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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 modest 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, the implications for industry size, as well as the welfare implications of the various instruments.

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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 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 agreements 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, important gaps still exist regarding the strategic motivations for firms to enter voluntary agreements, as well as how these agreements affect industry competition and structure. 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 coherent framework.

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. It has been suggested that regulators may wish to preempt future regulations if voluntary actions represent a more efficient way of achieving environmental goals, or if they wish to avoid the negative legal and political consequences associated with regulatory failure. While these motivations may explain the adoption of some voluntary agreements, it is not uncommon to find public voluntary environmental agreements in the

[1] See Maxwell, Lyon and Hackett (2000) and Lutz, Lyon and Maxwell (2000) for models in which industries or firm undertake unilateral actions aimed at preempting or weakening future regulations.

[2] See Segerson and Miceli (1998) and Hanson (1999) for models in which firms and regulators enter into voluntary agreements so as to preempt legislation dictating traditional regulations.

absence of strong regulatory threats. Thus, pure preemption appears not to exhaust the list of factors motivating firms to enter into voluntary agreements. If voluntary environmental agreements are not designed to preempt legislation, what then is motivating firm and regulatory adoption of these agreements, and what are the impacts of such agreements on industry size and social welfare? This paper attempts to answer these questions.

We begin by reviewing the political history of the U.S. Climate Change Action Program (CCAP), which has spawned numerous public voluntary agreements, which we discuss in more detail below. We find that the CCAP and its progeny arose in the absence 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 regulatory benefit 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 does 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 game features a continuum of firms differentiated according to their abatement costs, which produce homogeneous goods 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. 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 have undertaken abatement efforts do not have to pay the tax. Firms that did not choose voluntary abatement in stage one may 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 interest is primarily positive: we study which types of firms, under what conditions, engage in unilateral voluntary abatement efforts or enter public voluntary agreements. In so doing, we hope to sharpen the discussion of voluntary agreements by distinguishing carefully between unilateral agreements and public voluntary agreements, as well as distinguishing between public voluntary agreements designed to preempt mandatory regulations and those adopted when mandatory regulations prove infeasible. In addition, however, we also explore the welfare implications of the various alternative instruments.

2 Unilateral and Public Voluntary Agreements

In this section we provide details of the political backdrop to many U.S. public voluntary environmental agreements 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.[3] For a broader institutional analysis of the use of public voluntary agreements, see Maxwell and Lyon (2000).

Background to U.S. Public Voluntary Agreements

In her survey of U.S. voluntary environmental agreements (VAs), Mazurek (1998) identifies 31 public voluntary schemes, 9 unilateral agreements, and 2 negotiated agreements. The public voluntary schemes are grouped into two categories, based on their main thrust: 1) Global Warming and 2) Pollution Prevention. We argue that these two areas share several important features: 1) Both arguably can be implemented at little or no cost to at least some subset of firms, 2) Both are areas where EPA does not have a statutory mandate to

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

require any actions, and 3) The heterogeneity of the offenders would have made command and control regulation complex and costly for EPA to administer.[4]

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 had promised to be the "environmental president." Most of them, however, were 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.

The pollution prevention VAs also emphasize behavior that is alleged to provide private benefits to firms, as captured in the phrase "pollution prevention pays." These VAs followed in the wake of the Toxic Release Inventory (TRI), a reporting program created by Congress in 1986. The mere reporting of toxic emissions produced substantial public relations problems for major emitters like Dow, DuPont and Monsanto, who began to voluntarily reduce their

[4] 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.

toxic emissions. Hoping to enhance positive media treatment of their efforts, these firms approached the EPA to ask for formal recognition. By most accounts, the most prominent of the pollution prevention VAs, the EPA's 33/50 Program, sprang from these requests by major toxic polluters.

In neither of these policy arenas does there appear to have been a substantial regulatory "threat" driving the adoption of VAs. In our conversations with 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 U.S. 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."[5]

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

[5] Michael Winer, "Energy Plan's Foes Poured on the Coal Starting Last Year," *International Herald Tribune*, June 15, 1993.

or sticks to bring us into compliance if those don't work."[6]

The CCAP

Released in October 1993, the President's Climate Challenge Action Plan (CCAP) embodies the Clinton Administration's commitment to reduce U.S. greenhouse gas emissions to 1990 levels by the year 2000.[7] The plan is based on the premise that government and private enterprise can work together to achieve program goals without harming the economy. The plan involves 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 program including Green Lights, Climate Wise, Motor Challenge and Energy Star Buildings among many others.[8] IAE (1998) examines U.S. corporation Johnson and Johnson's decisions to participate in several of the CCAP's public voluntary agreements, including each of those mentioned above. The examination clearly indicates that the chief factors motivating Johnson and Johnson to join the programs were the programs' implicit subsidies to participants.

[6] William K. Stevens, "U.S. Prepares to Unveil Blueprint for Reducing Heat-Trapping Gases," *New York Times*, October 12, 1993, page C4.
[7] This goal, of course, was not actually achieved.
[8] For details on these and the other programs introduced under the CCAP, see U.S. Office of Global Change (1997).

According to IAE (1998), participation in the EPA's Green Lights program provided Johnson and Johnson with several benefits. To begin with, the EPA provided participants with case studies focusing on the experiences of companies which replaced their lights and, importantly, detailing the cost savings of those companies. Second, the EPA commissioned outside consulting firms to conduct lighting seminars and provided technical information providing relevant details about different lighting technologies. Finally, the EPA developed a directory of various rebate programs provided by lighting companies.

Johnson and Johnson also joined the EPA's ClimateWise program. EPA provided the company with an account representative charged with helping the company develop a program action plan. In addition, participants received ongoing technical information and were invited to quarterly information sharing meetings with the EPA, outside consultants, and other program participants.

As a result of its participation in the Department of Energy's Motor Challenge program, Johnson and Johnson was provided with access to a question hotline, free software, a source book and technical bulletins. A particularly important factor in the company's decision to participate in the program was the DOE's provision of a software database of motors, vendors and Motor Challenge allies, which allowed the company to run an analysis of motor operating costs and retrofits.

Participation in the EPA's Energy Star Buildings program provided Johnson and Johnson, as a participant, with many of the same benefits found in the other public voluntary programs in which the company has participated. These included a technical hotline, case studies documenting savings, educational materials, software tools for estimating energy savings, and a database of financing programs pertaining to building efficiency upgrades.

This section has attempted to make two key points that are developed more fully in the model of the succeeding section. 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 The Model

Drawing on the insights into unilateral and public voluntary agreements developed in Section 2, we develop a three-stage game played between a regulator and the firms in an industry.

Any model, of course, is a simplification of reality, and before laying out the model in detail, we highlight its key features as well as some things that are specifically excluded.

We are interested in the relative merits of alternative instruments for environmental protection, so our model includes three such instruments: unilateral actions by industry, a public tax, and a public voluntary agreement (a subsidy program). Previous work has suggested that voluntary agreements are particularly promising in settings featuring technology adoption and international trade, so we incorporate these elements in our framework.[9] In our view, heterogeneity between firms is very important in understanding public voluntary agreements, so we make this a central feature of our model. In doing so, we develop a model of competitive global trade in which no firm has significant market power.[10] In 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. We purposely do not assume that voluntary actions are always 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

[9] See Brau and Carraro (1999) for a survey of existing work on voluntary agreements and market structure.
[10] This approach allows us to highlight issues of which firms are in or out of the industry, but we sacrifice some of the strategic complexity that would accompany a model of an oligopolistic industry.

of "win/win" solutions in which the adoption of environmentally-friendly technology lowers cost, as economic analysis is not needed to conclude that these actions are desirable.

The basic set up 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. Firms, which are indexed by θ, differ according to their profitability and their fixed adoption costs of an environmental technology. 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.) We denote by $\pi(\theta)$ the gross profits of a firm of type θ, and we assume that $\partial\pi/\partial\theta > 0$. Similarly, let $c(\theta)$ represent the fixed adoption costs of the environmental technology for a firm of type θ. We assume that these adoption costs are decreasing in θ. Further, we assume that there exists some $\tilde{\theta} \in \left(\underline{\theta}, \overline{\theta}\right)$ that generates zero profits *gross* of the fixed costs of adoption. The regulator is assumed to have beliefs about the distribution of firm types in the industry but does not know the profitability of any particular firm.

The regulator is interested in maximizing social welfare. We assume that each operating firm emits pollutants which impose an external cost on domestic consumers of $x > 0$. The domestic value of a firm's profits is totally captured by $\pi(\theta)$. The net social welfare generated by firm θ prior to the adoption of the environmental technology is $\pi(\theta) - x$. Thus, absent adoption of the environmental technology, the optimal size of the industry is defined by θ^x where $\pi(\theta^x) - x = 0$. We assume that by adopting the environmental technology the firm can eliminate all environmental costs its production imposes on the domestic population.

In an unregulated equilibrium entry will occur until gross profits are driven to zero.[11] This will cause excessive entry from a social view point and the 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. 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. We follow Lewis in assuming that the probability that legislation allowing the imposition of the tax, $P(\Delta)$, is declining in Δ, where Δ represents the total value of industry losses arising from the tax program.

The imposition of a tax, however, is not the only strategy available to the regulator in our model. In particular the regulator may propose a public voluntary agreement to encourage the adoption of the environmental technology. As we have illustrated in Section

[11] Absent regulation there is no incentive for any firm to adopt the environmental technology since foreign consumers either do not care about the pollution costs borne by domestic consumers, or they cannot determine which firms have adopted the green technology. Thus, we do not consider green consumerism as a motivation for the adoption of environmental technologies. The practical importance of this motivation is unclear, anyway, as discussed in Lyon and Maxwell (2000).

2, many public voluntary agreements contain features which serve to subsidize the cost of corporate environmental actions. The subsidies consist of transfers of managerial costs to the regulatory agency as the agency undertakes to gather technical information about available green products, offers free publicity about corporations' green actions, and provides basic research on green product designs. 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 which voluntarily 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. One can imagine a more general subsidy that could also be collected by firms that choose to reduce their emissions by exiting the industry altogether.[12]

The regulatory actions contained in public voluntary agreements will generally involve a redirection of regulatory resources away from mandated regulatory activities. Thus, we assume that the subsidies paid to the regulatory authorities involve costly public funds. Consequently, if passing legislation is not too difficult, the regulator will prefer tax policies over the use of public voluntary agreements. We assume that firms which adopted the environ-

[12] Lewis (1996) models a subsidy in this fashion; his model does allow for the possibility of technology adoption, however.

mental technology prior to the establishment of the public voluntary agreement cannot be excluded from receiving the benefits of participating in the voluntary agreement, an assumption that is consistent with government practice in a number of public voluntary programs such as the US EPA's 33/50 Program.

Summarizing, firms decide whether or not to adopt the environmental technology based on the decision's impact on their expected profits. The regulator may decide to propose an environmental tax τ; if it chooses not to, 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.

The timing of the game is illustrated in Figure 1. At each node, the player making the decision is denoted by either "I" (Industry), "R" (Regulator), or "N" (Nature). In the first stage, in anticipation of the imposition of an environmental tax, firms may enter into a unilateral public voluntary agreement, in an attempt to preempt the tax.[13] As discussed above, we imagine the industry working in concert in its preemption efforts. Under this assumption, firms with the lowest technology adoption costs will be the first to enter the unilateral voluntary agreement. Thus, we denote by θ^v the firm with the highest technology

[13] We show below that firms will enter into a unilateral voluntary agreement only if their actions serve to preempt the formal proposal of the tax.

adoption costs that decides to join 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 $\theta^v = \overline{\theta}$.

If the regulator were to take no subsequent action, then social welfare conditional upon the industry's unilateral efforts, would be given by

$$W(\emptyset, \theta^v) = \int_{\tilde{\theta}}^{\theta^v} [\pi(\theta) - x]\, dF(\theta) + \int_{\theta^v}^{\bar{\theta}} [\pi(\theta) - c(\theta)]\, dF(\theta). \tag{1}$$

where the symbol $\emptyset$ indicates that no action is taken by the government. The first term on the right hand side of (1) denotes the social value of firms that decide not to voluntarily adopt the technology, while the second term captures the social value of those that do adopt.

Following the industry's unilateral efforts, the regulator in stage 2 may propose an environmental tax τ if the expected tax benefits $\overline{W}(\tau, \theta^v)$ exceed the fixed costs K it must incur in proposing the tax. The benefits of the proposed tax are uncertain because the tax proposal is subject to lobbying resistance from the industry which may ultimately prevent the imposition of the tax. Hence, expected welfare must also account for the action that will be taken by the government in stage 3 if the tax fails to pass, *i.e.* $\overline{W}(\tau, \theta^v) = P(\Delta) W(\tau, \theta^v) + [1 - P(\Delta)] W(s^*, \theta^v)$, where $W(\tau, \theta^v)$ is social welfare if the tax passes while $W(s^*, \theta^v)$ is social welfare if the tax is defeated and the regulator imposes the socially optimal subsidy s^* in stage 3.

At the beginning of the game's third stage, the outcome of legislative efforts is revealed to all players. If the legislative efforts are successful, firms are taxed at the proposed rate. The tax may induce exit from the industry by some firms and may induce adoption of the environmental technology by others. Firms that do not follow either of these options operate and pay the tax. If legislative efforts fail, the regulator may propose a public voluntary agreement, at a fixed cost of K, in which it subsidizes at a level s all firms that adopt the environmental technology. Participant firms will adopt the technology and receive the subsidy, while nonparticipants will operate as they would have in the absence of any regulatory efforts. Welfare under the subsidy is denoted by $W(s, \theta^v)$.

4 Model Analysis and Results

In this section, following standard practice, we solve for the subgame perfect Nash equilibrium of the game by working backward from the final stage to stage 1. We also provide a number of lemmas and propositions that characterize industry and regulator behavior.

Stage 3: The Public Voluntary Agreement

Should legislative efforts fail, the regulator may incur a fixed cost K and propose a public voluntary agreement consisting of a subsidy s, payable to firms which adopt the environmental technology. Define θ^s such that $c(\theta^s) = s$; thus, all firms of type $\theta \geq \theta^s$ adopt the technology. We consider first the case in which all companies that have previously adopted the technology also receive the subsidy. The subsidy is chosen to maximize social welfare. Thus, the regulator faces the following optimization problem:

$$\max_s W(s, \theta^v) = \int_{\tilde{\theta}}^{\theta^s} [\pi(\theta) - x] \, dF(\theta) + \int_{\theta^s}^{\theta^v} [\pi(\theta) - c(\theta) + s] \, dF(\theta) + \int_{\theta^v}^{\bar{\theta}} (\pi(\theta) - c(\theta) + s) \, dF(\theta) - [1 - F(\theta^s)] \, s(1 + \lambda), \qquad (2)$$

where $\lambda > 0$ indicating that the funds used to subsidize adoption are costly.[14]

The first term on the right hand side of (2) indicates the total net contribution to social welfare from firms operating in the industry that do not adopt the clean technology, *i.e.*, do not join the public voluntary program. The second term on the right hand side denotes the net contribution to social welfare arising from newly-adopting program participants, *i.e.* those who did not undertake unilateral efforts at stage 1. The third term measures profits of voluntary adopters under the unilateral public voluntary agreement and the final term captures the total costs of funding all program participants. All firms indexed by $\theta \in (\theta^s, \theta^v)$ join the public voluntary program by adopting the environmental technology, while all firms

[14]The reader will note that the second and third terms on the right hand side of (2) 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 $W(\cdot, \theta^v)$.

indexed by $\theta \geq \theta^v$ adopt unilaterally in stage 1.

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

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

It is worth noting that the optimization problem (2) is the same as the optimization of the net gains from the subsidy (relative to the case in which the government takes no action), which may be written as:

$$\max_s NW(s, \theta^v) = \int_{\theta^s}^{\theta^v} [x - c(\theta)]\, dF(\theta) - \lambda s [1 - F(\theta^s)] - K. \tag{4}$$

The components of the net welfare gains are illustrated in Figure 2. The first term in (4) is captured by the lightly shaded region between θ^s and θ^v , which shows the social gains that accrue when firms participate in the program, incurring costs $c(\theta)$ but reducing the social cost of emissions by x. The second term is captured by the darker shaded region between θ^s and $\overline{\theta}$, although the area of this region must be multiplied by $(1 + \lambda)$ to equal the cost of the subsidy to the government. The fixed cost, K, is not shown in the diagram. Note that if $\theta^v \leq \theta^s$ there is no net gain to the subsidy, and the public voluntary program will not be proposed. The first order condition of the optimization problem (4) is:

$$-\frac{d\theta^s}{ds} [x - c(\theta^s)] \; f(\theta^s) - \lambda[1 - F(\theta^s)] + \lambda s f(\theta^s) \frac{d\theta^s}{ds} = 0. \tag{5}$$

Using (3) the solution to first order condition (5) yields:

$$s^* = \frac{\lambda}{1+\lambda}\left(\frac{c'(\theta^s)[1-F(\theta^s)]}{f(\theta^s)}\right) + \frac{x}{1+\lambda}. \tag{6}$$

Let $W(s^*, \theta^v)$ denote the optimized value of social welfare under the public voluntary agreement. This optimization result leads directly to the following lemma.

Lemma 1 *When public funds are costly ($\lambda > 0$) the optimal subsidy s^* is less than x.*

Lemma 1 illustrates the fact that when public funds are costly the public voluntary agreement fails to achieve the first-best outcome. Too few firms will adopt the environmental technology. 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. As s increases, additional participation is reflected in the term $f(\theta^s)\frac{d\theta^s}{ds} \equiv f(\theta^s)/c'(\theta^s)$,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 more distorted when the absolute value of $c'(\theta^s)$ is large. 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, a VA will perform better when the cost of public funds is low and the cost of technology adoption does not vary greatly across firms.

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 forgo the public voluntary program. Then $\theta^{-s} > \theta^{s^*}$ is defined by

$$\int_{\theta^{s^*}}^{\theta^{-s}} \left[x - c\left(\theta^{s^*}\right)\right] dF\left(\theta^{s^*}\right) = \lambda s^* \left[1 - F\left(\theta^{s^*}\right)\right] + K. \tag{7}$$

It follows from comparing (7) with $NW(s^*, \theta^v)$ that 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. However, it is important that the cost of adopting the new technology is low relative to the social impact of emissions, so that the benefits from the program (captured on the left hand side of 7) are great enough to justify its costs. In other words, the public VA captures the "low hanging fruit" but is not powerful enough to reach the social optimum.

Stage 2: Proposal of an Environmental Tax

In the second stage of the game the regulator may incur a fixed cost K and propose an environmental tax. As we detail below, any tax proposal will result in losses to the industry.

As a result, industry will oppose even a first-best tax. We show below that the optimal tax proposed by the regulator will thus 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

$$\frac{d\theta^{\tau}}{d\tau} = \frac{1}{\pi'(\theta^{\tau})} > 0. \tag{8}$$

All firms indexed by $\theta \in \left[\tilde{\theta}, \theta^{\tau}\right)$ 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

$$\frac{d\theta^{a}}{d\tau} = \frac{1}{c'(\theta^{a})} < 0. \tag{9}$$

All firms indexed by $\theta \in [\theta^{\tau}, \min\{\theta^{a}, \theta^{v}\}$ will continue operations, but each firm will incur losses equal to the tax. If $\theta^{a} < \theta^{v}$ then firms indexed by $\theta \in [\theta^{a}, \min\{\theta^{v}, \theta^{s}\})$ will be induced to adopt the environmental technology rather than pay the tax. Note that firms with $\theta > \max\{\theta^{v}, \theta^{s}\}$ adopt regardless of whether the tax is enacted. In so doing, these firms will incur the adoption cost $c(\theta)$. 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.

Recall that as long as $\theta^{v} > \theta^{-s}$ the subsidy program will not be preempted by the industry's stage 1 unilateral voluntary efforts. In this case, the tax will result in a loss equal to s^* for all firms that either would have adopted the technology under the public voluntary agreement or that had already done so at stage 1, *i.e.* all firms indexed by $\theta \in \left[\theta^{s^*}, \bar{\theta}\right]$. These opportunity costs of a tax must also be taken into account. Thus, industry losses arising from the proposed tax may be written as

$$\begin{aligned}\Delta(\tau) &= \int_{\tilde{\theta}}^{\theta^{\tau}} \pi(\theta)\, dF(\theta) + \int_{\theta^{\tau}}^{\min\{\theta^{a},\theta^{v}\}} \tau dF(\theta) \\ &+\Phi\left(\theta^{-s}, \theta^{v}\right)\left(\Phi\left(\theta^{a}, \theta^{v}\right) \int_{\theta^{a}}^{\min\left\{\theta^{s^*},\theta^{v}\right\}} c(\theta)\, dF(\theta) + \int_{\theta^{s^*}}^{\bar{\theta}} s dF(\theta)\right) \\ &+\Phi\left(\theta^{v}, \theta^{-s}\right)\left(\Phi\left(\theta^{a}, \theta^{v}\right) \int_{\theta^{a}}^{\theta^{v}} c(\theta)\, dF(\theta)\right)\end{aligned} \tag{10}$$

where $\Phi(x, y)$is an indicator variable taking on the value 1 if $x < y$ and 0 otherwise. As mentioned above, we follow Lewis (1996) in assuming that the probability that the proposed tax legislation passes, $P(\Delta)$, is falling in Δ. A careful examination of (10) yields the following useful lemma, the proof of which is provided in the Appendix.

Lemma 2 *Industry losses $\Delta(\tau)$ are rising in the level of the environmental tax τ.*

Following the unilateral voluntary actions by industry, if any, the regulator may propose its optimal tax. Absent any political opposition, the regulator's objective function is given by

$$W(\tau, \theta^v) = \int_{\theta^\tau}^{\min\{\theta^a,\theta^v\}} [\pi(\theta) - x]\, dF(\theta) + \int_{\min\{\theta^a,\theta^v\}}^{\overline{\theta}} [\pi(\theta) - c(\theta)]\, dF(\theta) \tag{11}$$

The first term on the right hand side of (11) denotes the social value of firms remaining in the industry and paying the tax after its imposition. The second term denotes the social value of firms that adopt the new technology. We can also write the net gain from the tax, relative to government inaction, as

$$W(\tau, \theta^v) - W(\emptyset, \theta^v) = -\int_{\widetilde{\theta}}^{\theta^\tau} [\pi(\theta) - x]\, dF(\theta) + \Phi(\theta^a, \theta^v) \int_{\theta^a}^{\theta^v} [x - c(\theta)]\, dF(\theta) \tag{12}$$

These gains are illustrated in Figure 3. The first term represents social gains from forcing inefficient firms to exit the industry. It is positive because profits are less than than x on its range; this term is shown as the shaded area between $\widetilde{\theta}$ and θ^{τ^*} in the lower left part of the figure. The second term is only positive if $\theta^a < \theta^v$, since otherwise the tax induces no additional adoptions. The social gains from adoptions, assuming they are positive, are represented by the shaded region in the right hand side of the figure between θ^a and θ^v.

It is interesting to note that regardless of the ordering of θ^a and θ^v, the optimal tax, absent political opposition, is $\tau = x$. To see this, suppose first that $\theta^v < \theta^a$. Then the optimization of (11) yields

$$\frac{\partial W(\tau,\theta^v)}{\partial \tau} = -\frac{\partial \theta^\tau}{\partial \tau}\left[\pi(\theta^\tau) - x\right] f(\theta^\tau) = 0. \tag{13}$$

Recalling that $\pi(\theta^\tau) = \tau$, we see that the optimal tax equals x since we can rewrite (13) as

$$\frac{\partial W(\tau,\theta^v)}{\partial \tau} = (\tau - x)\left[-\frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right] = 0. \tag{14}$$

Next suppose that $\theta^a < \theta^v$. Optimization of (11) then yields

$$\frac{\partial W(\tau,\theta^v)}{\partial \tau} = \frac{\partial \theta^a}{\partial \tau}\left[c(\theta^a) - x\right] f(\theta^a) - \frac{\partial \theta^\tau}{\partial \tau}\left[\pi(\theta^\tau) - x\right] f(\theta^\tau) = 0 \tag{15}$$

Using the facts that $\pi(\theta^\tau) = \tau$ and $c(\theta^a) = \tau$ we can rewrite (15) as

$$\frac{\partial W(\tau,\theta^v)}{\partial \tau} = (\tau - x)\left[\frac{f(\theta^a)}{c'(\theta^a)} - \frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right] = 0. \tag{16}$$

Thus, absent political opposition it is optimal for the regulator to set the environmental tax equal to the environmental damage caused by the marginal firm. In reality, however, firms will have an incentive to oppose a tax since, from (10) 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 pass with probability $P(\Delta)$. Thus, in setting the tax the regulator solves the following optimization problem:

$$\max_{\tau} \bar{W}(\tau,\theta^v) = P(\Delta)\, W(\tau,\theta^v) + \left[1 - P(\Delta)\right] W(s^*,\theta^v). \tag{17}$$

Substituting (11) into (17) we see that:

$$\begin{aligned}\frac{\partial \bar{W}}{\partial \tau} &= P(\Delta)\left\{(\tau - x)\left(\Phi(\theta^a, \theta^v)\left[\frac{f(\theta^a)}{c'(\theta^a)} - \frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right] + \Phi(\theta^v, \theta^a)\left[-\frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right]\right)\right\} \qquad (18)\\ &\quad + P'(\Delta)\frac{\partial \Delta}{\partial \tau}\left[W(\tau, \theta^v) - W(s^*, \theta^v)\right],\end{aligned}$$

and thus, optimization of (17) yields:

$$\tau^* = x - \frac{P'(\Delta)}{P(\Delta)}\frac{\partial \Delta(\tau^*)}{\partial \tau}\frac{\left[W(\tau^*, \theta^v) - W(s^*, \theta^v)\right]}{\left(\Phi(\theta^a, \theta^v)\left[\frac{f(\theta^a)}{c'(\theta^a)} - \frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right] + \Phi(\theta^v, \theta^a)\left[-\frac{f(\theta^\tau)}{\pi'(\theta^\tau)}\right]\right)}. \qquad (19)$$

Recalling from lemma 2 that $\partial\Delta/\partial\tau > 0$, and observing that the denominator in parentheses on the right hand side of (19) is always negative, we see that the political resistance weakens the tax from its first-best level whenever the regulator prefers the tax over the public voluntary agreement (*i.e.,* whenever $W(\tau^*, \theta^v) > W(s^*, \theta^v)$). We record this result in the following Lemma:

Lemma 3 *Political resistance causes the regulator to propose a tax that is strictly less than the first-best level, i.e.* $\tau^* < x$.

The extent of the distortion away from the first-best depends on a number of factors, as is evident in (19). First, the distortion is greater when industry is highly responsive politically to losses, *i.e.* when $P'(\Delta)$ is large. Second, the distortion is greater when the probability of passing a tax, $P(\Delta)$, is small. This will occur when the political resistance to a tax is strong, 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, when resistance is high, optimization calls for proposing only a small tax. Third, the distortion is greater when losses rise rapidly with the tax rate, *i.e.* when $\partial\Delta(\tau^*)/\partial\tau$ is large. Fourth, the distortion is greater when the value to the regulator of passing the tax is high, as measured by $[W(\tau^*, \theta^v) - W(s^*, \theta^v)]$. In this case, the regulator wishes to raise the probability of passing the tax proposal by weakening it. Finally, the distortion is greater when a marginal change in the tax rate has a small impact on the number of firms that exit the industry or adopt the technology. This effect is captured in the denominator of (19). If $\theta^v < \theta^a$, then the tax will induce no additional adoptions, and only the exit effect is present. It is captured by the term $-f(\theta^\tau)/\pi'(\theta^\tau) \equiv -f(\theta^\tau)[\partial\theta^\tau/\partial\tau]$, which indicates the measure of firms that will be forced to exit due to the tax. This measure is greater when $\pi'(\theta^\tau)$ is small, *i.e.* when firms are not too heterogeneous in terms of their innate efficiency. If $\theta^v > \theta^a$, then the tax also has the effect of inducing additional adoptions, the effect of which is captured by the similar term $-f(\theta^a)/c'(\theta^a) \equiv -f(\theta^a)[\partial\theta^a/\partial\tau]$, which indicates the measure of firms that will be forced to adopt due to the tax. In either case, if a marginal increase in the tax induces little behavioral change from the industry, then its main impact will be to increase political resistance from those firms that must pay the tax; as a result, the tax rate will be distorted away from the optimal level.

The following Lemma compares the performance of the tax and the public VA under optimal conditions, *i.e.* when $\lambda = 0$ and $P(\Delta) = 1$. Under these conditions, $s^* = \tau^* = x$.

Lemma 4 *When regulators are not constrained by the costs of raising subsidy funds or the need to respond to political opposition from industry, i.e. when* $\lambda = 0$ *and* $P(\Delta) = 1$, *the optimal pollution tax generates greater social benefits than does the optimal public voluntary agreement.*

Proof. Define $\theta^x = c^{-1}(x)$. Then social welfare under the VA is

$$W\left(s^* = x, \overline{\theta}\right) = \int_{\widetilde{\theta}}^{\theta^x} \left[\pi\left(\theta\right) - x\right] dF\left(\theta\right) + \int_{\theta^x}^{\theta^v} \left[\pi\left(\theta\right) - c\left(\theta\right)\right] dF\left(\theta\right)$$

and social welfare under the tax is

$$W\left(\tau^* = x, \overline{\theta}\right) = \int_{\theta^\tau}^{\theta^x} \left[\pi\left(\theta\right) - x\right] dF\left(\theta\right) + \int_{\theta^x}^{\theta^v} \left[\pi\left(\theta\right) - c\left(\theta\right)\right] dF\left(\theta\right).$$

The only difference between these two expressions is that the tax induces exit by firms with $\theta \in [\widetilde{\theta}, \theta^\tau]$. These exits are socially beneficial, since these firms had profits that were less than the social cost of their emissions. ■

Clearly the tax is inherently a more powerful instrument than the public VA. As mentioned above, the fundamental limitation of the public 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. 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; we combine them and record the results in the following proposition.

Proposition 5 *The performance of 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. The performance of a pollution tax improves when political resistance is low and/or unresponsive to industry losses, and when innate efficiency does not vary greatly across firms.*

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.

Stage 1: Unilateral Voluntary Agreement Decision

In the first stage, 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 objectives. Because the full analysis of these effects is involved, and somewhat tedious, the formal analysis is relegated to the appendix. Here we provide the intuition behind the results in a less formal fashion.

To begin with, we assume that $W(\tau^*, \overline{\theta}\ ) > W(s^*, \overline{\theta})$, *i.e.* 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 $\theta^v = \overline{\theta}$, then the industry will take no preemptive action.

We consider now the impact of unilateral voluntary efforts on the regulator's benefits of offering a public voluntary agreement. As mentioned earlier, the regulator will choose not to offer the voluntary agreement if $\theta^v \leq \theta^{-s}$. Here we examine how regulatory benefits change as θ^v falls. Recall that those benefits are given by:

$$NW(s^*, \theta^v) = \int_{\theta^{s^*}}^{\theta^v} [x - c(\theta)]\, dF(\theta) - \lambda s^* \left[1 - F\left(\theta^{s^*}\right)\right] - K. \qquad (20)$$

Noting from (6) 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 following proposition arises directly from (20).

Lemma 6 *The regulatory benefits arising from a public voluntary agreement are strictly decreasing in* θ^v *and reach zero at* $\theta^v = \theta^{-s}$.

Lemma 6 shows that unilateral voluntary activity on the part of the industry will not enhance the likelihood that the regulator will provide the public voluntary program. Given the fact that these efforts also have no effect on the level of the subsidy, and noting that 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, it is clear that incentives for unilateral voluntary action exist only because of the threat of regulation. 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. These net benefits are:

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

Equation (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 the fixed cost K appears only in the bottom term since this cost is not incurred under the no-action option. Substituting (17) into (21) we see that the regulator's net benefit of taxation may be rewritten as

$$\overline{NW}\left(\tau^{*},\theta^{v}\right)=\begin{cases} P\left(\Delta\right)\left[W\left(\tau^{*},\theta^{v}\right)-W\left(s^{*},\theta^{v}\right)\right] & \theta^{v}\geq\theta^{-s} \\ P\left(\Delta\right)\left[W\left(\tau^{*},\theta^{v}\right)-W\left(\emptyset,\theta^{v}\right)\right]-K & \theta^{v}<\theta^{-s}\end{cases}. \tag{22}$$

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. Denote by $\theta^{-\tau}$ the level of θ^{v} such that $\overline{NW}\left(\tau^{*},\theta^{-\tau}\right)=0$. Note that $\partial\theta^{-\tau}/\partial K>0$, indicating that large K implies that preemption is possible with a smaller amount of unilateral action.

We show in the appendix that it must be the case that $\theta^{-\tau}<\theta^{-s}$, *i.e.*, unilateral abatement will preempt the public VA before it preempts the tax. In addition, the appendix also contains a proof that expected industry profits are increasing in θ^{v} all $\theta^{v}\in\left[\theta^{-\tau},\bar{\theta}\right]$. Consequently, the industry will never engage in unilateral voluntary actions that do not lead to the preemption of the proposed tax.[15] Nevertheless, we show that preemption is possible under the right conditions. Specifically, we prove

Proposition 7 *If $P'(\Delta)$ is sufficiently small then there exists K large enough that $\theta^{-\tau} \in \left(\theta^a, \theta^{-s}\right)$.*

Proposition 7 shows that when $P'(\Delta)$ is sufficiently small, preemption through unilateral voluntary agreements is possible if the costs of introducing a tax are large enough.[16] This possibility is illustrated in Figure 4, which traces out the impact of marginal increases in unilateral abatement on the government's net benefits from proposing a tax. We show in the proof of proposition 7 that changes in θ^v on the interval $(\theta^{-s}, \overline{\theta})$ have no impact on either the welfare arising from the subsidy or the welfare arising from the tax policy. Furthermore, industry losses are unaffected by changes in θ^v as long as $\theta^v > \theta^{-s}$. Consequently, the regulator's expected gain from proposing the tax, $P(\Delta)[W(\tau^*, \theta^v) - W(s^*, \theta^v)]$, remains constant on this interval in the face of rising unilateral voluntary efforts. When θ^v reaches θ^{-s} however, the subsidy program is preempted. Thus, as θ^v falls within the range $\left(\theta^a, \theta^{-s}\right)$ we must examine the impact of further unilateral actions on $P(\Delta)[W(\tau^*, \theta^v) - W(\emptyset, \theta^v)] - K$. We show in the proof of proposition 7 that these unilateral actions raise the value of $W(\emptyset, \theta^v)$,

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

[16] As we show in the proof, this is a sufficient but not necessary condition. Even with large $P'(\Delta)$, preemption is possible if industry losses are unresponsive to marginal voluntary efforts or if the welfare gains from taxation are small.

while from (11) $W(\tau^*, \theta^v)$ is unaffected. In the former case, unilateral voluntary adoption raises welfare directly because the adoptions would not take place under the "no action" policy. In the latter case, the adoptions would take place once the tax is imposed, thus they contribute nothing to social welfare.[17] Note that industry losses from a tax are declining as θ^v falls, thus we need to ensure that $P'(\Delta)$ is small enough that $P(\Delta)[W(\tau^*, \theta^v) - W(\emptyset, \theta^v)]$ declines as θ^v falls over the range $\left(\theta^a, \theta^{-s}\right)$. Under these conditions, we show that for K sufficiently large preemption is possible. This is illustrated in Figure 4, which shows the government's net welfare from proposing a tax, $\overline{NW}$. As K rises, the entire $\overline{NW}$ curve is shifted downward. For large enough K, this curve can be made to pass below zero, at which preemption is possible.

Of course, even if preemption is possible, it may not be profitable. In the appendix, however, 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 and λ.*

The proposition shows it is possible to find values of the parameters K and λ such that preemption will be accomplished with a minimal amount of unilateral action. Thus

[17] Note that the envelope theorem ensures that incremental unilateral adoptions do not affect τ^* and thus do not indirectly raise $W(\tau^*, \theta^v)$.

preemption is expected to occur when the cost of proposing a new government program is large and the cost of raising subsidy funds is high. This result extends that of Maxwell, Lyon and Hackett (2000), who show that preemption is possible when there is no possibility of a public voluntary agreement.

The relationship between K and the extent of unilateral action is shown in Figure 5. At high levels of K, legislation is effectively "blockaded" due to the excessive fixed cost of proposing 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, the threat of legislation rises so the 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. This is shown in the figure where there is a sharp, discontinuous, drop in unilateral activity.

5 Implications of VAs for Market Structure and Social Welfare

We consider now the effect of public VAs on the size of the industry. As discussed earlier, a key difference between a tax and a VA is that the tax forces some inefficient firms to exit the industry, while the VA does not. Thus the VA leads to a larger industry than does a tax. From this perspective, public VAs should not be thought of as having anti-competitive effects. Instead of serving as a barrier to entry, a VA simply represents a rent provided to high-efficiency firms.

It is worth noting that as λ grows, the VA subsidy will shrink, as can be seen from (6), but this has no impact on industry size since all firms remain in the industry. It will, however, reduce the number of firms joining the public VA, as is to be expected.

The effects of unilateral actions on industry size are somewhat more involved. In our model, unilateral actions take the form of early adoptions of the new technology by high-efficiency firms. No firms are forced to exit the industry as a result of unilateral actions. In fact, unilateral actions will have no effect on industry size unless the unilateral action preempts the regulator's tax proposal, in which case the unilateral abatement actually increases the size of the industry, relative to its expected value with no unilateral action. Once again, voluntary action has no negative effects on industry size. We record the above results in the next proposition.

Proposition 9 *Voluntary pollution abatement does not reduce industry size. A public voluntary agreement has no impact on industry size. Unilateral abatement only affects industry size if it preempts the regulator's tax proposal, in which case the size of the industry grows relative to its expected value with no unilateral action.*

Our analysis has been conducted in a setting where final products are homogeneous, so firms that adopt the new technology do not increase their sales as a result. We would expect the results of Proposition 9 to change if a significant portion of industry sales are made to "green consumers" who are willing to pay a premium for environmentally-friendly products. In this case, firms that participate in a public VA or that adopt the technology unilaterally would experience an increase in sales that would come in part at the expense of firms that did not adopt the technology. Some inefficient firms would then be expected to exit from the market.

Our analysis has implications for welfare as well as for market structure. 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 preemption raises welfare. The question turns on whether $W(\emptyset, \theta^{-\tau}) > \overline{W}(\tau^*, \overline{\theta})$, *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 10 *Expected social welfare is higher when unilateral industry action preempts government action, i.e., when* $W(\emptyset, \theta^{-\tau}) > \overline{W}(\tau^*, \overline{\theta}) - K$.

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

$$\frac{\partial \bar{W}(\tau^*, \theta^v)}{\partial \theta^v} = P(\Delta)\frac{\partial W(\tau^*, \theta^v)}{\partial \theta^v} + [1 - P(\Delta)]\frac{\partial W(s^*, \theta^v)}{\partial \theta^v} + P'(\Delta)\frac{\partial \Delta}{\partial \theta^v}[W(\tau^*, \theta^v) - W(s^*, \theta^v)] < 0. \tag{23}$$

The first two terms are less than or equal to zero for all $\theta^v > \theta^x$. The first term is zero for $\theta^v > \theta^a$ and negative for $\theta^v \in (\theta^x, \theta^a)$. 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 $W(\tau^*, \theta^v) - W(s^*, \theta^v) > 0$, 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. As a result, $\overline{W}(\tau^*, \theta^{-\tau}) > \overline{W}(\tau^*, \overline{\theta})$. Combining this with the definition of preemption, we have $W(\emptyset, \theta^{-\tau}) > W(\tau^*, \theta^{-\tau}) - K > \overline{W}(\tau^*, \overline{\theta}) - K$. ■

The proposition shows that unilateral action enhances social welfare. As shown in the proof, expected welfare with the tax increases with unilateral abatement, so welfare is higher at $\theta^v = \theta^{-\tau}$ than it would be at $\theta^v = \overline{\theta}$. 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.[18] Given this, public policy ought to encourage unilateral voluntary agreements by shielding them from antitrust

[18] This result parallels the welfare analysis of preemption provided by Maxwell, Lyon and Hackett (2000), extending it to the case where a public voluntary agreement is a possibility.

prosecution.

An interesting implication of the proposition is that a public voluntary agreement which preempts a tax may actually reduce welfare. This conclusion is at odds with the conventional view of public VAs, which sees them as a more efficient instrument than traditional mandatory regulations, and hence something to be encouraged. Nevertheless, we have shown that industry may take unilateral action to preempt the threat of a tax, but will never want to preempt the threat of a subsidy. We have also shown that preemption is socially beneficial. If the public VA is only a little better than a tax, then it is possible for welfare to fall as the public VA preempts an industry-led unilateral VA, 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 even when public VAs are more effective instruments than Pigouvian taxes, they may reduce welfare by preempting unilateral VAs that would be even better.

We show that under ideal conditions (*i.e.*, when government can costlessly raise funds for public voluntary programs and can pass efficient taxes without political resistance) taxation 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 these ideal conditions do not hold, but we do identify conditions under which they are appropriate policy instruments. First, they are better than government inaction in cases where taxation is desirable but cannot be passed due to political resistance by industry. Second, they 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. This result suggests that antitrust officials should not prosecute business-led unilateral voluntary agreements. In addition, our welfare result suggests another danger of substituting public VAs for traditional regulation: 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 business-led initiatives.

Our analysis indicates that voluntary pollution abatement is unlikely to have anticompetitive implications. Voluntary abatement–either unilateral or through a public VA–does not reduce industry size. It simply involves the adoption of environmentally-friendly technology by efficient firms. Taxation, on the other hand, reduces industry size by inducing inefficient firms to exit. Thus voluntary agreements should be more favorable to product-market competition than traditional regulatory instruments. This conclusion could be reversed under certain conditions. If public VAs induced more environmental improvement than taxation, and if consumers had strong preferences for buying "green" products, then a public VA could drive customers away from dirtier firms, thereby inducing exit and consolidating market power in the hands of a group of large clean firms. Such an outcome does not occur in our model, which focuses on a homogeneous-product industry with global competition. Future research that extends our model to incorporate product differentiation and imperfect competition would be worthwhile.

Appendix A

A Proofs of Propositions and Lemmas

Proof of Lemma 2

The proof follows directly from the differentiation of (10) in each of the following cases.

Case 1: $\theta^{v} > \theta^{-s} > \theta^{a} > \theta^{\tau}$

In this case

$$\Delta(\tau) = \int_{\tilde{\theta}}^{\theta^{\tau}} \pi(\theta)\, dF(\theta) + \int_{\theta^{\tau}}^{\theta^{a}} \tau dF(\theta) + \int_{\theta^{a}}^{\theta^{s^*}} c(\theta)\, dF(\theta) + \int_{\theta^{s^*}}^{\bar{\theta}} s dF(\theta), \tag{A.1}$$

so

$$\frac{\partial \Delta}{\partial \tau} = \pi(\theta^{\tau}) f(\theta^{\tau}) \frac{\partial \theta^{\tau}}{\partial \tau} + [F(\theta^{a}) - F(\theta^{\tau})] + \frac{\partial \theta^{a}}{\partial \tau} \tau f(\theta^{a}) - \frac{\partial \theta^{\tau}}{\partial \tau} \tau f(\theta^{\tau}) - \frac{\partial \theta^{a}}{\partial \tau} c(\theta^{a}) f(\theta^{a}). \tag{A.2}$$

Recalling that $c(\theta^{a}) = \tau = \pi(\theta^{\tau})$ we see that equation (2) reduces to

$$\frac{\partial \Delta}{\partial \tau} = [F(\theta^{a}) - F(\theta^{\tau})] > 0. \tag{A.3}$$

Case 2: $\theta^{-s} > \theta^{v} > \theta^{a} > \theta^{\tau}$

In this case unilateral industry efforts preempt the public voluntary agreement and industry losses arising from the tax may be written as

$$\Delta(\tau) = \int_{\tilde{\theta}}^{\theta^{\tau}} \pi(\theta)\, dF(\theta) + \int_{\theta^{\tau}}^{\theta^{a}} \tau dF(\theta) + \int_{\theta^{a}}^{\theta^{v}} c(\theta)\, dF(\theta), \tag{A.4}$$

and

$$\frac{\partial \Delta}{\partial \tau} = \pi(\theta^{\tau}) f(\theta^{\tau}) \frac{\partial \theta^{\tau}}{\partial \tau} + [F(\theta^{a}) - F(\theta^{\tau})] - \frac{\partial \theta^{a}}{\partial \tau} c(\theta^{a}) f(\theta^{a}). \tag{A.5}$$

Recalling (8) and (9), we see that all terms on the right hand side of (A.5) are positive.

<u>Case 3: $\theta^{-s} > \theta^{a} > \theta^{v} > \theta^{\tau}$</u>

In this case all industry members that would adopt the environmental technology under the proposed tax have already adopted. Thus industry losses arising from the tax are

$$\Delta(\tau) = \int_{\tilde{\theta}}^{\theta^{\tau}} \pi(\theta)\, dF(\theta) + \int_{\theta^{\tau}}^{\theta^{v}} \tau dF(\theta), \tag{A.6}$$

and

$$\frac{\partial \Delta}{\partial \tau} = \pi(\theta^{\tau}) f(\theta^{\tau}) \frac{\partial \theta^{\tau}}{\partial \tau} + [F(\theta^{v}) - F(\theta^{\tau})] > 0. \tag{A.7}$$

Thus we see that the proposition holds for all $\theta^{v} \in \left(\theta^{\tau}, \bar{\theta}\right]$. ■

Lemma 11 $\theta^{-\tau} < \theta^{-s}$.

Proof. As discussed in the text, we assume $\overline{W}(\tau^{*}, \overline{\theta}) > W(s^{*}, \overline{\theta})$, which also implies $W(\tau^{*}, \overline{\theta}) > W(s^{*}, \overline{\theta})$. The proof proceeds by contradiction. Suppose $\theta^{-\tau} > \theta^{-s}$,which implies that $W(\tau^*, \theta^{-\tau}) \leq W(s^*, \theta^{-\tau})$, since the tax is preempted in favor of the public VA at $\theta^v \leq \theta^{-\tau}$.

Note that

$$\partial W(\tau^*, \theta^v)/\partial \theta^v = \begin{cases} 0 \quad \theta^v \geq \theta^a \\ c(\theta) - x < 0 \quad \theta^v < \theta^a \end{cases}. \tag{A.8}$$

$$\partial W(s^*, \theta^v)/\partial \theta^v = \begin{cases} 0 \quad \theta^v \geq \theta^{s^*} \\ c(\theta) - x < 0 \quad \theta^v < \theta^{s^*} \end{cases}. \tag{A.9}$$

Recall that we have already shown in the text that $\theta^{-s} > \theta^{s^*}$. Thus, if $\theta^a > \theta^{s^*}$, then $W(\tau^*, \theta^v) > W(s^*, \theta^v)$ for all $\theta^v > \theta^{s^*}$, which implies $W(\tau^*, \theta^{-\tau}) > W(s^*, \theta^{-\tau})$. Alternatively, if $\theta^a < \theta^{s^*}$, it is still true that $W(\tau^*, \theta^v) > W(s^*, \theta^v)$ for all $\theta^v > \theta^{s^*}$,which implies $W(\tau^*, \theta^{-\tau}) > W(s^*, \theta^{-\tau})$. This contradicts our assumption that $\theta^{-\tau} > \theta^{-s}$. ■

The following lemma, along with Propositions 7 and 8, addresses the desirability of engaging in a unilateral voluntary agreement under the threat of taxation.

Lemma 12 *Expected industry profits are monotonically increasing in* θ^v *for all* $\theta^v \in \left[\theta^{-\tau}, \bar{\theta}\right]$.

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

$$\Pi(\Delta) \;=\; P(\Delta)\left(\int_{\theta^\tau}^{\bar{\theta}} \pi(\theta)\, dF(\theta) + \int_{\theta^\tau}^{\min\{\theta^a, \theta^v\}} -\tau dF(\theta) + \int_{\min\{\theta^a, \theta^v\}}^{\bar{\theta}} -c(\theta)\, dF(\theta)\right)$$

$$+\left(1-P\left(\Delta\right)\right)\left(\begin{array}{c}\int_{\tilde{\theta}}^{\bar{\theta}}\pi\left(\theta\right)dF\left(\theta\right)+\Phi\left(\theta^{-s},\theta^{v}\right)\int_{\min\{\theta^{a},\theta^{v}\}}^{\bar{\theta}}s^{*}-c\left(\theta\right)dF\left(\theta\right)\\+\Phi\left(\theta^{v},\theta^{-s}\right)\int_{\theta^{v}}^{\bar{\theta}}-c\left(\theta\right)dF\left(\theta\right)\end{array}\right) \quad (A.10)$$

From (A.10) we see that the functional form of expected industry profits change as θ^{v}declines from $\bar{\theta}$. The following cases are possible.

Case 1: $\theta^{v}>\theta^{-s}>\theta^{a}>\theta^{-\tau}$

In this case expected industry profits are

$$\begin{aligned}\Pi\left(\Delta\right) &= P\left(\Delta\right)\left(\int_{\theta^{\tau^{*}}}^{\bar{\theta}}\pi\left(\theta\right)dF\left(\theta\right)+\int_{\theta^{\tau^{*}}}^{\theta^{a}}-\tau dF\left(\theta\right)+\int_{\theta^{a}}^{\bar{\theta}}-c\left(\theta\right)dF\left(\theta\right)\right) \quad (A.11)\\ &\quad+\left(1-P\left(\Delta\right)\right)\left(\int_{\tilde{\theta}}^{\bar{\theta}}\pi\left(\theta\right)dF\left(\theta\right)+\int_{\theta^{a}}^{\bar{\theta}}s^{*}-c\left(\theta\right)dF\left(\theta\right)\right).\end{aligned}$$

Under the tax the non-adopting firms that remain in the industry pay the tax, while adopters incur the associated adoption costs $c\left(\theta\right)$. From (A.11) it is easy to see that as long as θ^{v} exceeds θ^{-s} the only possible impact on $\Pi\left(\Delta\right)$ of a decrease in θ^{v} must arise from changes in $P\left(\Delta\right)$ or from changes in the optimal tax, and in turn $\theta^{\tau^{*}}$and θ^{a} . However, one can observe from (A.1) that $\Delta\left(\tau\right)$ is invariant to changes in θ^{v}over this range as long as the optimal tax does not change. Recalling from (15) that $W\left(\tau^{*},\theta^{v}\right)$ does not change in this case, and from (6) and (2) that $W\left(s^{*},\theta^{v}\right)$ is invariant to changes in θ^{v} we see from (19) that the optimal tax is invariant with respect to changes in θ^{v} under the conditions of case 1. Thus, we see that $\Pi\left(\Delta\right)$ is similarly invariant to changes in θ^{v} in this case.

Case 2: $\theta^{-s} > \theta^{v} > \theta^{a} > \theta^{-\tau}$

In this case industry unilateral efforts preempt the offering of a public voluntary agreement in the event of a failed tax initiative, and expected industry profits are

$$\begin{aligned}\Pi(\Delta) &= P(\Delta)\left(\int_{\theta^{\tau^*}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{\tau^*}}^{\theta^{a}} -\tau^* dF(\theta) + \int_{\theta^{a}}^{\bar{\theta}} -c(\theta)\,dF(\theta)\right) \\ &\quad + (1-P(\Delta))\left(\int_{\tilde{\theta}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{v}}^{\bar{\theta}} -c(\theta)\,dF(\theta)\right).\end{aligned} \tag{A.12}$$

The expression above illustrates that industry profits under taxation are possibly affected changes in θ^{v} only through changes in $P(\Delta)$. One may observe from (A.4) that in this case $\Delta(\tau)$ is decreasing as θ^{v} falls. This is so because as more firms voluntarily adopt the environmental technology they incur no losses from the imposition of a tax once the public voluntary agreement (which would yield the benefits) has been preempted. Since

$$\int_{\theta^{\tau^*}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{\tau^*}}^{\theta^{a}} -\tau^* dF(\theta) + \int_{\theta^{a}}^{\bar{\theta}} -c(\theta)\,dF(\theta) < \int_{\tilde{\theta}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{v}}^{\bar{\theta}} -c(\theta)\,dF(\theta), \tag{A.13}$$

It follows that industry profits fall as θ^{v} falls, that is as industry participation in the unilateral voluntary agreement rises.

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

$$\Pi(\Delta) = P(\Delta)\left(\int_{\theta^{\tau^*}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{\tau^*}}^{\theta^v} -\tau^* dF(\theta) + \int_{\theta^v}^{\bar{\theta}} -c(\theta)\,dF(\theta)\right) \tag{A.14}$$
$$+ (1 - P(\Delta))\left(\int_{\tilde{\theta}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^v}^{\bar{\theta}} -c(\theta)\,dF(\theta)\right).$$

Observe first that both

$$\int_{\theta^{\tau^*}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^{\tau^*}}^{\theta^v} -\tau^* dF(\theta) + \int_{\theta^v}^{\bar{\theta}} -c(\theta)\,dF(\theta) \tag{A.15}$$

and

$$\int_{\tilde{\theta}}^{\bar{\theta}} \pi(\theta)\,dF(\theta) + \int_{\theta^v}^{\bar{\theta}} -c(\theta)\,dF(\theta) \tag{A.16}$$

are declining as θ^v decreases. Next observe that (A.16) declines faster than (A.15) with a decrease in θ^v. Thus, if $P(\Delta)$ also decreases with a decrease in θ^v it will follow that industry profits fall as participation in the unilateral voluntary agreement rises (*i.e.*, as θ^v falls). To see that this is so observe from (A.6) that $\Delta(\tau)$ is rising in θ^v under the conditions of case 3 and recall that $P(\Delta)$ is rising in Δ. ■

Proof of Proposition 7

Let $\psi(\theta^v) = P(\Delta)[W(\tau^*, \theta^v) - W(\emptyset, \theta^v)]$. It is sufficient to show that $\partial\psi/\partial\theta^v > 0$ for $\theta^v \in \left(\theta^a, \theta^{-s}\right)$ in order to prove that the proposition holds. In this case $\psi(\theta^v)$ is decreasing as more companies enter the unilateral voluntary agreement, and thus for sufficiently large

K it the regulator's net benefit of taxation will reach zero. For $\theta^v \in \left(\theta^a, \theta^{-s}\right)$ we see from

$$\frac{\partial \psi\left(\theta^v\right)}{\partial \theta^v} = \left(P'\left(\Delta\right) \frac{\partial \Delta}{\partial \theta^v} \left[W\left(\tau^*, \theta^v\right) - W\left(\emptyset, \theta^v\right)\right]\right) + P\left(\Delta\right) \left[\frac{\partial W\left(\tau^*, \theta^v\right)}{\partial \theta^v} - \frac{\partial W\left(\emptyset, \theta^v\right)}{\partial \theta^v}\right]. \tag{A.17}$$

To see that the expression in (A.17) can be positive observe from (11) that

$$\frac{\partial W\left(\tau^*, \theta^v\right)}{\partial \theta^v} = \left[\pi\left(\theta^v\right) - c\left(\theta^v\right)\right] f\left(\theta^v\right) > 0 \quad \forall \theta^v \in \left(\theta^a, \theta^{-s}\right). \tag{A.18}$$

and from (1) that

$$\frac{\partial W\left(\emptyset, \theta^v\right)}{\partial \theta^v} = \left[\pi\left(\theta^v\right) - x\right] f\left(\theta^v\right) - \left[\pi\left(\theta^v\right) - c\left(\theta^v\right)\right] f\left(\theta^v\right) = \left[c\left(\theta^v\right) - x\right] f\left(\theta^v\right) < 0, \tag{A.19}$$

with the inequality arising from the fact that $c\left(\theta\right) < x$ for all firms indexed by $\theta \in \left(\theta^a, \theta^{-s}\right)$. Thus the final term in (A.17) is positive. Thus, while the term in round brackets on the right hand side of (A.17) is negative (with the first term within the round brackets being negative, while the other two are positive) we see that for sufficiently small $P'\left(\Delta\right)$, $\partial\Delta/\partial\theta^v$, or $\left[W\left(\tau^*, \theta^v\right) - W\left(\emptyset, \theta^v\right)\right]$ we obtain $\partial\psi/\partial\theta^v > 0$ and the proposition holds. ■

Proof of Proposition 8

Industry profits under unilateral preemptive action are

$$E(\pi^U) = \int_{\widetilde{\theta}}^{\overline{\overline{\theta}}} \pi(\theta) dF(\theta) - \int_{\theta^{-\tau}(K)}^{\bar{\theta}} c\left(\theta\right) dF\left(\theta\right), \tag{A.20}$$

while expected profits with no unilateral action reflect both the possibility of a tax and the possibility of a voluntary agreement,

$$\begin{aligned} E(\pi^{NU}) \;\; = \;\; & P(\Delta)\left[\int_{\theta^{\tau}}^{\overline{\theta}} \pi\left(\theta\right) dF\left(\theta\right) - \int_{\theta^{\tau}}^{\theta^{a}} \tau dF\left(\theta\right) - \int_{\theta^{a}}^{\overline{\theta}} c\left(\theta\right) dF\left(\theta\right)\right] \qquad \text{(A.21)} \\ & + [1 - P(\Delta)]\left[\int_{\widetilde{\theta}}^{\overline{\theta}} \pi\left(\theta\right) dF\left(\theta\right) + \int_{\theta^{s*}}^{\overline{\theta}} [s - c\left(\theta\right)] dF\left(\theta\right)\right]. \end{aligned}$$

The benefit of preemption is the difference between (21) and (20),

$$\begin{aligned} E(\pi^{U}) - E(\pi^{NU}) = \quad & P(\Delta)\left[\int_{\tilde{\theta}}^{\theta^{\tau}} \pi\left(\theta\right) dF\left(\theta\right) + \int_{\theta^{\tau}}^{\theta^{a}} \tau dF\left(\theta\right) + \int_{\theta^{a}}^{\theta^{s^*}} c\left(\theta\right) dF\left(\theta\right)\right] \\ + \quad & \int_{\theta^{s*}}^{\theta^{-\tau}(K)} c(\theta) dF\left(\theta\right) - [1 - P(\Delta)]\left[\int_{\theta^{s*}}^{\bar{\theta}} s^{*} dF\left(\theta\right)\right] \qquad \text{(A.22)} \end{aligned}$$

The terms inside the first set of 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 term that 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. The final term represents the loss of subsidy payments if the public voluntary agreement is preempted.

As K increases, so does $\theta^{-\tau}$,thereby reducing the direct cost of preemption by lowering the requisite level of unilateral adoption. As λ increases, the optimal subsidy s^* decreases, thereby reducing the loss of subsidy payments to the industry if preemption occurs. Since the expression in (a.22) is continuous in K and λ, there exists some pair (K, λ) that makes preemption profitable. ■

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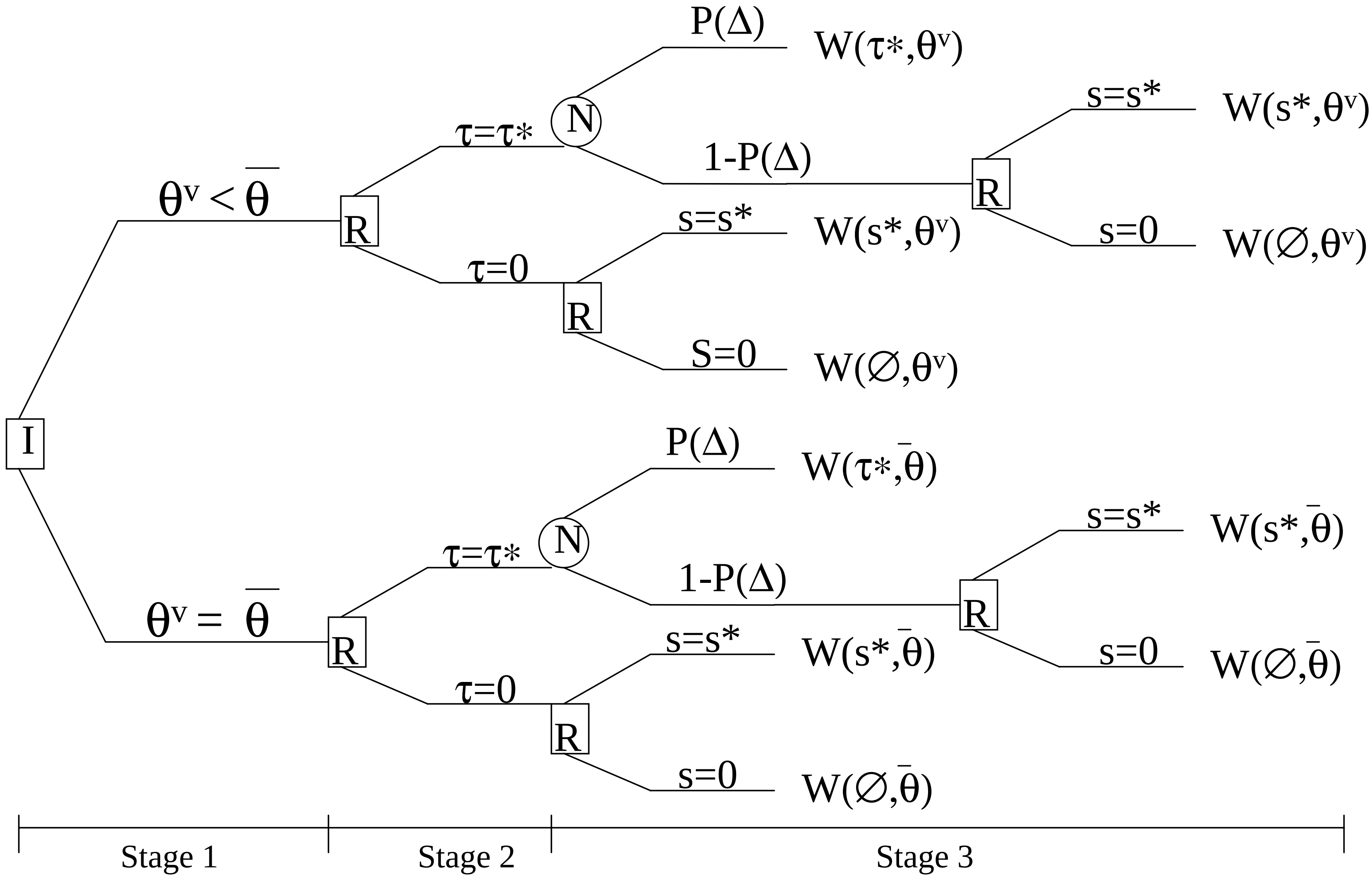

Figure 1: Game Tree

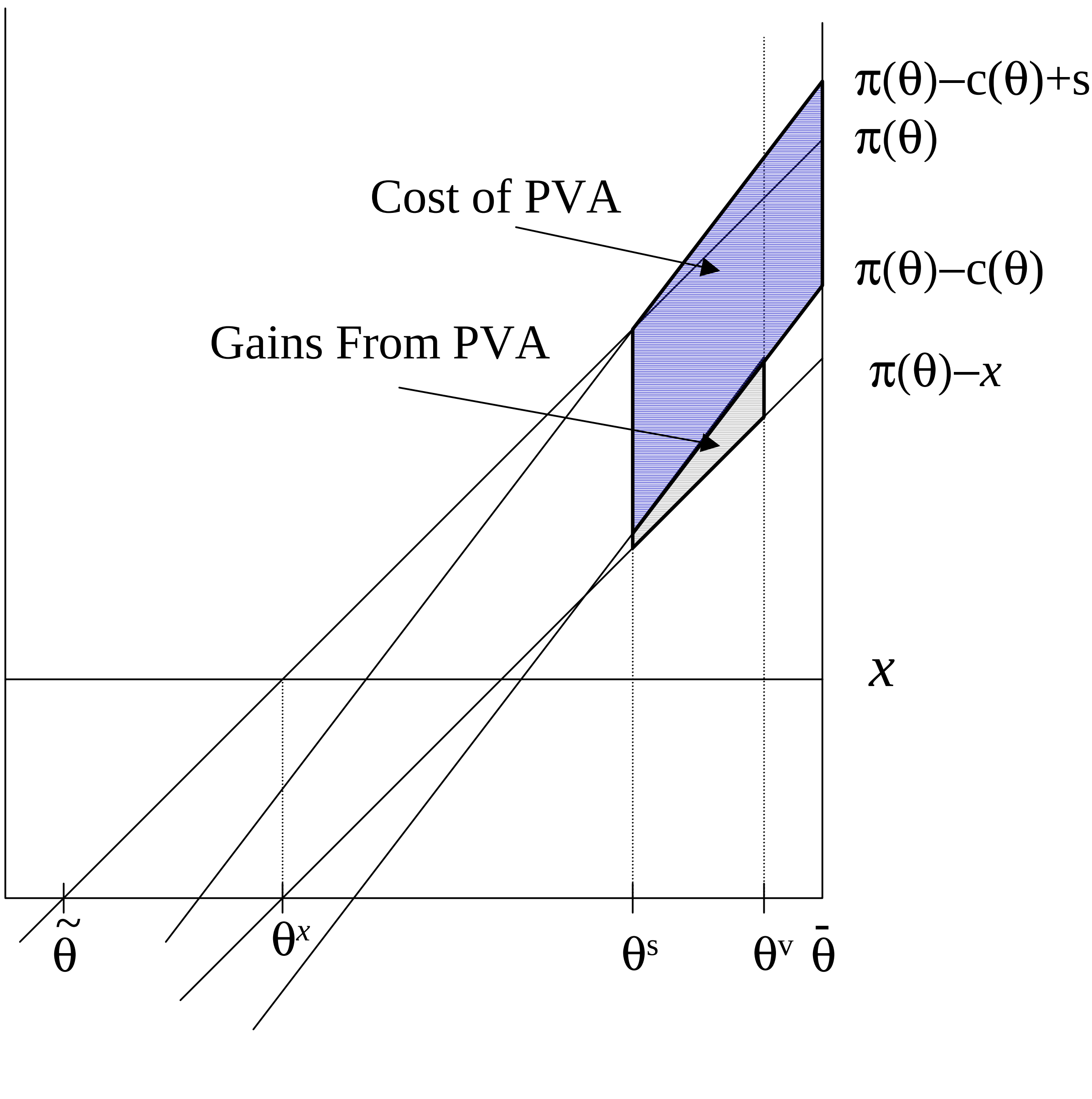

Figure 2: Welfare Gains and Costs of Public VA

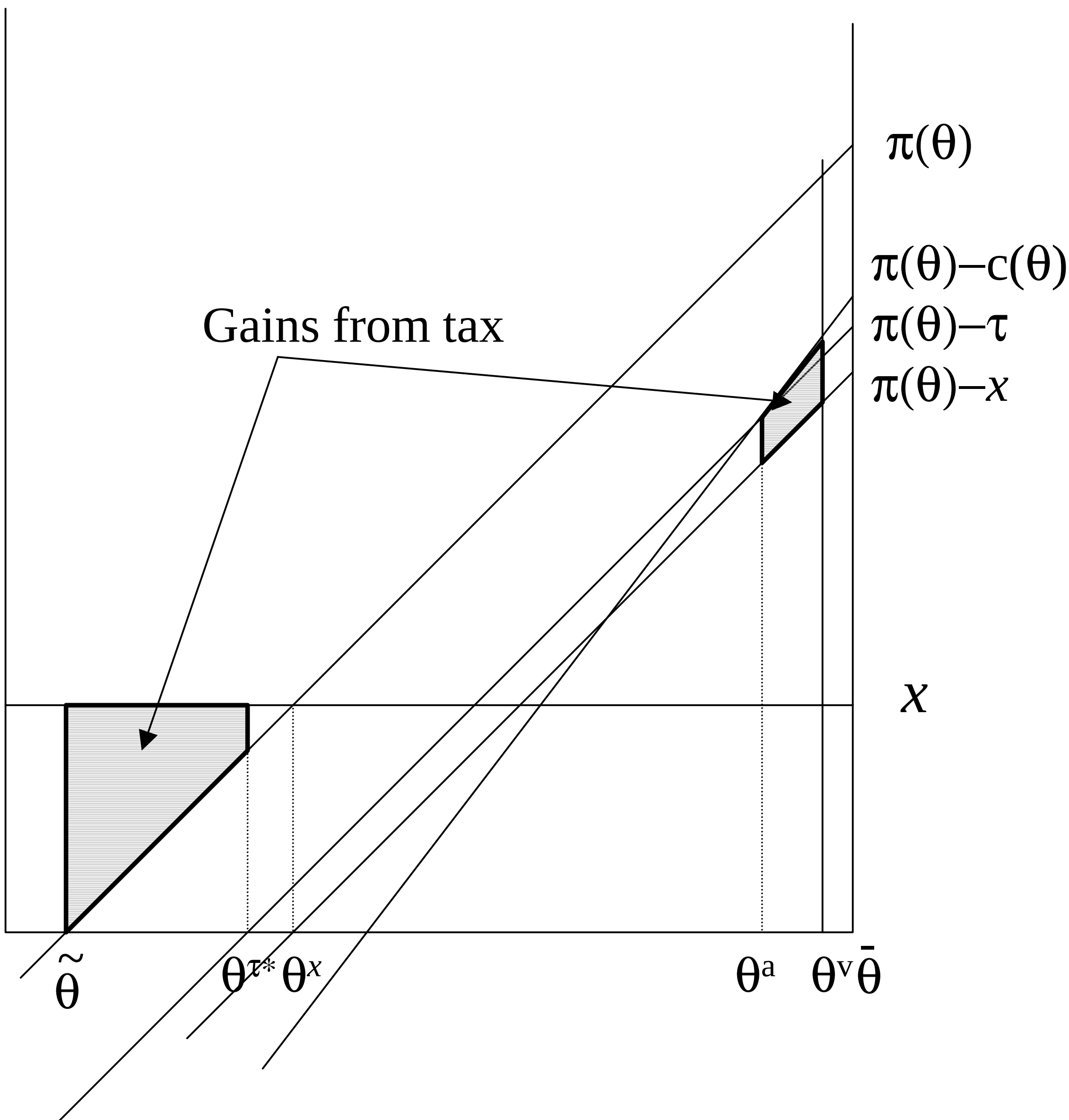

Figure 3: Welfare Gains from Taxation.

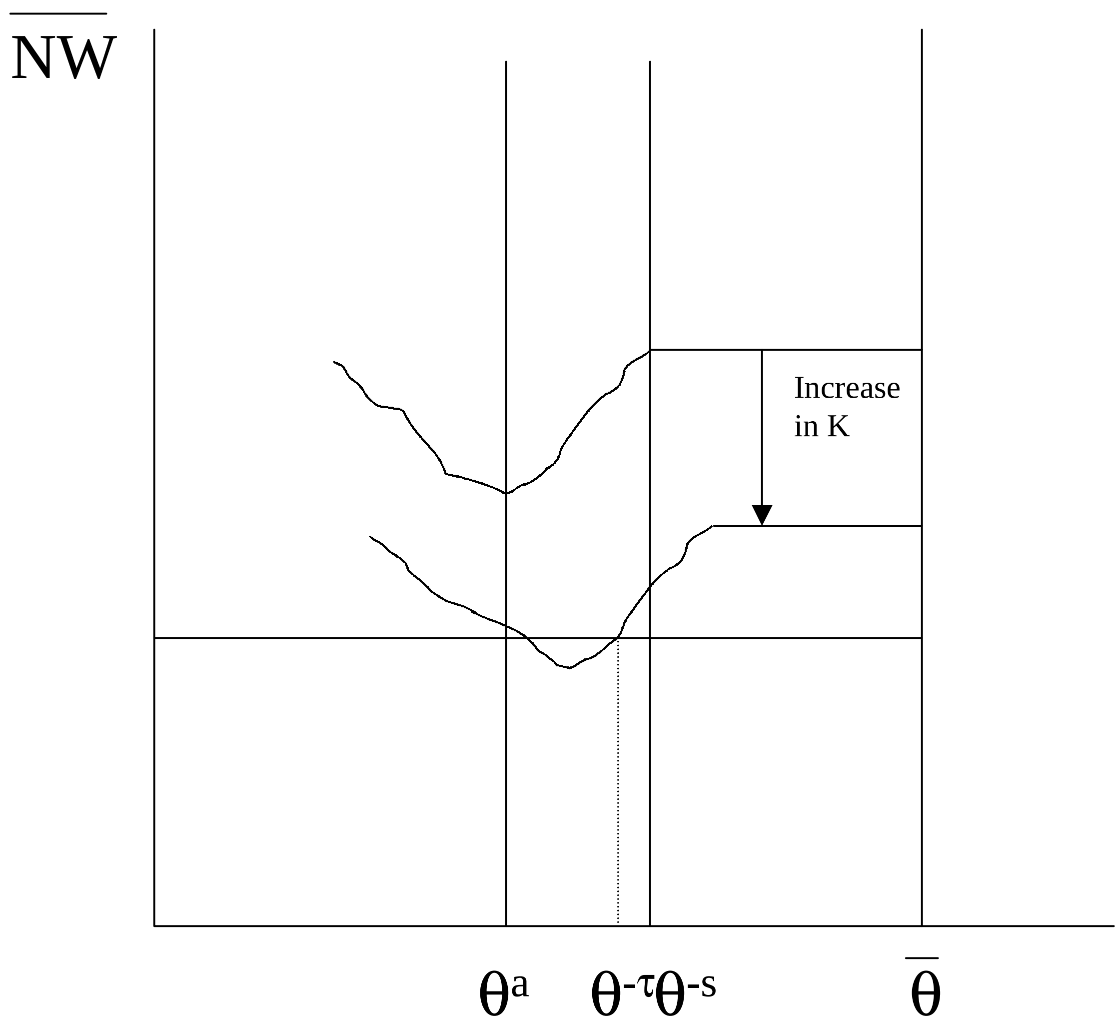

Figure 4: The Possibility of Preemption

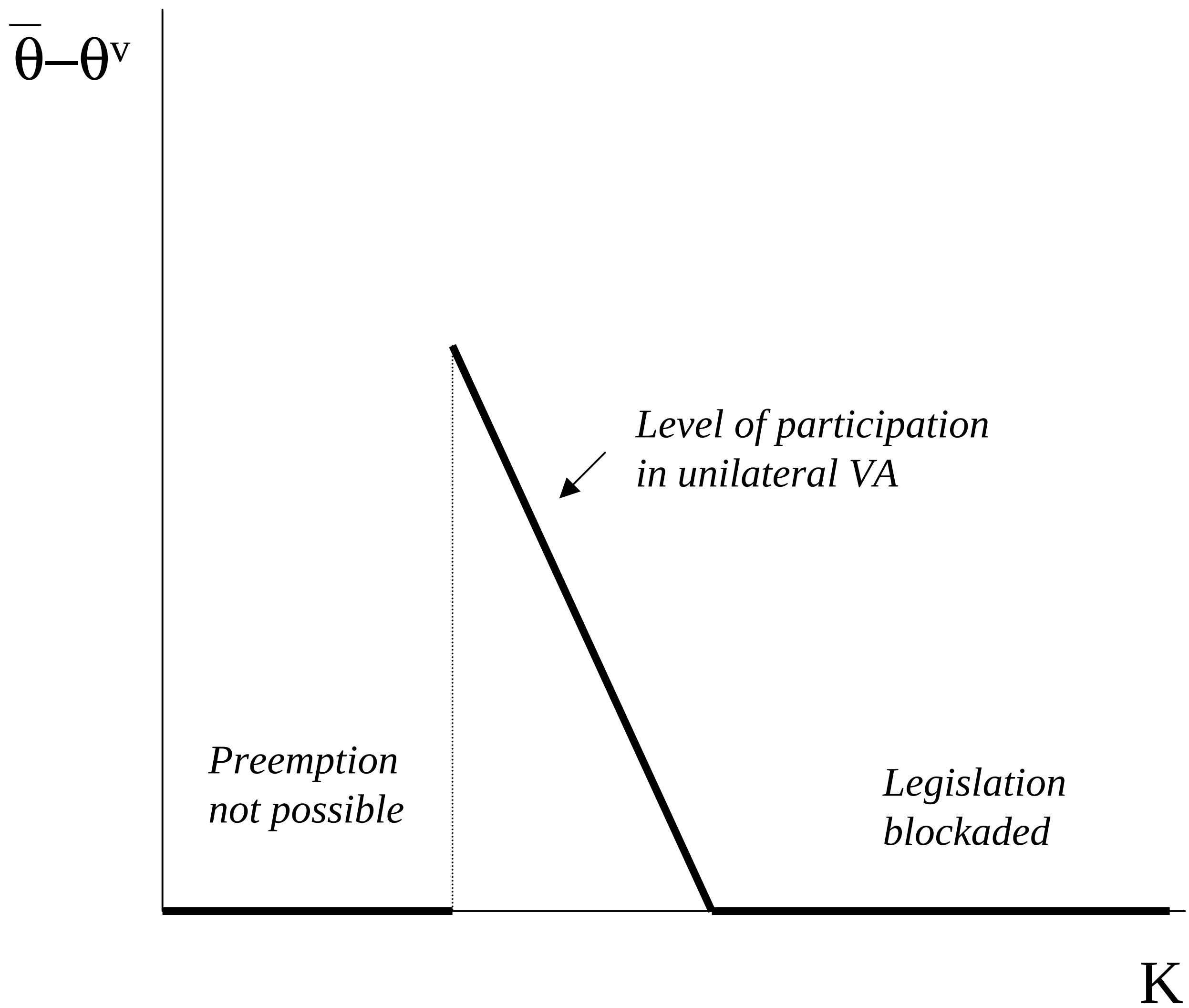

Figure 5: Size of Unilateral VA