Tampere University

TAMPERE ECONOMIC WORKING PAPERS

ENTRY, EXIT, AND INSTRUMENT CHOICE IN ENVIRONMENTAL REGULATION

Harri Nikula

Working Paper 126
May 2020

FACULTY OF MANAGEMENT AND BUSINESS

FI-33014 TAMPERE UNIVERSITY, FINLAND

ISSN 1458-1191
ISBN 978-952-03-1592-4 (pdf)

Entry, exit, and instrument choice in environmental regulation*

Harri Nikula†

May 22, 2020

Abstract

We study market-based regulation where a government tries to avoid excessive firm closures by providing reliefs from emission fees for incumbent firms. Regulation is asymmetric as only incumbents, not new entrants are subsidized by the payment reliefs. We ask whether this feature affects the choice between environmental taxes and tradable permits under uncertainty. We find a trade-off between tax-beneficial inefficiency effect and permit-beneficial volume effect. The latter effect arises as the free quotas makes the number of aggregate permits and the aggregate emissions to fluctuate in the quantity implementation. We show that the subsidization of incumbent firms does not unambiguously favor one of the instruments but the advantage depends on policy- and industry-specific factors.

Keywords: Emission taxation, firm closure, environmental subsidies, tradable emission permits, uncertainty

JEL Codes: D62, D81, H23, Q58

*I want to thank Pauli Lappi, Hannu Laurila and Kaisa Kotakorpi for valuable comments. The usual disclaimer applies.

†Tampere University. Correspondence: harri.nikula@tuni.fi

1 Introduction

A prominent feature of environmental taxes and tradeable permits is that they generate revenue streams from regulated companies to government. The streams are not always determined by the level of emissions alone as the implemented policy may include various reliefs for the companies. Depending on the chosen instrument, the policy may allow some tax-free level of emissions or it may distribute some number of permits for free. In this study, we ask whether incorporating these revenue streams into the analysis affects the instrument choice between environmental taxes (price instrument) and tradable permits (quantity instrument) and, if so, we ask about the extent to which the instrument choice is affected. By answering these questions, we extend the study of prices vs. quantities (Weitzman [20]) toward subsidization issues.

Our specific question concerns asymmetrical treatment of incumbent firms and new entrants in regulation. We consider a policy that applies positive payment reliefs for incumbent firms and zero reliefs for new entrants.[1] This policy has two major consequences in our model: aggregate emissions reduction becomes inefficiently organized and the level of emissions becomes unpredictable with tradable permits. Regarding the instrument choice, we summarize the consequences in two concepts: the cost and the volume effects. Altogether, we show that subsidization does not unambiguously favor one of the instruments but the advantage is case-specific.[2]

The cost effect captures the influence of inefficiency on instrument choice. This effect invariably favors stable prices, so the tax system with a fixed price has an unambiguous advantage. The volume effect in turn is related to a non-binding quota. As the emissions follow the quota, the volume effect makes the aggregate damage uncertain under the quantity regime. Interestingly, mainly because non-binding quota may reduce the cost of cutting emissions, the volume effect may also favor the quantity

[1]The policy follows the familiar principle of grandfathering, where "*prior emissions increase future emission entitlements*." (Knight [10], p. 410).

[2]Our research agenda is a topic in the current climate policy. There is a vivid dispute over the benefits of carbon tax against the cap-and-trade system (Carl and Fedor [2]; Keohane [8]; Keohane, Revesz, and Stavins [9]). Moreover, in the implementation of EU ETS, incumbent firms receives some initial allocation of permits for free. The system is heading toward auctioning but some number of free permits will remain in the future. (Ellerman *et. al.* [5]; Åhman *et. al.* [21]; European Commission [6].)

instrument. Notably, Roberts and Spence [17] applied the same finding in their classical study of instrument design in 1976, so the volume effect can be thought of as a new interpretation of their original idea.

The government provides reliefs for incumbent firms as it tries to avoid excessive firm closures. We will follow Hagem [7] as our model does not determine these payment reliefs but takes them as exogenously given. Hagem also notes that the government must restrict the transferability of the payments as the objective is to curb firm closures. In our framework, this requirement is met as the payments are conditional on positive output.

Our interest is on the application of market-based policies. These policies promise to implement regulation in a cost-efficient manner (Stavins [19]). However, the literature (Pezzey [16]) has shown that payment reliefs affect the entry-exit decisions of firms and thus affect the efficiency properties of tradable permits and environmental taxes. Specifically, Pezzey [16] divides payment reliefs into subsidy and property right payments. Market-based implementation uses subsidies as long as it applies conditional payments which causes inefficiency.[3] To retain efficiency under various payment reliefs, Pezzey suggests the use of property payments. However, these are inoperative in our framework. As we explained above, the payments must be conditional because of the purpose of the policy.

The study of the choice between policy instruments dates back to 1974, when Martin Weitzman [20] published his influential paper, "Prices vs. Quantities." Because of the uncertainty, not only the goal but also the means were shown to be important in environmental regulation. In comparing the two control modes, Weitzman disregards monetary payments between companies and government as they only reduce the existing producers' surpluses. In our framework, instead, the instrument payments have important real effects.

In our framework, every firm in the incumbent sector chooses between three alternatives: they may continue with old brown technology (technology b), update their old technology greener (technology g) or stop producing altogether. Every new firm, on the other hand, invests in the same technology (technology n) upon entering the

[3] See also Cramton and Kerr [3] and Ellerman [4].

market.[4] Within this framework, the firm closures are shown to be pivotal. Changes in firm closures will trigger (through the permit market transactions) future amendments in green production both in the incumbent and the entrant sectors so that aggregate permit allocation starts to fluctuate. This is possible, as the subsidization generates endogenous private permit supply into the permit markets and this part of the total supply is sensitive to the changes in the business environment.

The subsidization of incumbent firms turns the analysis into a second-best analysis. Montero [13],[14] has studied the second-best instrument choice [5] in a similar type of framework as the one proposed here. He studies consequences of incomplete enforcement in a one-sector (Montero [14]) and in a multi-sectoral (Montero [13]) model. In both cases, Montero finds that incomplete enforcement invariably favors the quantity instrument, tradable permits. Our results, however, are more ambiguous. The impact of subsidization becomes indeterminate as we add sector-heterogeneity into our framework. Subsidization may favor either price or quantity instrument and the overall effect depends on the policy- and industry-specific factors.

We start by setting up the model. We introduce the regulated industry and the second-best policy choice that the subsidization induces. We then derive our main result that the instrument choice is changed by the substitution of incumbent firms. We also briefly examine the one-sector model, which serves as a useful benchmark to study the influence of sector heterogeneity. We will provide a summary of the main results in the concluding section.

2 The Model

2.1 Polluting Industry

We construct a simple entry-exit model to illustrate our main points. We have two polluting sectors that together form a polluting industry. One of the sectors consists of incumbent firms. These firms have produced before the environmental regulation, so

[4]The analysis can be extended so that the entrants may choose between green and brown technologies as well.

[5]See Meunier [12] for a review. Under a second-best instrument choice, there are more constraints than the commonly assumed constraint on information.

their technology choices reflects past politics and regulation. The other sector consists of new entrants. Notably, these firms are able to incorporate the new environmental policy regime into their choices.[6]

Even though the technology is inherited from the past, incumbent firms can update their technology. In practice, they may choose between two technologies. They may continue to use the old, polluting brown technology (technology b) or modify their production greener (technology g). New entrants are assumed to apply new technology (technology n) which differs in its characteristics from the production methods of the old sector. More formally, given an incumbent firm λ that uses technology i, the profit is

$$\Pi_i(\lambda) = B_i(\lambda) - s(\alpha_i - l_i) \tag{1}$$

with

$$B_i(\lambda) = b_i + \theta - c_i\lambda, \tag{2}$$

where $i = b, g$. Similarly, given an entrant μ, the profit is

$$\Pi_n(\mu) = B_n(\mu) - s\alpha_n, \tag{3}$$

where

$$B_n(\mu) = b_n + \theta - c_n\mu. \tag{4}$$

We denote the private benefits by B_j, where b_j and c_j are positive constants and θ is an industry-wide random variable. We assume additive uncertainty, where $E(\theta) = 0$ and $Var(\theta) = \sigma^2$. The emission factors are assumed constant within technologies and are denoted by α_j. Thus, the production by technology j produces emissions α_j, where $j = b, g, n$. We have $\alpha_b > \alpha_g$, so the green alternative to brown production has lower pollution content. Throughout the presentation, we write $\Delta b = b_g - b_b$, $\Delta\alpha = \alpha_b - \alpha_g$, and $\Delta c = c_g - c_b$. Furthermore, there is no intrinsic reason to limit

[6] In referring to the subjects of regulation, we may use the words firms and (polluting) units interchangeably. For example, a power company may consist of several power plants. It is plausible that the plant, not the company, is the ultimate regulatory subject.

the set of plausible parameter values in the entrant sector, so we will allow various types of differences between the sectors.

The unit price of emissions is denoted by s and l_j is the subsidy threshold. The notation allows the use of both tradable permits and environmental taxes. We let $s = p, \tau$ with permits and taxes, respectively. In case of permits, the threshold l_j is the initial allocation of permits to a firm while with taxes, l_j gives the tax-free level of emissions. We assume from the outset that $l_b = l_g = l$ and $l_n = 0$. Therefore, firms are not subsidized upon entering the market. We further assume that $\alpha_b > l$, so that brown firms has to buy additional permits from the permit markets. Our model allows the possibility that $\alpha_g < l$, so green incumbent firms may end up selling their excess permits in the permit markets. Finally, we assume that the policy applies non-zero and conditional payments (Pezzey [16]). The payment sl_i in Equation (1) is conditional as it is paid only to an active incumbent firm. Altogether, as $l > 0$, we say that incumbent firms are subsidized.

Figure 1 illustrates the determination of the polluting sectors. The private benefits (B_j) are drawn by solid lines and the operating profits (Π_j) by non-solid lines. Regarding the incumbent firms, we assume (without loss of generality) that $\Delta b > 0$ and $\Delta c > 0$. In Figure 1(a), this assumption means that firms at low end of the distribution use green technology while firms at high end use brown technology. In particular, there are two cut-off firms in Figure 1(a). First, a firm λ_b satisfies

$$\Pi_b(\lambda_b) = 0. \tag{5}$$

The firm is indifferent between producing and closing down the factory. Second, there is a firm λ_g that satisfies

$$\Pi_i^g(\lambda_g) = \Pi_i^b(\lambda_g). \tag{6}$$

This particular firm, in turn, absolutely produces, but it is indifferent between green and brown technology. The entry in turn is driven by a zero-profit condition. There exists a firm μ_n that satisfies

$$\Pi_n(\mu_n) = 0, \tag{7}$$

see Figure 1(b).

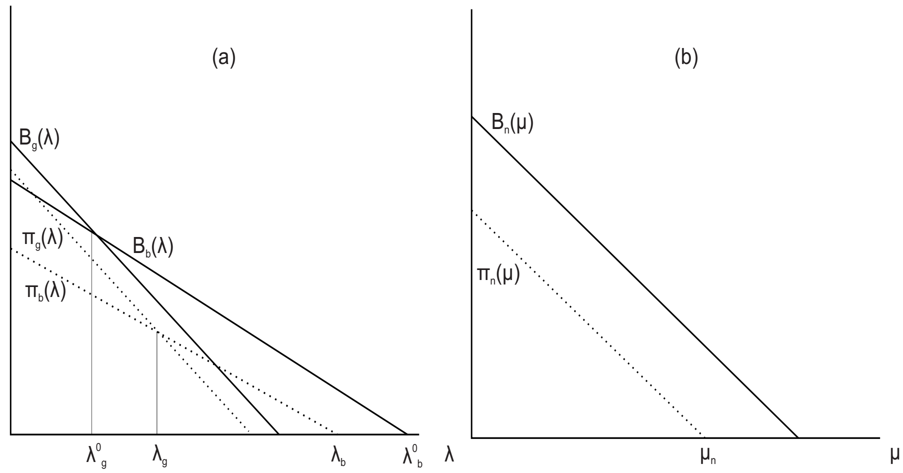

Figure 1: The Polluting Industry: A Sector of Inbumbent Firms (a) and a Sector of Entrants (b).

We consider the firms as negligible (McKitrick and Collinge [11]; Spulber [18]). By definition, an entry of an additional negligible firm has negligible effects on marginal social damages.[7] The variables λ and μ can be interpret to represent the number of firms. Thus, λ_b is the number of incumbent firms. As λ_g is the number of firms that use green technology, then $\lambda_b - \lambda_g$ is the number of incumbent firms that use brown technology. Similarly, μ_n is the number of new entrants in the regulatory equilibrium. Note, in particular, how the policy changes the composition of incumbent sector in Figure 1(a). We denote the cut-off firms in the absence of regulation by λ^0_g and λ^0_b, so regulation induces $\lambda_g - \lambda^0_g > 0$ technology modifications and $\lambda^0_b - \lambda_b > 0$ firm closures in sector A.

2.2 Social Welfare

Our aim is to study the details of market-based environmental regulation in cases, where only incumbent firms are subsidized by non-zero thresholds (as shown by Equations (1) and (3) above). The ultimate goal of regulation is to find an instrument that will maximize the expected societal welfare. The social welfare is the difference

[7]The units are small enough so that differentiation and integration are plausible methods.

between the total benefits (B) and damages (D) of emissions. Regarding the benefits, we write

$$B = \int_0^{\lambda_g(s)} B_g d\lambda + \int_{\lambda_g(s)}^{\lambda_b(s)} B_b d\lambda + \int_0^{\mu_n(s)} B_n d\mu, \tag{8}$$

where the technology-specific benefits B_g, B_b, and B_n were given above (Equations (2) and (4)). In our framework, the regulator takes the emission thresholds l as given and chooses only the emission price s. Any choice of s produces a certain amount of harmful emissions. The level of aggregate emissions is given by

$$e = \int_0^{\lambda_g(s)} \alpha_g d\lambda + \int_{\lambda_g(s)}^{\lambda_b(s)} \alpha_b d\lambda + \int_0^{\mu_n(s)} \alpha_n d\mu. \tag{9}$$

We assume that the damage is homogeneous in nature, so that the aggregate amount of emissions, not the distribution of emissions between firms is important. The damage itself equals $D(e)$, where $D'(e) > 0$ and $D''(e) > 0$.

A chosen instrument should maximize expected social welfare, EW. In our approach, this amounts to optimization problem

$$\underset{s}{Max} E\left[B - D\right].$$

By Equations (8) and (9), the first-order condition is

$$\begin{aligned} \frac{dEW}{ds} &= E\left[(B_g(\lambda_g(s), \theta) - B_b(\lambda_g(s), \theta)) + \Delta\alpha D'(e))\frac{d\lambda_g(s))}{ds}\right] \\ &+ E\left[(B_b(\lambda_b(s), \theta) - \alpha_b D'(e))\frac{d\lambda_b(s))}{ds}\right] \\ &+ E\left[(B_n(\mu_n(s), \theta) - \alpha_n D'(e))\frac{d\mu_n(s))}{ds}\right] = 0. \end{aligned}$$

The cut-off firms $\lambda_g(s)$, $\lambda_b(s)$, and $\mu_n(s)$ are given by Equations (5), (6), and (7), respectively. They can be written explicitly as

$$\lambda_g(s) = \frac{\Delta b + s\Delta\alpha}{\Delta c}, \tag{10}$$

$$\lambda_b(s) = \frac{b_b + \theta - s(\alpha_b - l)}{c_b}, \tag{11}$$

and

$$\mu_n(s) = \frac{b_n + \theta - s\alpha_n}{c_n}. \tag{12}$$

We calculate Appendix (see Equation (35)) that the policy satisfies

$$E(s) - \frac{\gamma}{\Gamma} ED'(e(s)) = 0,$$

where

$$\gamma = \frac{c_b \Delta c c_n}{\Delta c c_n (\alpha_b - l)^2 + c_b c_n \Delta\alpha^2 + c_b \Delta c \alpha_n^2} \tag{13}$$

and

$$\Gamma = \frac{c_b \Delta c c_n}{\Delta c c_n (\alpha_b - l)\alpha_b + c_b c_n \Delta\alpha^2 + c_b \Delta c \alpha_n^2}. \tag{14}$$

In assessing the second-best policy, we write first

$$c = \frac{c_b \Delta c c_n}{\Delta c c_n {\alpha_b}^2 c_b c_n \Delta\alpha^2 + c_b \Delta c \alpha_n^2} \tag{15}$$

as the slope of the marginal benefit function under $l = 0$. Consequently, the familiar condition

$$E(s) = ED'(e(s)) \tag{16}$$

holds only if

$$\gamma = \Gamma = c.$$

In other words, the Condition (16) holds only if the emission thresholds are set equal to zero.

In the implementation of the policy, the regulator may use environmental taxation. Denoting the tax rate by τ, the regulator sets

$$s = \tau.$$

Alternatively, the regulator may apply a system of tradable permits. The agency auctions off number of L permits in the permit markets As supply equals demand,[8] then

$$L=\int_0^{\lambda_g}(\alpha_g-l)d\lambda+\int_{\lambda_g}^{\lambda_b}(\alpha_b-l)d\lambda+\int_0^{\mu_n}\alpha_n d\mu. \tag{17}$$

After incorporating the cut-off firms (from Equations (10), (11), and (12)) into the equilibrium condition, the equilibrium price can be solved as

$$p=\overline{p}+\gamma\left(\frac{\alpha_b-l}{c_b}+\frac{\alpha_n}{c_n}\right)\theta, \tag{18}$$

where

$$\overline{p}=Ep=\gamma\left(\frac{b_b}{c_b}(\alpha_b-l)-\frac{\Delta b}{\Delta c}\Delta\alpha+\frac{b_n}{c_n}\alpha_n-L\right), \tag{19}$$

and γ is given by Equation (13). Specifically, the regulator may take $\overline{p}$ as the policy variable, so it sets

$$E(s)=\overline{p}.$$

Equation (19) provides the link between $\overline{p}$ and L.

3 Instrument Choice under Uncertainty

We move next to our main subject of this study, to the choice between subsidized quantities and subsidized prices. In the incumbent sector, the policy will reduce the number of brown firms as some firms switch to green technology while some brown firms will exit from the market altogether. However, at the time the regulation is initiated, the regulator does not know the exact numbers as the realization of θ eventually determines the final number of firms. Similarly, the number of entrants settles down permanently after the realization of θ.

In what follows, we find it convenient to work in terms of price variable. By Equations (31) and (32) in Appendix, the benefits can be written as

$$B(s)=\frac{(\Delta b)^2}{2\Delta c}+\frac{(b_b+\theta)^2}{2c_b}+\frac{(b_n+\theta)^2}{2c_n}-\frac{1}{2\gamma}s^2 \tag{20}$$

[8] We assumed earlier that $\alpha_b-l<0$ and that $\alpha_g-l\lesseqgtr 0$. However, as long as $l>0$, there exists private permit supply on the market.

while regulated emissions are

$$e(s) = \frac{b_b + \theta}{c_b}\alpha_b - \frac{\Delta b}{\Delta c}\Delta\alpha + \frac{b_n + \theta}{c_n}\alpha_n - \frac{s}{\Gamma}, \tag{21}$$

where γ and Γ are given by Equations (13) and (14), respectively. We further assume that

$$D(e) = \frac{d}{2}e^2,$$

where $d > 0$. We conclude that both the benefits and the damages of emissions are quadratic functions of emission price (Weitzman [20]; Adar and Griffin [1]).[9]

Following Weitzman [20], we define the comparative advantage between instruments τ and p as

$$\Delta(\tau, p) = E\left[B(\tau) - D(e(\tau))\right] - E\left[B(p) - D(e(p))\right]. \tag{22}$$

Referring to our analysis above (especially to Equations (18) and (21)), it holds that

$$p = \tau + \gamma\left(\frac{\alpha_b - l}{c_b} + \frac{\alpha_n}{c_n}\right)\theta. \tag{23}$$

Denoting

$$\overline{e} = Ee(s),$$

it also holds that

$$e(\tau) = \overline{e} + \left(\frac{\alpha_b}{c_b} + \frac{\alpha_n}{c_n}\right)\theta. \tag{24}$$

However,

$$e(p) = \overline{e} + (1 - \frac{\gamma}{\Gamma})\left(\frac{\alpha_b}{c_b} + \frac{\alpha_n}{c_n}\right)\theta + \frac{\gamma}{\Gamma}l\theta. \tag{25}$$

We then write

Lemma 1 *Assume that incumbent firms are subsidized so that emission thresholds are strictly larger than zero while new entrants are not subsidized at all. Then, the*

[9] We assume the damage function is known with certainty. It can be shown that this assumption does not reduce generality of our analysis for as long as benefit and damage uncertainties are independent. If this assumption does not hold, then we should incorporate damage uncertainties into the analysis as well. See, Weitzman [20].

quantity instrument (tradable permits) does not fix the aggregate emissions at a constant level.

By Equations (13) and (14), we know that $\frac{\gamma}{\Gamma} \neq 1$ as long as $l > 0$. Conversely, if $l = 0$, then $\frac{\gamma}{\Gamma} = 1$. Only in the latter case, the quantity instrument fixes the emissions at the level L that amounts to the aggregate number of auctioned permits.

We incorporate various prices and quantities from above (Equations (23), (24), and (25)) into comparative statistic (Equation (22)). We have

Proposition 1 *Assume that the regulation applies asymmetrical subsidization. In that case, the comparative advantage in instrument choice equals*

$$\Delta(\tau, p) = \frac{Z}{2}\frac{Var(p)}{\gamma^2}(c - \frac{\Theta}{\rho}d).$$

The formula is derived in the appendix. There are two novel features in the comparative statistic, the cost effect ρ and the volume effect Θ. The size of the relative volume-cost effect $\frac{\Theta}{\rho}$ determines the influence of subsidization on instrument choice. If $\frac{\Theta}{\rho} = 1$, then we are back on the traditional Weitzman [20] comparison, where the magnitudes of the slopes c and d alone determine the instrument choices. If $\frac{\Theta}{\rho} > 1$ (< 1) instead, then subsidization favors the quantity (the price) instrument.

The cost-effect represents the pure influence of inefficiency. Subsidization breaks down the basic property of market-based regulation, namely, its ability to yield cost-efficient emission allocation between various sectors in the polluting industry (Stavins [19]). To see this effect, denote the counterfactual benefits and emissions by B_U and U, respectively.[10] By Equation (21), the relation between prices and quantities is given by

$$s = \Gamma\left(U - e\right),$$

so the benefits are

$$B(e) = B_U - \rho\frac{c}{2}\left(U - e\right)^2, \tag{26}$$

where

$$\rho = \frac{\Gamma^2}{\gamma c}. \tag{27}$$

[10] Counterfactual values exist in the absence of regulation. In the present context, the counterfactual benefits and emissions are obtained by setting $s = 0$ in Equations (20) and (21).

Factor ρ is the cost-effect. We will show below (see Equation (29)) that

$$\rho > 1$$

as long as the incumbent firms are subsidized. Conversely, in the absence of subsidization, $\rho = 1$. By definition of efficiency (Stavins [19]), aggregate benefits are maximal only if the given aggregate emission level e is efficiently distributed between sectors. Consequently, by Equation (26), the benefits are maximal in the absence of subsidization.

The instrument choice is further complicated by the presence of volume effect. By Lemma 1, both the price and the quantity instruments yield emissions that reacts to the changes in the random variable. This is not a standard results in the literature as usually the quantity instrument fixes the emissions to a predetermined level (see Weitzman [20]). Basically, emissions in the system of tradable permits fluctuate as the agency commits to the number of auctioned permits, not to the number of total permits. The gap between these two numbers arises as private supply of threshold permits exists in the market (see the market equilibrium in Equation (17) above). The aggregate number of permits is then partially determined by the number of closures in the incumbent industry, by the number of technology modifications that remaining incumbent firms accomplish, and by the entries of new firms. We show below that the sign of the volume effect is ambiguous. That is, depending on the values that model parameters take, the volume effect may favor either the price or the quantity instrument.[11]

In the derivation of the comparative statistic, we find it convenient to use some auxiliary notation. We define

$$k \equiv \frac{(\alpha_b - l)}{\alpha_n},\ u \equiv \frac{c_n}{c_b},\ a \equiv \frac{\alpha_b}{\alpha_n}, \text{ and } r \equiv 1 + \frac{c_n \Delta\alpha^2}{\Delta c \alpha_n^2}. \tag{28}$$

In particular, using the definition of the cost effect in Equation (27), we may write

[11] The firm closures are pivotal in our framework. If the number of incumbent firms is a constant number, then the aggregate number of permits is a constant number as well.

(see Equation (37) in Appendix) that

$$\rho = 1 + \frac{ru\,(k-a)^2}{(r+uak)^2}. \tag{29}$$

Clearly, as long as $l > 0$ (so that $a > k$), we have $\rho > 1$. If $l = 0$ instead, then $\rho = 1$. Furthermore, we may write the volume effect (by Equations (43) and (44) in Appendix) as

$$\Theta = 2q - 1,$$

where

$$q = \frac{r+uk^2}{r+uka}\frac{1+au}{1+ku}.$$

Specifically,

$$q \gtreqless 1 \Leftrightarrow u\left((r-k)\,(a-k)\right) \gtreqless 0. \tag{30}$$

By definitions in (28), subsidization means that $a > k$, so the size of the volume effect depends on the sign of the difference $r - k$. We have

$$r - k = \frac{\Delta c\alpha_n\,(\alpha_n - \alpha_b) + c_n\Delta\alpha^2 + c_n\Delta\alpha^2 + \Delta c\alpha_n l}{\Delta c\alpha_n^2},$$

so the nature of the volume effect ultimately depends on the difference between α_n and α_b. Finally, if $l = 0$, then $\Theta = 1$.

Proposition 1 tells us that the effect of subsidization is given by $\frac{\Theta}{\rho}$. The preceding analysis show that $\frac{\Theta}{\rho} = 1$ in the absence of subsidization. Consequently, if government abandons the payment reliefs for incumbent firms, we are back in the original analysis of Weitzman [20]. The preceding analysis also shows that $\rho > 1$ but $\Theta \lesseqgtr 1$ under subsidization. Consequently, we cannot nail down the effect of subsidization by studying cost and volume effect separately. We then calculate (see Equation (45) in Appendix) that

$$\Theta - \rho = \frac{r+uk^2}{r+uka}\frac{a-k}{1+ku}u\left(\frac{r-k}{r+uk^2} + \frac{r-a}{r+uak}\right).$$

We have $a > k$, so the effect of subsidization on instrument choice depends on the differences $r - k$ and $r - a$. We have three possibilities: If $r > a$, then $\Theta > \rho$.

Conversely, If $k > r$, then $\Theta < \rho$. Finally, if $a > r > k$, the sign of the difference $\Theta - \rho$ is indeterminate. Specifically, it holds that

$$\Theta - \rho = \begin{cases} < 0, & r = k \\ > 0, & r = a \end{cases} .$$

Then, by the continuity of ρ and Θ, there exists $r^* \in (k, a)$, so that the sign of $\Theta - \rho$ changes at $r = r^*$.

Our model complements the literature of second-best instrument choice (Meunier [12]). Specifically, our work introduces the possibility that the second-best policy implementation may favor either the price or the quantity instrument. In earlier studies of second-best instrument choice, this has not always been the case (Montero [13], [14]). We conclude our study by briefly illustrating this phenomenon. Consider then a somewhat reduced framework, where no entry will takes place. There is one (incumbent) industry, where regulation together with the random variable determines the number of firm closures and the division of firms between green and brown technologies. As in Proposition 1, the effect of subsidization on instrument choice can be shown to depend on the relation between the cost and the volume effects.[12] We denote

$$\widetilde{k} \equiv \frac{(\alpha_b - l)}{\Delta\alpha},\ \widetilde{u} \equiv \frac{\Delta c}{c_b},\text{ and } \widetilde{a} \equiv \frac{\alpha_b}{\Delta\alpha},$$

so the cost and the volume effects can be written as

$$\widetilde{\rho} = 1 + \frac{\widetilde{u}\left(\widetilde{k} - \widetilde{a}\right)^2}{\left(1 + \widetilde{u}\widetilde{a}\widetilde{k}\right)^2}$$

and

$$\widetilde{\Theta} = 1 + 2\frac{\left(\widetilde{a} - \widetilde{k}\right)}{\widetilde{k} + \widetilde{u}\widetilde{a}\widetilde{k}^2},$$

respectively. By definition, subsidization is equivalent to a condition $l > 0$. Consequently, as $\widetilde{a} > \widetilde{k}$, it holds that both the cost and the volume effect are larger than

[12] The one-sector analysis closely follows our earlier analysis that employs two sectors. The complete one-sector analysis is available from the author by request.

one. Furthermore, we can calculate that

$$\widetilde{\Theta} - \widetilde{\rho} = \frac{1 + \widetilde{u}\widetilde{k}^2}{1 + \widetilde{u}\widetilde{a}\widetilde{k}} \left[\frac{1}{1 + \widetilde{u}\widetilde{k}^2} + \frac{1}{1 + \widetilde{u}\widetilde{a}\widetilde{k}} \right] \frac{\left(\widetilde{a} - \widetilde{k} \right)}{\widetilde{k}}.$$

As $\widetilde{a} > \widetilde{k}$ (and as $\widetilde{u}$, $\widetilde{k}$, and $\widetilde{a}$ are all positive), it holds that

$$\widetilde{\Theta} > \widetilde{\rho}.$$

We may conclude that the subsidization invariably favors the quantity instrument, tradable permits.

4 Conclusions

The Weitzman [20] model provides a fundamental rule for instrument choice under uncertainty. The rule is derived by assuming an efficient allocation of emissions between the regulated units. In real-life implementations, however, efficiency may be only one goal among variety of other goals. In our model, for instance, there are concerns about excessive firm closures that the introduction of regulation causes. These concerns are facilitated by providing payment reliefs for incumbent firms in the implementations of market-based policies (environmental taxes and tradable permits). We show that the payment reliefs are in conflict with the efficiency goals, and therefore, the fundamental rule of instrument choice is eventually affected.

Our analysis shows that the permit implementation in particular goes through major changes. Basically, this happens as the permit implementation uses free permit allocations that will generate endogenous private permit supply into the permit markets. However, in the instrument choice under uncertainty, the non-binding quota may not necessarily be a problem for the permit implementation (Roberts and Spence [17]). Our study supports this conclusion, as it derives a specific set of parameter values, where the private permit supply will end up favoring the quantity instrument over the price instrument.

The instrument choice in Weitzman [20] model is a restricted choice as there exist asymmetrical information between the regulator and the regulated firms. In addition to that, the payment reliefs incorporate another constraint on the policy and, consequently, on the instrument choice in our framework. Increasing the number of constraints increases our understanding of real-life phenomena, but at the same time will make the analysis more challenging. Consequently, new applications[13] and interpretations are needed in the study of second-best instrument choices (Meunier([12]).

References

[1] Adar, Z., & Griffin, J. M. (1976). Uncertainty and the choice of pollution control instruments. *Journal of Environmental Economics and Management*, 3(3), 178-188.

[2] Carl, J., & Fedor, D. (2016). Tracking global carbon revenues: A survey of carbon taxes versus cap-and-trade in the real world. *Energy Policy*, *96*, 50-77.

[3] Cramton, P., & Kerr, S. (2002). Tradeable carbon permit auctions: How and why to auction not grandfather. *Energy policy*, *30(4)*, 333-345.

[4] Ellerman, A. D. (2008). New entrant and closure provisions: How do they distort?. *The Energy Journal*, 63-76.

[5] Ellerman, A. D., Marcantonini, C., & Zaklan, A. (2016). The European union emissions trading system: ten years and counting. *Review of Environmental Economics and Policy*, *10(1)*, 89-107.

[6] European Commission. EU Emissions Trading System (EU ETS) (2020). Retrieved from https://ec.europa.eu/clima/policies/ets_en

[7] Hagem, C. (2003). The merits of non-tradable quotas as a domestic policy instrument to prevent firm closure. *Resource and Energy economics*, 25(4), 373-386.

[8] Keohane, N. O. (2009). Cap and trade, rehabilitated: Using tradable permits to control US greenhouse gases. *Review of Environmental Economics and policy*, *3(1)*, 42-62..

[9] Keohane, N. O., Revesz, R. L., & Stavins, R. N. (1998). The choice of regulatory instruments in environmental policy. *Harv. Envtl. L. Rev*, *22*, 313.

[10] Knight, C. (2013). What is grandfathering?. *Environmental Politics*, *22(3)*, 410-427.

[13] In a related paper, Nikula [15] studies voluntary participation provision in a framework that is developed above.

[11] McKitrick, R., & Collinge, R. A. (2000). Linear Pigovian taxes and the optimal size of a polluting industry. *Canadian Journal of Economics/Revue canadienne d'économique*, *33(4)*, 1106-1119.

[12] Meunier, G. (2018). Prices versus quantities in the presence of a second, unpriced, externality. *Journal of Public Economic Theory*, *20(2)*, 218-238.

[13] Montero, J. P. (2001). Multipollutant markets. *RAND Journal of Economics*, 762-774.

[14] Montero, J. P. (2002). Prices versus quantities with incomplete enforcement. *Journal of Public Economics*, *85(3)*, 435-454.146.

[15] Nikula, H. (2020). Voluntary opt-in provision and instrument choice in environmental regulation. Unpublished Working Paper.

[16] Pezzey, J. C. (2003). Emission taxes and tradeable permits a comparison of views on long-run efficiency. *Environmental and Resource Economics*, *26(2)*, 329-342..

[17] Roberts, M. J., & Spence, M. (1976). Effluent charges and licenses under uncertainty. *Journal of Public Economics*, *5(3)*, 193-208.

[18] Spulber, D. F. (1985). Effluent regulation and long-run optimality. *Journal of Environmental Economics and Management*, *12(2)*, 103-116..

[19] Stavins, R. N. (2007). *Environmental economics* (No. w13574). National Bureau of Economic Research.

[20] Weitzman, M. L. (1974). Prices vs. quantities. *The review of economic studies*, *41(4)*, 477-491.

[21] Åhman, M., Burtraw, D., Kruger, J., & Zetterberg, L. (2007). A Ten-Year Rule to guide the allocation of EU emission allowances. *Energy Policy*, *35(3)*, 1718-173

Appendix

We start by incorporating the types $\lambda_g(s)$, $\lambda_b(s)$, and $\mu_n(s)$ (Equations (10), (11), and (12)) into benefits (Equation (8)) and into emissions (Equation (9)). Consequently, the benefits are

$$B(s) = \frac{(\Delta b)^2}{2\Delta c} + \frac{(b_b+\theta)^2}{2c_b} + \frac{(b_n+\theta)^2}{2c_n} - \frac{1}{2\gamma}s^2 \tag{31}$$

and the emissions are

$$e(s) = \frac{b_b+\theta}{c_b}\alpha_b - \frac{\Delta b}{\Delta c}\Delta\alpha + \frac{b_n+\theta}{c_n}\alpha_n - \frac{s}{\Gamma}, \tag{32}$$

where

$$\gamma = \frac{c_b \Delta c c_n}{\Delta c c_n(\alpha_b - l)^2 + c_b c_n \Delta\alpha^2 + c_b \Delta c \alpha_n^2} \tag{33}$$

and

$$\Gamma = \frac{c_b \Delta c c_n}{\Delta c c_n(\alpha_b - l)\alpha_b + c_b c_n \Delta\alpha^2 + c_b \Delta c \alpha_n^2}. \tag{34}$$

The optimal (second-best) price s satisfies

$$\frac{dE\left[B(s) - D(e(s))\right]}{ds} = 0,$$

so it satisfies

$$-\frac{Es}{\gamma} + \frac{ED'(e)}{\Gamma} = 0. \tag{35}$$

Regarding the results in instrument choice, we repeatedly apply definitions

$$k \equiv \frac{(\alpha_b - l)}{\alpha_n},\ u \equiv \frac{c_n}{c_b},\ a \equiv \frac{\alpha_b}{\alpha_n}, \text{ and } r \equiv 1 + \frac{c_n \Delta\alpha^2}{\Delta c \alpha_n^2}.$$

By Equations (15), (33), and (34) we write

$$\rho = \frac{\Gamma^2}{\gamma c} = \frac{\left(\frac{c_b \Delta c c_n}{\Delta c c_n(\alpha_b - l)\alpha_b + c_b c_n (\Delta\alpha)^2 + c_b \Delta c (\alpha_n)^2}\right)^2}{\frac{c_b \Delta c c_n}{\Delta c c_n(\alpha_b - l)^2 + c_b c_n (\Delta\alpha)^2 + c_b \Delta c (\alpha_n)^2}\frac{c_b \Delta c c_n}{\Delta c c_n(\alpha_b)^2 + c_b c_n (\Delta\alpha)^2 + c_b \Delta c (\alpha_n)^2}}$$

or, after using the definitions just made, we have

$$\rho = \frac{(r + uk^2)(r + ua^2)}{(r + uak)^2}. \tag{36}$$

After doing the multiplications in the numerator (and after adding and subtracting the factor $2ruak$ in there), it holds that

$$\rho = \frac{(r + uak)^2 + ru(a^2 + k^2 - 2ak)}{(r + uak)^2} = 1 + \frac{ru(k - a)^2}{(r + uak)^2}. \tag{37}$$

Next, we write prices and quantities as

$$s = Es + \left(R_b \frac{\alpha_b}{c_b} + R_n \frac{\alpha_n}{c_n} \right) \Gamma\theta \tag{38}$$

and

$$e(s) = Ee + \left((1 - R_b) \frac{\alpha_b}{c_b} + (1 - R_n) \frac{\alpha_n}{c_n} \right) \theta, \tag{39}$$

where

$$R_b(p) = \frac{(\alpha_b - l)}{\alpha_n} \frac{\alpha_n}{\alpha_b} \frac{\gamma}{\Gamma} = \frac{k}{a} \frac{\gamma}{\Gamma} \equiv R_b, \tag{40}$$

$$R_n(p) = \frac{\gamma}{\Gamma} \equiv R_n, \tag{41}$$

and

$$R_b(\tau) = R_n(\tau) = 0$$

(see Equations (18) and (32)). We insert the price formulas (Equation (38)) into the benefits (Equation (31)), so we can write

$$E\left[B(\tau) - B(p)\right] = \frac{1}{2\gamma} \left(\left(R_b \frac{\alpha_b}{c_b} + R_n \frac{\alpha_n}{c_n} \right) \Gamma\theta \right)^2,$$

or, as $E\theta = 0$, the difference is

$$E\left[B(\tau) - B(p)\right] = \frac{\Gamma^2}{2\gamma} \left(R_b \frac{\alpha_b}{c_b} + R_n \frac{\alpha_n}{c_n} \right)^2 E\theta^2.$$

We further apply the definition of ρ (Equation (27) in the main text), and the fact that

$$Var(p) = \Gamma^2 \left(R_b \frac{\alpha_b}{c_b} + R_n \frac{\alpha_n}{c_n} \right)^2 E\theta^2, \tag{42}$$

so we can write

$$E\left[B(\tau)-B(p)\right]=\frac{1}{2}\frac{Var(p)}{\Gamma^2}c\rho.$$

The difference between damages is

$$E\left[D(\tau)-D(p)\right]=\frac{d}{2}E\left[(e(\tau))^2-(e(p))^2\right].$$

Using the formula in Equation (39), and the fact that $E\theta=0$, we may write

$$E\left[D(\tau)-D(p)\right]=\frac{dE\theta^2}{2}\left(2\left(R_b\frac{\alpha_b}{c_b}+R_n\frac{\alpha_n}{c_n}\right)\left(\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}\right)\right)$$
$$-\frac{dE\theta^2}{2}\left(\left(R_b\frac{\alpha_b}{c_b}+R_n\frac{\alpha_n}{c_n}\right)^2\right)$$

or, by Equation (42), we may further write

$$E\left[D(\tau)-D(p)\right]=\frac{Var(p)}{2\Gamma^2}\left(2\frac{\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}}{R_b\frac{\alpha_b}{c_b}+R_n\frac{\alpha_n}{c_n}}-1\right).$$

We define the volume effect as

$$\Theta=2q-1, \tag{43}$$

so that

$$q=\frac{\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}}{R_b\frac{\alpha_b}{c_b}+R_n\frac{\alpha_n}{c_n}},$$

and

$$E\left[D(\tau)-D(p)\right]=\frac{1}{2}\frac{Var(p)}{\Gamma^2}d\Theta.$$

Regarding the size of the volume effect, we calculate (by using Equations (40) and (41)) that

$$q \quad = \quad \frac{\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}}{R_b\frac{\alpha_b}{c_b}+R_n\frac{\alpha_n}{c_n}}=\frac{\Gamma}{\gamma}\frac{\left[\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}\right]}{\left[\frac{k}{a}\frac{\alpha_b}{c_b}+\frac{\alpha_n}{c_n}\right]}=\frac{\Gamma}{\gamma}\frac{1+au}{1+ku}.$$

As

$$\frac{\Gamma}{\gamma} \quad = \quad \frac{\frac{c_b\Delta cc_n}{\Delta cc_n(\alpha_b-l)\alpha_b+c_bc_n(\Delta\alpha)^2+c_b\Delta c(\alpha_n)^2}}{\frac{c_b\Delta cc_n}{\Delta cc_n(\alpha_b-l)^2+c_bc_n(\Delta\alpha)^2+c_b\Delta c(\alpha_n)^2}}=\frac{1+\frac{c_n(\Delta\alpha)^2}{\Delta c(\alpha_n)^2}+\frac{\Delta cc_n(\alpha_b-l)^2}{c_b\Delta c(\alpha_n)^2}}{1+\frac{c_n(\Delta\alpha)^2}{\Delta c(\alpha_n)^2}+\frac{c_n(\alpha_b-l)\alpha_b}{c_b(\alpha_n)^2}}=\frac{r+uk^2}{r+uka},$$

we may also write

$$q = \frac{r + uk^2}{r + uka}\frac{1 + au}{1 + ku}. \tag{44}$$

Finally, we calculate the aggregate effect of imperfect participation on instrument choice. It is given by the difference between volume and cost effects

$$\Theta - \rho.$$

We use straightforward calculations. As a start, we write

$$\begin{aligned}\Theta - \rho &= \left(2\frac{r + uk^2}{r + uka}\frac{1 + au}{1 + ku} - 1\right) - \left(\frac{(r + uk^2)(r + ua^2)}{(r + uak)^2}\right)\\ &= \frac{r + uk^2}{r + uka}\left(2\frac{1 + au}{1 + ku} - \frac{r + uka}{r + uk^2} - \frac{r + ua^2}{r + uak}\right).\end{aligned}$$

by using Equations (36) and (43), and (44). We develop the term inside the parenthesis, so that

$$\begin{aligned}\Theta - \rho \quad = \quad & \frac{r + uk^2}{r + uka}\frac{1}{1 + uk}\left(\frac{uk^2 + rua - uka - ruk}{r + uk^2}\right)\\ & + \frac{r + uk^2}{r + uka}\frac{1}{1 + uk}\left(\frac{uak + rua - ua^2 - ruk}{r + uak}\right).\end{aligned}$$

After arranging terms, it holds that

$$\Theta - \rho = \frac{r + uk^2}{r + uka}\frac{u}{1 + uk}\left(\frac{k(k - r) - a(k - r)}{r + uk^2} + \frac{k(a - r) - a(a - r)}{r + uak}\right),$$

or, alternatively written, it holds that

$$\Theta - \rho = \frac{r + uk^2}{r + uka}\frac{a - k}{1 + uk}u\left(\frac{r - k}{r + uk^2} + \frac{r - a}{r + uak}\right). \tag{45}$$