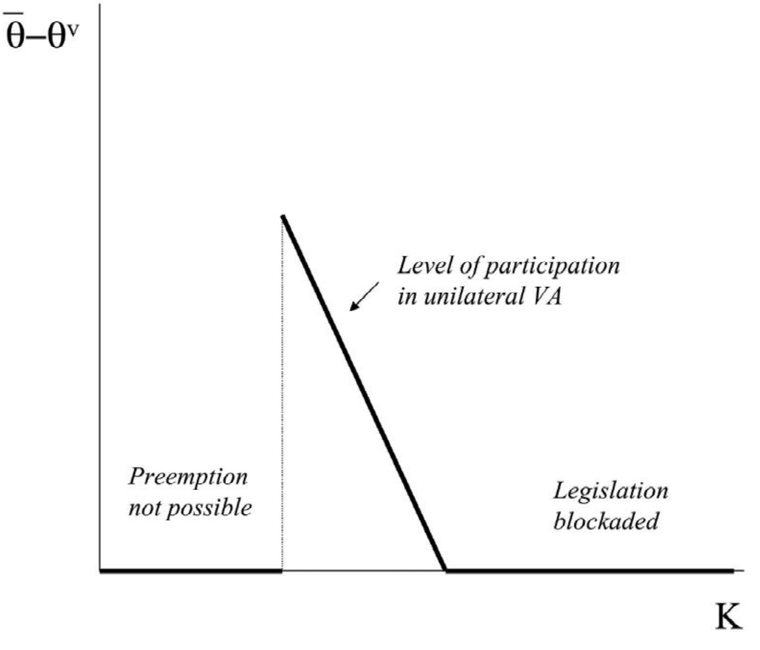

Fig. 3. Unilateral technology adoption and political transaction costs, K.

level of unilateral action needed for preemption rises. Beyond a certain point, however, the requisite level of unilateral action becomes too expensive, and industry is unwilling to undertake it. This is shown in the figure where there is a sharp, discontinuous, drop in unilateral activity.

Our analysis of self-regulation has implications for welfare as well as for industry behavior. Indeed, throughout our analysis we have assumed that the industry is able to coordinate in fighting a tax proposal and in taking unilateral action that would preempt the tax. An important policy question is whether such cooperation should be allowed. The answer turns on whether $W(\emptyset, \theta^{-\tau}) > \bar{W}(\tau^*, \bar{\theta}) - K$, i.e., whether welfare is higher when the industry's unilateral action preempts the tax proposal or when the industry takes no unilateral action and the regulator proposes the optimal tax. We address this question in the following proposition.

Proposition 9. *Expected social welfare is higher when unilateral industry action preempts government action, i.e., when* $W(\emptyset, \theta^{-\tau}) > \bar{W}(\tau^*, \bar{\theta}) - K$.

Proof. By definition, preemption occurs when $W(\emptyset, \theta^{-\tau}) > W^{T}(\tau^*, \theta^{-\tau}) - K$. Differentiating expected welfare from the tax with respect to θ^{v}, we find that

$$\frac{\partial \bar{W}(\tau^*, \theta^{\mathrm{v}})}{\partial \theta^{\mathrm{v}}} = P(\Delta)\frac{\partial W^{\mathrm{T}}(\tau^*, \theta^{\mathrm{v}})}{\partial \theta^{\mathrm{v}}} + [1 - P(\Delta)]\frac{\partial W^{\mathrm{S}}(s^*, \theta^{\mathrm{v}})}{\partial \theta^{\mathrm{v}}} + P'(\Delta)\frac{\partial \Delta}{\partial \theta^{\mathrm{v}}}[W^{\mathrm{T}}(\tau^*, \theta^{\mathrm{v}}) - W^{\mathrm{S}}(s^*, \theta^{\mathrm{v}})] < 0.$$

The first two terms are less than or equal to zero for all $\theta^{v} > \theta^{x}$. The first term is zero for $\theta^{v} > \theta^{\mathrm{a}}$ and negative for $\theta^{v} \in (\theta^{x}, \theta^{\mathrm{a}})$. The second term is zero for $\theta^{v} > \theta^{s*}$ and negative for $\theta^{v} \in (\theta^{x}, \theta^{s*})$. The third term is negative if $W^{\mathrm{T}}(\tau^*, \theta^{v}) - W^{\mathrm{S}}(s^*, \theta^{v}) > 0$, which must be the case if the government is choosing to propose the tax. Combining these terms, expected welfare always falls when θ^{v} rises, i.e., when industry undertakes less unilateral action. (Note that the foregoing logic also applies to the case where $s^* = 0$, i.e., where the regulator prefers not to offer a VA.) As a result, $\bar{W}(\tau^*, \theta^{-\tau}) > \bar{W}(\tau^*, \bar{\theta})$. Combining this with the definition of preemption, we have

$$W(\emptyset, \theta^{-\tau}) > W^{\mathrm{T}}(\tau^*, \theta^{-\tau}) - K > \bar{W}(\tau^*, \bar{\theta}) - K. \quad \square$$

The proposition shows that unilateral action enhances social welfare. As shown in the proof, expected welfare with the tax increases with unilateral abatement, so self-regulation raises the welfare level that the regulator can claim by proposing a tax. If the regulator allows the tax proposal to be preempted, it must be the case that welfare is even higher under preemption than it would be if the tax were imposed when there is no unilateral action.

Given that self-regulation enhances welfare, it is important to examine how public VAs affect the incentives for industry to undertake unilateral actions. This is the focus of our final proposition.

Proposition 10. *Public voluntary agreements reduce the industry's incentives to engage in preemptive self-regulation, and consequently may reduce social welfare.*

Proof. Consider first a reference case in which the regulator commits not to offer a VA. Then the preemptive level of unilateral adoption is $\theta^{v} = \theta^{-\tau}(K)$, where the latter is defined by $W(\emptyset, \theta^{-\tau}(K)) = \bar{W}(\tau^*, \bar{\theta}) - K$. Consider a K such that the industry is just indifferent between taking preemptive unilateral action and taking no action at all. Now compare this reference case to one in which the regulator makes available a VA if the tax proposal fails. By Proposition 6, the presence of the VA lowers social welfare if the tax elasticity of political resistance is high enough; let us assume this to be the case. Now note that the introduction of the VA raises the expected profitability of taking no unilateral action by the amount

$$[1 - P(\Delta)]\int_{\theta^{s*}}^{\bar{\theta}} [s - c(\theta)]\, \mathrm{d}F(\theta) > 0.$$

Thus, the introduction of the VA makes unilateral action unprofitable. But by assumption, it also reduces expected social welfare in the event that preemption does not occur. Thus, the availability of the VA program reduces social welfare. □

The proposition shows that when the regulator is expected to offer a public VA in the absence of a tax, industry self-regulation may be discouraged, with negative effects on social welfare. This result extends that of Proposition 6, which showed that making the VA available could reduce welfare in a setting where self-regulation is not possible. Proposition 10 goes on to show that the availability of the VA may induce industry to eschew self-regulation, and that this change in industry behavior can harm welfare. This conclusion is at odds with the conventional view of public VAs, which sees them as a more efficient instrument than traditional approaches to pollution control, and hence something to be encouraged. We do not deny that this is possible in some circumstances, but we emphasize that it is not a general conclusion. It is clear that while industry may elect to take unilateral action to preempt the threat of a tax, it does not want to preempt the 'threat' of a subsidy. Furthermore, we have shown that preemption is socially beneficial. Hence, even if the VA is strictly better than government inaction, it is possible for expected welfare to fall as the VA preempts industry-led unilateral action, which could be even more beneficial.

6. Conclusions

We have presented a model of environmentally friendly technology adoption in which a broad array of instruments—unilateral industry actions, public voluntary agreements (VAs), and legislatively imposed taxes—can be jointly considered. Previous work has often failed to distinguish carefully between unilateral and public voluntary agreements, and thus reaches misleading policy conclusions. In particular, it is often thought that voluntary agreements emerge only under pressure of strong legislative threats, and that public voluntary programs should be promoted as efficient instruments that can preempt clumsy, old-fashioned, taxes and/or standards. Our more general analysis reaches very different conclusions: public voluntary programs are often weak instruments that are used precisely because strong legislation is infeasible due to industry's political resistance. We argue that this view aptly characterizes the most numerous group of public voluntary programs in the US, namely those developed by the EPA for issues of global warming. Furthermore, we show that public VAs may reduce welfare by preempting unilateral VAs that would have been better.

We show that if government can pass tax proposals without political resistance, then taxation always dominates public VAs, because taxation has the power to induce inefficient firms to exit the industry as well as the power to induce adoption of the environmental technology, while VAs can do only the latter. We are also skeptical of the value of public VAs in many settings where political resistance exists. Indeed, we show that social welfare may fall when regulators have the option of offering a VA, because firms increase their political resistance to welfare-superior tax schemes when they foresee the possibility of a VA should the tax fail to pass. Nevertheless, we do identify conditions under which a VA may be desirable. First, and most obviously, a VA is often better than government inaction in cases where taxation is desirable but will not be proposed due to political resistance by industry. Second, a VA may be more efficient than taxation under certain conditions: if the cost of raising public funds is low, the cost of the environmental technology is modest, the cost of technology adoption does not vary greatly across firms, and political resistance to taxation is high.

Unilateral action by industry may be undertaken in order to preempt taxation, and we show that if this occurs, then it increases social welfare. In addition, our welfare analysis suggests another danger of substituting public VAs for taxation: industry will not undertake unilateral actions to preempt subsidy programs. By substituting the 'threat' of a handout for the threat of a tax, regulators may inadvertently preempt socially beneficial corporate self-regulation.

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Appendix A. Proofs of propositions and lemmas

Lemma 11. *If a greater number of firms adopt under the tax than under the public voluntary agreement, or if γ is sufficiently small, then $\theta^{-\tau} < \theta^{-s}$.*

Proof. We present this proof in two parts. The first part examines the case in which $\theta^{a} < \theta^{s*}$ and the second considers $\theta^{a} > \theta^{s*}$.

$\underline{\theta^{a} < \theta^{s*}}$: In this case, more firms will adopt under the tax than under the public voluntary agreement. As discussed in the text, we assume $\overline{W}(\tau^*, \overline{\theta}) > W^{S}(s^*, \overline{\theta})$, which also implies $W^{T}(\tau^*, \overline{\theta}) > W^{S}(s^*, \overline{\theta})$. However, for all $\theta^{v} \geq \theta^{s*} \geq \theta^{a}$ it follows from (2) and (9) that $\mathrm{d}W^{S}(s^*, \theta^{v})/\mathrm{d}\theta^{v} = 0$ and $\mathrm{d}W^{T}(\tau^*, \theta^{v})/\mathrm{d}\theta^{v} = 0$.

Thus $W^{T}(\tau^{*}, \theta^{v}) > W^{S}(s^{*}, \theta^{v})$ $\forall \theta^{v} \in (\theta^{s*}, \bar{\theta})$. Now recall from (20) that $\theta^{-s} > \theta^{s*}$, so $W^{T}(\tau^{*}, \theta^{-s}) > W^{S}(s^{*}, \theta^{-s})$, and therefore $\bar{W}(\tau^{*}, \theta^{-s}) > W^{S}(s^{*}, \theta^{-s})$, which implies $\theta^{-\tau} < \theta^{-s}$.

$\underline{\theta^{a} > \theta^{s*}}$: In this case, voluntary adoptions resulting in $\theta^{v} < \theta^{a}$ will cause the regulator to alter the optimal tax. Our goal is to identify the level of voluntary adoptions at which the government prefers to abandon a particular policy (either tax or VA) in favor of the inaction option, whose social value is given by (13). Thus, we seek the levels of θ^{v} at which $\bar{W}(\tau^{*}, \theta^{v}) = W(\emptyset, \theta^{v})$ and $W^{S}(s^{*}, \theta^{v}) = W(\emptyset, \theta^{v})$. Since $\bar{W}(\tau^{*}, \bar{\theta}) > W^{S}(s^{*}, \bar{\theta})$, we know $W^{T}(\tau^{*}, \bar{\theta}) > W^{S}(s^{*}, \bar{\theta})$. In addition, we know $W^{S}(s^{*}, \theta^{v})$ is constant for $\theta^{v} \in (\theta^{-s}, \bar{\theta})$, and $W^{T}(\tau^{*}, \theta^{v})$ is constant for $\theta^{v} \in (\theta^{a}, \bar{\theta})$. Furthermore, we know $\bar{W}(\tau^{*}, \theta^{a}) > \bar{W}(\tau^{*}, \bar{\theta})$ since the optimal tax when $\theta^{v} = \theta^{a}$ imposes lower losses on industry than does the optimal tax when $\theta^{v} = \bar{\theta}$, hence inducing less political resistance and raising the probability the tax is passed. It follows that $\bar{W}(\tau^{*}, \theta^{a}) > W^{S}(s^{*}, \theta^{a}) = W^{S}(s^{*}, \bar{\theta})$. Given that $W(\emptyset, \theta^{v})$ is decreasing in θ^{v} (rising in the number of voluntary adoptions) over the relevant range we can ensure $\theta^{-\tau} < \theta^{-s}$ by showing that $d\bar{W}(\tau^{*}, \theta^{v})/d\theta^{v} < 0$ for $\theta^{v} \in (\theta^{-s}, \theta^{a})$, i.e. $\bar{W}(\tau^{*}, \theta^{v})$ is always above $W^{S}(s^{*}, \theta^{v})$ on the relevant range. From (15) and (16) we see that

$$\frac{d\bar{W}(\tau^{*}, \theta^{v})}{d\theta^{v}} = P(\Delta)\left[\frac{dW^{T}(\tau^{*}, \theta^{v})}{d\theta^{v}}\right] + P'(\Delta)\frac{d\Delta}{d\theta^{v}}[W^{T}(\tau^{*}, \theta^{v}) - W^{S}(s^{*}, \theta^{v})]. \tag{A.1}$$

If $W^{T}(\tau^{*}, \theta^{v}) > W^{S}(s^{*}, \theta^{v})$, the second term will be negative since $P'(\Delta) < 0$ and $d\Delta/d\theta^{v} > 0$, as can be seen by differentiating (18). Recall that we know $W^{T}(\tau^{*}, \theta^{a}) > W^{S}(s^{*}, \theta^{a})$, and that $dW^{S}(s^{*}, \theta^{v})/d\theta^{v} = 0$ for all $\theta^{v} \in (\theta^{-s}, \theta^{a})$, thus as long as $dW^{T}(\tau^{*}, \theta^{v})/d\theta^{v} < 0$ over the relevant range, both the first and second terms in (A.1) are negative for all $\theta^{v} \in (\theta^{-s}, \theta^{a})$.

To establish the sign of $dW^{T}(\tau^{*}, \theta^{v})/d\theta^{v}$, we note that

$$\frac{dW^{T}(\tau^{*}, \theta^{v})}{d\theta^{v}} = \frac{\partial W^{T}(\tau^{*}, \theta^{v})}{\partial \tau^{*}}\frac{\partial \tau^{*}}{\partial \theta^{v}} + \frac{\partial W^{T}(\tau^{*}, \theta^{v})}{\partial \theta^{v}}, \tag{A.2}$$

which, substituting in for the partial derivative of (15), can be rewritten as

$$\frac{dW^{T}(\tau^{*}, \theta^{v})}{d\theta^{v}} = \frac{\partial W^{T}(\tau^{*}, \theta^{v})}{\partial \tau^{*}}\frac{\partial \tau^{*}}{\partial \theta^{v}} + [c(\theta^{v}) - x + \gamma\tau^{*}]f(\theta^{v}). \tag{A.3}$$

Note that the second term is negative for γ sufficiently small. The first component of the first term is positive given our assumption that $W^{T}(\tau, \theta^{v})$ is concave in τ and our result in Lemma 4, which shows that τ^{*} falls short of the welfare-maximizing level due to political resistance. Thus, we see that $dW^{T}(\tau^{*}, \theta^{v})/d\theta^{v} < 0$ when $\partial\tau^{*}/\partial\theta^{v} < 0$.

To establish the sign of $\partial\tau^{*}/\partial\theta^{v}$, observe that by totally differentiating the first-order condition governing the choice of τ^{*} we obtain

$$\frac{\partial^2 \bar{W}(\tau^*, \theta^v)}{\partial \tau^{*2}} \mathrm{d}\tau^* + \frac{\partial^2 \bar{W}(\tau^*, \theta^v)}{\partial \tau^* \, \partial \theta^v} \mathrm{d}\theta^v = 0, \tag{A.4}$$

and therefore

$$\frac{\mathrm{d}\tau^*}{\mathrm{d}\theta^v} = -\frac{\partial^2 \bar{W}(\tau^*, \theta^v)/\partial \tau^* \, \partial \theta^v}{\partial^2 \bar{W}(\tau^*, \theta^v)/\partial \tau^{*2}}. \tag{A.5}$$

Since $\bar{W}(\tau^*, \theta^v)$ is concave, we see that the denominator of (A.5) is negative, and thus $\mathrm{d}\tau^*/\mathrm{d}\theta^v < 0$ if the numerator is positive. Differentiating (A.1) with respect to τ and evaluating at τ^* yields

$$\begin{aligned}\frac{\partial^2 \bar{W}(\tau^*, \theta^v)}{\partial \tau^* \, \partial \theta^v} = {} & P(\Delta)\frac{\partial^2 W^T(\tau^*, \theta^v)}{\partial \tau^* \, \partial \theta^v} \\ & + P'(\Delta)\Bigg[\frac{\partial \Delta}{\partial \theta^v}\frac{\partial W^T(\tau^*, \theta^v)}{\partial \tau^*} + \frac{\partial^2 \Delta}{\partial \tau^* \, \partial \theta^v}[W^T(\tau^*, \theta^v) \\ & - W^S(s^*, \theta^v)]\Bigg] \\ & + P''(\Delta)\Bigg[\frac{\partial \Delta}{\partial \theta^v}\frac{\partial \Delta}{\partial \tau^*}[W^T(\tau^*, \theta^v) - W^S(s^*, \theta^v)]\Bigg].\end{aligned} \tag{A.6}$$

It is straightforward to show that all terms in the large square brackets of (A.6) are positive. Furthermore, we know $P'(\Delta) < 0$ and $P''(\Delta) < 0$, so (A.6) is positive if the first term is small enough in magnitude. Using (15) one can show that $\partial^2 \underline{W}^T(\tau^*, \theta^v)/\partial \tau^* \, \partial \theta^v = \gamma f(\theta^v)$. Thus, we see that for sufficiently small γ, $\partial^2 \bar{W}(\tau^*, \theta^v)/\partial \tau^* \, \partial \theta^v < 0$. Thus, from (A.5), $\mathrm{d}\tau^*/\mathrm{d}\theta^v$ is also negative for sufficiently small γ. Finally, from (A.3) we have that for sufficiently small γ, $\mathrm{d}W^T(\tau^*, \theta^v)/\mathrm{d}\theta^v < 0$. □

The following lemma, along with Proposition 8, addresses the desirability for industry of engaging in a unilateral voluntary agreement under the threat of taxation.

Lemma 12. *Expected industry profits are increasing in θ^v, and therefore decreasing in the number of firms that voluntarily adopt, for all $\theta^v \in [\theta^{-\tau}, \bar{\theta}]$.*

Proof. Expected profits for the industry, as a function of Δ, are

$$\Pi(\Delta) = P(\Delta)\left(\int_{\theta^{\tau}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) - \int_{\theta^{\tau}}^{\min\{\theta^{a},\,\theta^{v}\}} \tau\,\mathrm{d}F(\theta) - \int_{\min\{\theta^{a},\,\theta^{v}\}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta)\right)$$
$$+ (1-P(\Delta))\left(\int_{\underline{\theta}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) + \Phi(\theta^{-s},\theta^{v}) \int_{\min\{\theta^{a},\,\theta^{v}\}}^{\bar{\theta}} [s^{*} - c(\theta)]\,\mathrm{d}F(\theta) - \Phi(\theta^{v},\theta^{-s})\int_{\theta^{v}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta)\right). \tag{A.7}$$

From (A.7) we see that the functional form of expected industry profits changes as θ^{v} declines from $\bar{\theta}$. The following cases are possible: (1) $\theta^{v} > \theta^{-s} > \theta^{a} > \theta^{-\tau}$, (2) $\theta^{-s} > \theta^{v} > \theta^{a} > \theta^{-\tau}$, (3) $\theta^{-s} > \theta^{a} > \theta^{v} > \theta^{-\tau}$. In each case we examine how $P(\Delta)$ changes as θ^{v} changes, and then we examine how profits under the tax policy and under the subsidy or no action policy change as θ^{v} changes. For the sake of brevity we present only case (3). In case (1) it is straightforward to show that neither $P(\Delta)$ nor any other component of industry profits changes with θ^{v}. In case (2), $P(\Delta)$ falls as θ^{v} rises, further industry profits under taxation are invariant and always lower than profits under a no action policy; thus profits are increasing in θ^{v}.

Case 3. ($\theta^{-s} > \theta^{a} > \theta^{v} > \theta^{-\tau}$) In this case, all firms that would adopt under the optimal tax have already adopted unilaterally. The impact of further unilateral adoption can be analyzed by examining

$$\Pi(\Delta) = P(\Delta)\left(\int_{\theta^{\tau*}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) - \int_{\theta^{\tau*}}^{\theta^{v}} \tau^{*}\,\mathrm{d}F(\theta) - \int_{\theta^{v}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta)\right)$$
$$+ (1-P(\Delta))\left(\int_{\underline{\theta}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) - \int_{\theta^{v}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta)\right). \tag{A.8}$$

Observe first that both

$$\int_{\theta^{\tau*}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) - \int_{\theta^{\tau*}}^{\theta^{v}} \tau^{*}\,\mathrm{d}F(\theta) - \int_{\theta^{v}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta) \tag{A.9}$$

and

$$\int_{\underline{\theta}}^{\bar{\theta}} \pi(\theta)\,\mathrm{d}F(\theta) - \int_{\theta^{v}}^{\bar{\theta}} c(\theta)\,\mathrm{d}F(\theta) \tag{A.10}$$

are increasing as θ^{v} rises. Next observe that (A.10) rises faster than (A.9) with an increase in θ^{v}. Thus, if $P(\Delta)$ also increases with an increase in θ^{v}, it will follow that industry profits rise as participation in the unilateral voluntary agreement declines (i.e., as θ^{v} rises). To see that this is so, observe from the definition of $\Delta(\tau)$ in (18) that $\Delta(\tau)$ is rising in θ^{v} and recall that $P'(\Delta) > 0$. □

Proof of Proposition 8. Industry profits under unilateral preemptive action are

$$E(\pi^{U}) = \int_{\underline{\theta}}^{\bar{\theta}} \pi(\theta)\, dF(\theta) - \int_{\theta^{-\tau}(K)}^{\bar{\theta}} c(\theta)\, dF(\theta). \tag{A.11}$$

For large enough K, the public VA will not be offered because its benefits are less than its costs; let us define the value of K such that the regulator is just indifferent to offering the VA as K^{-s}. Then for $K > K^{-s}$, the VA is not offered and expected profits with no unilateral action are

$$E(\pi^{NU}) = P(\Delta)\left[\int_{\theta^{\tau}}^{\bar{2}} \pi(\theta)\, dF(\theta) - \int_{\theta^{\tau}}^{\theta^{a}} \tau\, dF(\theta) - \int_{\theta^{a}}^{\bar{2}} c(\theta)\, dF(\theta)\right] + [1 - P(\Delta)]\int_{\underline{\theta}}^{\bar{\theta}} \pi(\theta)\, dF(\theta). \tag{A.12}$$

The benefit of preemption is the difference between (A.12) and (A.11):

$$E(\pi^{U}) - E(\pi^{NU}) = P(\Delta)\left[\int_{\underline{\theta}}^{\theta^{\tau}} \pi(\theta)\, dF(\theta) + \int_{\theta^{\tau}}^{\theta^{a}} \tau\, dF(\theta) + \int_{\theta^{a}}^{\bar{\theta}} c(\theta)\, dF(\theta)\right] - \int_{\theta^{-\tau}(K)}^{\bar{\theta}} c(\theta)\, dF(\theta). \tag{A.13}$$

The terms inside the square brackets represent savings to the industry if the tax is preempted. They consist of several parts: some firms are not forced to exit the industry, some do not have to pay the tax, and some are not forced to adopt the technology. The final term, which is not in brackets, reflects the difference between the level of adoption required to preempt, and the level that would be required under the voluntary agreement; this term may in principle be either positive or negative.

As K increases, so does $\theta^{-\tau}$, thereby reducing the direct cost of preemption by lowering the requisite level of unilateral adoption. Since the expression in (A.13) is continuous in K, there exists some K that makes preemption profitable. □

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