Environmental Regulation in a Mixed Economy

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ABSTRACT

Many developing countries are mixed economies in which public and private firms engage in Cournot competition. We show that some fundamental results in environmental economics fail to hold in these economies: more stringent environmental regulation does not necessarily reduce pollution levels, the equivalence between environmental taxes and standards breaks down, and not every emission level can be induced by emission taxes. These results are due to the endogeneity of the public firm CEO's career choices. Instruments that can induce the CEO to choose a public career are most effective in reducing emissions and improving social welfare.

Keywords: Mixed economy, environmental regulation, developing countries

JEL Codes: Q58, L13, L32

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I. Introduction

Developing nations such as China and India are increasingly becoming important players in global environmental protection due to their rapid economic growth, large population base and fragility of domestic ecosystems. For transboundary and global pollutants such as greenhouse gases, pollution abatement in these nations is critical to ensure the success of international mitigation efforts. Solving global environmental externalities requires better understanding of the environmental protection incentives and mechanisms within developing nations.

Environmental economics research has made significant contributions to environmental policy making in industrialized nations (Hahn, 2000). A central theme of the literature deals with choices and levels of regulatory instruments, and many of the models and findings have been incorporated in textbooks such as Baumol and Oates (1988) and Hanley, Shogren and White (2007). The following statements are examples of the "standard results" of the literature: (i) Environmental taxes and standards are equivalent under certainty and firm homogeneity; (ii) Desirable abatement amounts can be achieved through properly setting the levels of taxes or standards; (iii) Which instrument should be chosen depends largely on uncertainties, firm heterogeneity, transaction costs and innovation incentives (Jaffe and Stavins, 1995; Jung et al. 1996; Zhao, 2003); (iv) Market instruments such as taxes and tradable emission permits perform better than command-and-control approaches such as performance and technology standards (Stavins, 2003).

In this paper, we study to what extent these findings about environmental regulation and instruments are "transferrable" to the particular institutional settings of many developing countries. These countries are unique in many aspects, such as lower per capita income, weak institutions (e.g., weak enforcement of environmental regulations), corruption and rent seeking by government officials, and imperfectly competitive market structures. Not every peculiarity destroys the transferability. For instance, differences in income levels between developing and developed nations do not affect the transferability: the same principles regarding instrument choices still apply, although optimal policy levels need to account for the different preferences towards the environment and possibly for different risk attitudes. Similarly, as shown in Montero (2002), imperfect enforcement of environmental regulation in developing nations do not affect the transferability either: regulators only need to tighten the standard or raise the tax to compensate for the effects of lax enforcement. The main reason for the transferability is that mechanisms through which regulations affect economic activities in markets work similarly despite differences in levels of economic development or regulatory enforcement.

However, some institutional peculiarities of developing nations do render major findings on environmental regulation less applicable to these nations. In this paper, we study one such peculiarity: many developing nations are characterized by mixed economies or mixed oligopolies, markets where state owned firms are major players with strong presence of private firms. We investigate the implications of this unique market structure for optimal choices of environmental policy instruments. We show that, under otherwise standard settings, the equivalence between taxes and standards break down, tougher environmental regulation does not always reduce emissions, and certain emission levels may not be achieved by emission taxes alone.

A mixed oligopoly describes a situation where public (or state owned) and private firms have market power and compete against each other in a single market. Public firms differ from private firms because by government mandates, public firms often pursue objectives that go beyond pure profit maximization. The vector of objectives might include social responsibilities such as job creation (Shleifer and Vishny1994), income redistribution (Zeckhauser and Horn 1989, pp. 12–14), and consumer welfare (Matsumura 1998). The literature on mixed economies has focused mainly on the welfare implications of the presence of public firms, recognizing early on that social welfare maximizing public firms can regulate or "discipline" private oligopolies (Merill and Schneider, 1966). The welfare effects of public firms are, however, "mixed:" DeFraja and Delbono (1989) show that the presence of a public firm increases welfare when there are only a few Cournot rivals but decreases welfare when the number of rivals is large. The effects are ambiguous even when strategic delegation is allowed (Barros 1995, Matsumura 1998, Jansen, Lier and Witteloostuijn 2006, Du, Heywood and Ye 2013) and the role of leadership is accounted for (Fjell and Heywood 2004, Heywood and Ye 2009).

In this paper we consider the impacts of public firms on environmental protection and regulation. Whether or not public firms are "cleaner" than private firms is subject to debate (Kikeri et al, 1992). Public firms can be cleaner (Baumol and Oates, 1988) because they might be required to take leadership roles in carrying out the government's environmental objectives (Mascarenhas, 1989) and to do more in reducing their emissions (Darnall and Edwards, 2006), and because soft budget constraints imply that they are more willing to incur losses from abatement than private firms (Gentry, 1998). On the other hand, public firms can be "dirtier" because they might face lax enforcement of environmental regulations due to their closer connections to government agencies (Talukdar and Meisner, 2001), and because they are often equipped with older and more polluting technologies (Kikeri et al, 1992). The empirical evidence is also mixed. Pargal and Wheeler (1996) find that state owned firms in Indonesia were less responsive to informal pressure from local communities to reduce emissions, and Wang and Jin (2007) show that state owned enterprises (SOEs) in China generated more water pollution than private firms. Using 1987 – 1995 data from 44 developing countries, Talukdar and Meisner (2001) find that a country with higher degrees of private sector involvement experiences less severe environmental degradation. In contrast, Garcia et al. (2009) find that public firms in Indonesia were (weakly) more responsive to public disclosures of pollution data than private firms (but less responsive than foreign firms), and Earnhart and Lizal (2006) use data of Czech firms from 1993 to 1998 to show that higher state ownership raises environmental performance relative to all other types of ownership.

We abstract away from the variety of factors that might cause public firms to be cleaner or dirtier and focus instead on their fundamental characteristics of serving societal objectives in addition to profit maximization. The specific societal objectives then determine their environmental performance relative to private firms. For instance, Wang and Jin (2007) find that in China, collectively owned enterprises - public firms that serve objectives set by local governments – have lower pollution levels than private firms. At the national level, the Chinese government set a strict national goal of reducing the energy intensity by 20% from 2006 to 2010. Cao and Karplus (2014) find that during this period, while private firms' electricity use responded more to prices, the electricity use of SOEs responded more to non-price measures such as regulatory mandates and performance evaluations. We assume that the societal objective of a public firm concerns social welfare, i.e., it maximizes a weighted sum of the social welfare and the firm's own profit, and because public and private firms are otherwise identical, the public firm ends up being cleaner. However, our central message that "standard" environmental economics results fail to hold in mixed economies is still valid even if we assume instead that public firms are dirtier than private firms.

Another important feature of mixed economies is that the CEOs of public firms are appointed by the government and are often former or future government officials. In the case of China, a CEO typically carries a "rank" in government bureaucracy.[1] Successful performance at a public firm can be rewarded by promotion in government official ranks. Alternatively, the CEO can choose to pursue careers in the private sector. Different career paths require different skills, as shown in Wilson (1989) for the US, and call for different signals sent by the CEO. The large literature on optimal signaling under endogenous career choices (Dewatripont et al, 1999a, b) indicates that a public career CEO should emphasize the social welfare impacts of the public firm, while a

[1] For instance, the CEO at a national iron and steel corporation usually carries the rank at the vice minister level.

private career CEO should pay more attention to profit advantages over private firm competitors. Thus in our model, a public career CEO will put more weight on social welfare than a private career CEO.

We show that the endogeneity of CEO career choices is the major factor driving the performance of regulatory instruments. Environmental regulation often influences the public and private firms differently: if a public firm has already been doing more in environmental protection, regulation will tilt the competition to its advantage. The effects also depend on the regulatory instrument: while under a binding standard, both public and private firms must undertake the same level of abatement, the public firm might abate more under an environmental tax due to its preference for social welfare and the fact that the tax revenue contributes to social welfare. The impacts naturally depend on the public firm's weight on social welfare, and thus on the CEO's career objective. More importantly, the CEO's career objective can also be changed by environmental regulation. If the CEO switches from a public career to a private career objective due to the regulation, the public firm's incentive to abate will decrease: environmental friendly regulation could have perverse effects on the environment. A contribution of this paper is to study the endogenous choices of the nature of the public firm, determined by the CEO's career objectives, which in turn are affected by environmental policies. We show that the endogeneity leads to non-monotonic effects of environmental regulation: a higher tax or more stringent standard does not always lead to lower net emissions. Further, the equivalence between taxes and standards breaks down: there are cases in which pollution levels induced by one instrument cannot be achieved by the other instrument.

In our model, public and private firms engage in Cournot competition, similar to the literature of environmental regulation under imperfect competition (see, for example, Katsoulacos and Xepapadeas 1995, Simpson 1996, and Requate 2006). The main insight of this literature is that optimal taxes or standards should target both the environmental externality and welfare losses due to the firms' strategic behavior. Standard monotonicity results (e.g., higher taxes always reduce total emissions) and equivalence between taxes and standards still hold. Our results, however, are drastically different due to the endogenous career choices of public firm CEOs, and provide an example of "standard results" being sensitive to institutional complexities.[2]

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[2] As another example, the "standard result" of market instruments dominating command-and-control approaches is also sensitive to the specific institutional settings. For instance, Endres (1997) and Endres and Finus (2002) show that when heterogeneous nations negotiate an international environmental agreement, an emission reduction standard agreed upon by the negotiating nations might dominate an emission tax.

Although our focus on mixed economies is motivated by experiences of developing countries, the presence of strong public firms is by no means limited to developing countries only. It is not uncommon for an industrialized nation to have some sectors that are mixed. The US package delivery sector, for example, is dominated by the USPS, a public firm, and Fedex and UPS, two private firms. Our results are applicable to environmental regulation in such mixed sectors in industrialized nations.[3]

The paper is organized as follows. Section II sets up the model and presents results of a Cournot duopoly under pollution taxes. Section III examines the consequences of emission standards. Section IV compares the performances of pollution taxes and emission standards. Section V provides concluding remarks.

II. A model of mixed economies

Consider an economy consisting of one public firm indexed by 0 and one private firm indexed by 1 competing in a single domestic market. Both firms produce a homogeneous good and share the same production cost function, $C(q) = kq$, where $k > 0$ is the (constant) marginal cost. The firms face a linear inverse demand function $P(Q) = a - Q$ where $Q = q_0 + q_1$ and q_i is the output of firm *i, i=0, 1*. The linearity assumption of the cost and demand functions, fairly standard in the mixed economy literature (Pal 1998, White 2001 and 2002, Matsumura 2003), greatly simplifies our analysis; we will discuss their implications and the generality of our results in Section V.

Each firm generates emissions that are proportional to its output level. Without loss of generality, we assume that one unit of output generates one unit of emission so that firm *i*'s gross emission is q_i. The firm can abate its emission by a proportion of α_i, i.e., from q_i to $e_i = (1-\alpha_i)q_i$ at a unit cost of *c*. The government imposes a pollution tax at rate τ, so that firm *i* has to pay an environmental tax $\tau(1-\alpha_i)q_i$. Firm i's profit is

$$\pi_i = q_i(a - q_0 - q_1) - kq_i - c\alpha_i q_i - \tau(1-\alpha_i)q_i, \qquad i = 0,1 \tag{1}$$

Assumption 1: $a - k - \max\{\tau, c\} > 0$: production is "desirable" regardless of a firm's pollution abatement decisions.

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[3] One important caveat is that the nature of public firms might vary significantly across countries. For instance, Koppell (2007) argues that while SOEs in China compete with private firms, "hybrid" firms in the US typically do not compete with private firms performing similar functions.

The social welfare consists of four components: consumer surplus, firm profits, tax revenue, and the (linear) environmental damage $D(E) = \delta E$ where $E = e_0 + e_1$:

$$W = \int_0^Q P(t)dt - P(Q)Q + \sum_{i=0}^{1} (\pi_i + T_i) - D(E) \tag{2}$$

Note that the social welfare does not explicitly include the payoffs of the public firm or its CEO (to be specified below): the welfare aggregates the payoffs of individual citizens instead of firms, and the CEO is one among millions of citizens and thus has a measure of almost zero.[4] We further make the following assumptions:

Assumption 2: (i) $\delta > c$: pollution abatement is socially desirable. (ii) $a - k - \delta > 2(\delta - \tau)$: this technical assumption guarantees that all equilibrium outputs are nonnegative.

The setup of the private firm is fairly standard: it chooses output q_1 and abatement α_1 to maximize its own profit π_1 given in (1). The public firm, on the other hand, serves dual objectives of social welfare and profit maximization. Let $0 \le \lambda \le 1$ be the weight the firm puts on profit.[5] Then it chooses q_0 and α_0 to maximize

$$G = (1 - \lambda)W + \lambda \pi_0 \tag{3}$$

The public firm's profit weight λ is chosen by its CEO, who represents the government to oversee the firm's management. There are thus three levels of players associated with the public firm: the government who "owns" the firm, the CEO who sets the profit weight, and the manager who maximizes G in (3) given λ. The setting is similar to the three tier principal-supervisor-agent hierarchical model pioneered by Tirole (1986) and Demski and Sappington (1987). A central concern of the hierarchical agency literature is collusion between the supervisor and the agent (Kofman and Lawarree, 1993), and in this paper, we assume that there is perfect collusion between the CEO and the manager: the CEO simply hires a type of manager whose objectives are fully aligned with the CEO's chosen profit weight λ.[6]

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[4] This is not always true in developing countries with severe nepotism and corruption, where a group of collusive and interconnected elites control the governments and public firms.

[5] Parameter λ also represents the partial privatization ratio in the literature on privatization in mixed oligopolies (Matsumura, 1998).

[6] The degree to which the CEO dominates firm decisions can also be determined by managerial discretion, or the CEO's latitude of actions (Hambrick and Finkelstein, 1987), and varies across industries (Hambrick and Abrahamson, 1995). As long as CEO preferences substantially influence the firm's behavior, our results are robust to varying the degree of managerial discretion.

Although the government owns the public firm, the CEO can have substantial influence on the profit weight λ because of information asymmetries that can arise from hidden actions (when the CEO's choice of λ is unobserved by the government) or from hidden information (when the appropriate balance between social welfare and firm profit is determined by market conditions observed by the firm/CEO but not by the government). To focus on environmental regulation, we abstract away from the contractual issues between the government and the CEO and assume that the CEO can freely choose λ to maximize his own payoff, which depends on the type of career he would like to pursue in the future:[7]

$$\underset{\{\lambda\}}{Max}\ U = \begin{cases} f(\pi_0 - \pi_1) & \text{if private career} \\ g(W) & \text{if public career} \end{cases} \qquad (4)$$

with $f' > 0, f'' \leq 0$, $g' > 0$ and $g'' \leq 0$. As discussed earlier, the CEO needs to send different kinds of signals depending on his career choices because public and private careers require different skill sets. The private sector emphasizes competition and profitability, and a private career CEO thus needs to signal through the public firm's performance (profit level) relative to its competitor, the private firm. Government bureaucracy emphasizes non-profit societal objectives, which are assumed to be social welfare. Thus a public career CEO needs to signal his ability to steer the public firm to help maximize social welfare *W*.

The game has three stages. In stage one, given the environmental regulation, the public firm's CEO decides which type of career to pursue in the future. Given the chosen career path, the CEO chooses weight λ in the public firm's objective function in stage two. In stage three, the public and private firms engage in Cournot competition by simultaneously choosing their output and abatement levels. We solve for the subgame perfect Nash equilibrium using backward induction.

II.1 Subgame perfect Nash equilibrium

Given pollution tax τ and the public firm's profit weight λ, the public and private firms simultaneously choose their abatement and output levels. Since the abatement technology is linear, a firm conducts either no abatement or full abatement. If the tax rate is higher than the unit cost of abatement, i.e., if $\tau \geq c$, both firms fully abate so that $\alpha_0 = \alpha_1 = 1$. If $\tau < c$, the private firm does not abate, i.e., $\alpha_1 = 0$, but the public firm might still abate if its weight on social welfare $(1-\lambda)$ is sufficiently high: $\alpha_0 = 1$ if and only if $\lambda < \lambda^I(\tau)$ where

[7] Alternatively we can interpret λ as capturing the "residual" influence the CEO has over the firm's objective function in a contract between the government and the CEO.

$$\lambda^I(\tau) \equiv (\delta - c)/(\delta - \tau) \tag{5}$$

is a threshold profit weight so that the public firm is indifferent between abating and not abating when $\lambda = \lambda^I$. In this case we assume that it chooses not to abate. The equilibrium output and abatement levels and their properties are given in Appendix A. Substituting these optimal output and abatement levels (equations (8)-(10) in Appendix A) back to (1) and (2), we obtain the optimal profit and social welfare functions given profit weight λ and tax τ, denoted as $\hat{\pi}_i(\lambda,\tau)$, i=0,1 and $\hat{W}(\lambda,\tau)$.

<u>Stage 2: choice of</u> λ. Given his career choice, the CEO chooses profit weight λ to maximize his payoff in (4), knowing the effects of this choice on the firms' equilibrium output and abatement levels. If the CEO has chosen a public career, he would like the public firm to maximize social welfare so that his optimal choice of profit weight is $\lambda^G = 0$. We let $W^*(\tau) \equiv \hat{W}(\lambda^G = 0, \tau)$ denote the social welfare function *given that the CEO has chosen a public career*.

If the CEO has chosen a private career, he chooses weight λ to maximize $\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau)$. The optimal weight λ^P depends on tax τ. If $\tau \ge c$, both the public and private firms fully abate. Our model falls back to a standard mixed economy model with production costs being $k+\tau$. To gain a larger market share and thus competitive advantage, the public firm CEO has incentive to choose $\lambda < 1$ since the public firm with social welfare considerations will produce more. The special functional forms then imply that $\lambda^P = 1/4$.

If $\tau < c$, the private firm does not abate but the public firm fully abates if and only if $\lambda < \lambda^I(\tau)$ where threshold λ^I is given in (5). Let

$$\lambda_1^P(\tau) \equiv \arg\max_\lambda (\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau))|_{\alpha_0=0,\alpha_1=0} = \frac{1}{2}\frac{a-k-6\delta+5\tau}{-3\delta+2a-2k+\tau} \tag{6}$$

be the CEO's optimal weight λ given that neither firm abates, and

$$\lambda_2^P(\tau) \equiv \arg\max_\lambda (\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau))|_{\alpha_0=1,\alpha_1=0} = \frac{1}{4}\frac{a-k-4c+3\tau}{a-k-c} \tag{7}$$

be his optimal λ given that the public firm fully abates but the private firm does not abate. Figure 1 shows the payoff curves $f(\hat{\pi}_0 - \hat{\pi}_1)$ given the two abatement profiles (noting that $\hat{\pi}_0 - \hat{\pi}_1$ is lower when $\alpha_0 = 1$ than when $\alpha_0 = 0$), the associated values of λ_i^P , as well as threshold λ^I . Which payoff curve is relevant depends on the value of λ relative to λ^I : the relevant payoffs are represented by the bold curves, corresponding to the payoffs associated with $\alpha_0 = 1$ when $\lambda < \lambda^I$ and those associated with $\alpha_0 = 0$ when $\lambda \geq \lambda^I$.

[Insert Figure 1 Here]

As shown in Figure 1, let $\hat{\lambda}(\tau)$ be given by the maximum value of λ so that

$$(\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau))\,|_{\alpha_0=0,\alpha_1=0} = (\hat{\pi}_0(\lambda_2^P(\tau),\tau) - \hat{\pi}_1(\lambda_2^P(\tau),\tau))\,|_{\alpha_0=1,\alpha_1=0}\,,$$

i.e., $\hat{\lambda}(\tau)$ is the largest λ value that equates the CEO's payoff when the public firm is not abating with the maximum payoff the public firm obtains when it fully abates. In other words, if the CEO has to choose a value of λ that exceeds $\hat{\lambda}$ in order to induce full abatement by the public firm, then the CEO is better off choosing λ_2^P even though it induces no abatement by the public firm. Finally, let $\lambda_3^P(\tau) = \max\left\{\lambda_2^P(\tau), \hat{\lambda}(\tau)\right\}$.

Using Assumptions 1 and 2, we can show that $\lambda_2^P(\tau) > \lambda_1^P(\tau)$ which implies that $\lambda_3^P(\tau) > \lambda_1^P(\tau)$. Similar to the mixed economy literature, a private career CEO has incentive to choose a smaller value of λ (with $\lambda < 1$) so as to induce the public firm to produce more in order to gain competitive advantage. But this incentive is reduced by emission tax τ when the public firm does not abate and by abatement cost c when it fully abates. Since $\tau < c$, the incentive is reduced more under full abatement ($\alpha_0 = 1$) than under no abatement ($\alpha_0 = 1$). That is, the CEO would like to choose a larger λ value under full abatement than under no abatement, implying that $\lambda_2^P(\tau) > \lambda_1^P(\tau)$.

Since the CEO pursues a private career and cares only about profit, he always prefers the public firm not to abate. But his only influence on the firm's abatement decision is through setting the value of profit weight λ . Since full abatement is induced when λ is lower than λ^I , he has incentive to choose a value of λ that exceeds λ^I . The optimal profit weight λ depends on the trade-off between this incentive and the incentive to set a low λ value in order to gain competitive advantage (discussed in the previous paragraph). Specifically, it is determined by comparing the critical values λ_i^P , *i=1,2,3*, with λ^I : λ_1^P or λ_2^P is the CEO's optimal choice if the associated abatement profile, specifically $\alpha_0 = 1$ or $\alpha_0 = 0$, is consistent with the comparison between λ_i^P and λ^I. From Figure 1, we obtain the following result on the optimal profit weight.

Proposition 1 *Suppose the CEO pursues a private career and* $\tau < c$. *Then*

(i) If $\lambda_1^P(\tau) \geq \lambda^I(\tau)$ *(Figure 1(a)),* $\lambda^P = \lambda_1^P$ *and the public firm does not abate in stage three;*

(ii) If $\lambda_1^P(\tau) < \lambda^I(\tau) \leq \lambda_3^P(\tau)$ *(Figure 1(b)),* $\lambda^P = \lambda^I$ *and the public firm does not abate in stage three;*

(iii) If $\lambda^I(\tau) > \lambda_3^P(\tau)$ *(Figure 1(c)),* $\lambda^P = \lambda_2^P$ *and the public firm fully abates in stage three.*

The proof is given in Appendix A. When threshold λ^I is low so that $\lambda_1^P \geq \lambda^I$ (case (i)), it is relatively easy to induce the public firm not to abate (by setting $\lambda \geq \lambda^I$), a scenario preferred by a private career CEO who cares only about profits since the emission tax is lower than the abatement cost. When λ^I is high so that $\lambda^I(\tau) > \lambda_3^P(\tau)$ (case (iii)), if the CEO still wishes to induce no abatement, he will have to choose a high value of λ that exceeds λ_3^P, sacrificing too much in terms of the public firm's output level and thus competitive advantage. In this case, it is optimal for him to set a lower $\lambda^P = \lambda_2^P$ and induce full abatement. When the value of λ^I is intermediate (case (ii)), it is still optimal for the CEO to induce no abatement by setting $\lambda \geq \lambda^I$ but the competitive advantage incentive of reducing λ implies that he will choose a corner solution, $\lambda^P = \lambda^I$.

It is straightforward to verify that $\partial\lambda_i^P(\tau)/\partial\tau > 0$, for *i=1, 2,* and $\partial\lambda^I(\tau)/\partial\tau > 0$. Thus, unless the optimal λ^P jumps between the three threshold values as τ changes, λ^P increases as the tax rate rises. The reason again lies in the CEO's incentive to choose the profit weight to make sure that the public firm cares about social welfare so as to produce more, thereby gaining a competitive advantage. As the emission tax increases, the tax burden of producing more increases if the public firm does not abate, reducing the CEO's incentive to lower λ and thus raising the values of $\lambda_1^P(\tau)$ or $\lambda^I(\tau)$ (with both values inducing no abatement by the public firm). In the case of $\lambda^P(\tau) = \lambda_2^P(\tau)$ where the public firm fully abates, a higher emission tax reduces the output of the private firm (which does not abate), again reducing the public firm CEO's need to lower λ in order to gain competitive advantage over the private firm. Thus, $\lambda_2^P(\tau)$ also increases in τ. In sum, *as emission tax rises, the public firm will likely behave more like a private firm if the CEO has chosen a* *private career and if there are no jumps in* λ^P *values*. Since the public firm cares less about social welfare as λ^P rises, the endogeneity of the profit weight mitigates the effectiveness of emission taxes.

As the tax increases, not only will the values of the four threshold weights change, but also their relative positions and thus which of them will be the one chosen by the CEO. There are many configurations, sharing a common and significant pattern: as the tax increases, the optimal weight might shift from one threshold value to another, leading to jumps in the public firm's abatement level and thus the payoffs. Below we illustrate one such case in Figure 2 – Appendix A discusses the technical details in support of the layout in the Figure. As the tax increases, the relative position of λ^I changes although the ranking of the other three threshold weights remains unchanged. Consider first low tax levels such that $\tau \le \tau_1$ where τ_1 is defined as the crossing point of $\lambda_1^P(\tau)$ and $\lambda^I(\tau)$. In this case, $\lambda^I(\tau) < \lambda_1^P(\tau)$ and from Proposition 3, the optimal weight is $\lambda^P = \lambda_1^P(\tau)$ and the public firm does not abate. As the tax further increases so that $\tau_1 < \tau \le \tau_2$ where τ_2 is the crossing point of $\lambda_3^P(\tau)$ and $\lambda^I(\tau)$, $\lambda_1^P(\tau) < \lambda^I(\tau) < \lambda_3^P(\tau)$ and the optimal weight becomes $\lambda^P = \lambda^I(\tau)$, i.e., the CEO chooses weight $\lambda^I(\tau)$ and the public firm does not abate. When the tax is sufficiently high so that $\tau_2 < \tau < c$, $\lambda^I(\tau) > \lambda_3^P(\tau)$, the optimal weight jumps down to $\lambda^P = \lambda_2^P(\tau)$ and the public firm fully abates. Finally, when $\tau \ge c$, the optimal $\lambda^P = 1/4$. The optimal weights when the CEO chooses a private career are depicted by the bold curves in Figure 2.

[Insert Figure 2 Here]

Figure 2 shows that, although each threshold weight function $\lambda_i^P(\tau)$ or $\lambda^I(\tau)$ is increasing in τ, the private career CEO's optimal weight λ^P is discontinuous and non-monotonic: it jumps down at $\tau = \tau_2$, at which point the public firm switches from no abatement to full abatement. This happens when the benefit of inducing no abatement decreases so much due to the higher tax level that it cannot overcome the cost of lost competitive advantage due to behaving too much like a private firm. Thus although higher taxes in many cases cause the public firm to behave more like a private firm, they can also discontinuously cause the CEO to set a low profit weight.

Stage 1: the CEO's career choice. Substituting the CEO's optimal weight choices in Proposition 1 into profit functions $\hat{\pi}_i(\lambda,\tau), \quad i=0,1$, we obtain the (reduced form) optimal profit functions given that the CEO pursues a private career: $\pi_i^*(\tau) \equiv \hat{\pi}_i(\lambda^P(\tau),\tau)$, $i=0,1$. In (4), we defined the payoff functions $f(\bullet)$ and $g(\bullet)$ rather "generically," characterizing them as being dependent on profit difference $\pi_0 - \pi_1$ and social welfare W respectively. We choose not to explicitly "anchor" the two payoff functions (e.g., by imposing specific intercept values of *f* and *g* when both functions are linear). Instead, we only require that one payoff function do not completely dominate the other for all parameter values, to ensure that the career choice decision is not trivial.

II.2 Effects of pollution taxes

As we showed earlier, the pollution tax affects the public firm CEO's choices of profit weights and the two firms' abatement levels. We next show how it affects the public firm CEO's career choice. We follow the setup of Figure 2, with $\tau_1 < \tau_2 < c$.

Proposition 2. *(i) When* $\tau \geq c$, $\frac{\partial W^*(\tau)}{\partial \tau} = \frac{\partial(\pi_0^*(\tau) - \pi_1^*(\tau))}{\partial \tau} = 0$ *: a tax increase does not affect the public firm CEO's career choice.*

(ii) When $\tau_2 \leq \tau < c$, $\frac{\partial W^*(\tau)}{\partial \tau} < \frac{\partial(\pi_0^*(\tau) - \pi_1^*(\tau))}{\partial \tau}$ *: a tax increase tends to favor the private career.*

(iii) When $0 \leq \tau < \tau_1$, $\frac{\partial W^*(\tau)}{\partial \tau} > \frac{\partial(\pi_0^*(\tau) - \pi_1^*(\tau))}{\partial \tau}$ *: a tax increase tends to favor the public career.*

(iv) When $\tau_1 \leq \tau < \tau_2$*, the relative effects of* τ *on* $W^*(\tau)$ *and* $\pi_0^*(\tau) - \pi_1^*(\tau)$ *and thus on the CEO's career choice are ambiguous.*

When the tax rate is higher than abatement cost, both firms choose to fully abate, effectively paying no pollution tax. Thus neither the welfare nor the relative profit is affected as the environmental tax varies. When the tax rate is lower so that $\tau_2 \leq \tau < c$, the public firm abates but the private firm does not abate. Within this range, tax increases hurt the private firm and thus raise the relative profit for the public firm. The tax increases further result in higher deadweight loss due to lower output levels, and thus hurt social welfare. Consequently a higher tax favors the private career more than the public career. When the tax rate is even lower so that

$0 \le \tau < \tau_1$, neither firm abates. As we showed earlier, a high tax in this range would reduce social welfare but reduces the relative profit $\pi_0 - \pi_1$ even more than welfare since $q_0 > q_1$. That is, the public firm's profit is hurt more by the higher tax due to its higher output and emission levels. A higher tax thus favors the public career. When the tax rate is modest so that $\tau_1 \le \tau < \tau_2$, these two forces are almost balanced, resulting in ambiguous effects.

Starting at low tax levels (lower than τ_1), increases in the tax rate favor the public career more than the private career. In other words, as the tax rate increases, it is possible that a CEO who has chosen a private career switches to a public career. However, as the tax rate further increases, Proposition 2(ii) indicates that the higher tax rate might favor the private career more than the public career. It is thus possible that the CEO will switch his career choice back to the private career. The tax rates that can induce a public career tend to be in the "intermediate range." Figure 3 (a) illustrates this possibility: as emission tax increases, the ranking of payoffs from the two career choices changes signs multiple times.

[Insert Figure 3 Here]

The effects of emission taxes on career choices have important implications for the total emissions in the economy. Not surprisingly, when the CEO switches from a public career to a private career, total emissions in the economy jump up. Figure 3(b) shows the changes in emission levels as the tax rate increases. Given a fixed career choice, the total emission level is always decreasing in the tax rate, and the emission levels associated with the public career lie below those of the private career unless the tax rate $\tau \ge c$ (in which case they are equal). Shifts from public to private careers always involve upward jumps in total emissions. Thus, endogeneity of CEO's career choices destroys the standard monotonicity results: emission levels are not monotonically decreasing in emission taxes anymore. Further, the jump in total emissions as career choices change also implies that some emission levels in Figure 3(b) are not achievable. That is, the public firm CEO's career endogeneity limits the set of emission levels that can be induced by emission taxes.

Figure 3(c) shows the net welfare effects of emission taxes. As expected, the social welfare associated with a public career dominates that of a private career. Note that the welfare associated with the private career is non-monotonic and discontinuous. For instance, when the tax levels are low, neither the public nor the private firm abates. Emission tax does not affect the abatement level and is distortionary, and thus reduces the social welfare. However, social welfare can jump up when a higher tax cause one or both firms to fully abate. More importantly, Figure 3(c) shows that welfare levels can jump down as the tax rate increases if it causes the public firm's CEO to switch from a public to a private career. Given that a public career welfare-dominates a private career, and in light of Proposition 2, the optimal tax rates tend to be in the intermediate range. Specifically, it tends to be below the Pigouvian tax rate of $\tau = \delta$.

III. Emission Standard

The effects of emission standards parallel those of taxes, but with some important differences. We consider a particular form of standard, namely the proportion of emissions that a firm has to abate. Let $\bar{\alpha} \in [0,1]$ be the standard, representing the proportion of a firm's emissions that has to be abated. If a firm's output (and thus its gross emission) is *q*, its net emission level under this standard is $(1-\bar{\alpha})q$. With this setup, Assumption 1 simplifies to the assumption of $a-k-c>0$, Assumption 2(ii) is replaced by assuming $a-k-\delta > 2(\delta-\bar{\alpha})$ to ensure that all equilibrium outputs are nonnegative, and we continue to assume $\delta > c$ as in Assumption 2(i).

III.1 Subgame perfect Nash equilibrium

Similar to the case of pollution taxes, we use backward induction to find the subgame perfect Nash equilibrium. In stage 3, given standard $\bar{\alpha}$ and profit weight λ, the public and private firms engage in Cournot competition. Since the private firm only cares about its profit, it always abates only up to the standard: $\alpha_1 = \bar{\alpha}$. The public firm, however, may abate more than $\bar{\alpha}$ if it cares enough about the social welfare. Similar to the case of pollution tax, there exists a threshold weight level $\tilde{\lambda}^I \equiv (\delta - c)/\delta$ such that when $\lambda \geq \tilde{\lambda}^I$, the public firm abates only up to the standard, and when $\lambda < \tilde{\lambda}^I$, it fully abates so that $\alpha_0 = 1$. The equilibrium abatement and output profiles are given in Appendix A. Substituting the optimal output and abatement levels (equations (12) and (13) in Appendix A) back to (1) and (2), we obtain the optimal profit and social welfare functions, denoted as $\tilde{\pi}_i(\lambda,\bar{\alpha})$, i=0,1, and $\tilde{W}(\lambda,\bar{\alpha})$.

Depending on his career objective, the CEO again chooses the profit weight λ in order to maximize his payoff in (4). Similar to the case of pollution tax, if the CEO chooses a public career, the optimal profit weight is $\tilde{\lambda}^G = 0$. The private career CEO's optimal choice of weight $\tilde{\lambda}^P$ again depends on the comparisons of several critical weight levels. Parallel to the case of emission taxes, let

$$\tilde{\lambda}_1^P(\overline{\alpha}) \equiv \arg\max_{\lambda}(\tilde{\pi}_0(\lambda,\overline{\alpha}) - \tilde{\pi}_1(\lambda,\overline{\alpha}))|_{\alpha_0=\overline{\alpha},\alpha_1=\overline{\alpha}} = \frac{1}{2}\frac{a-k-6\delta-c\overline{\alpha}+6\delta\overline{\alpha}}{-3\delta+2a-2k-2c\overline{\alpha}+3\delta\overline{\alpha}}$$

be the CEO's optimal weight λ given that both firms abate only up to the standard, and

$$\tilde{\lambda}_2^P(\overline{\alpha}) \equiv \arg\max_{\lambda}(\tilde{\pi}_0(\lambda,\overline{\alpha}) - \tilde{\pi}_1(\lambda,\overline{\alpha}))|_{\alpha_0=1,\alpha_1=\overline{\alpha}} = \frac{1}{4}\frac{a-k-4c+3c\overline{\alpha}}{a-k-c}$$

be the CEO's optimal weight λ given that the public firm fully abates and the private firm abates only up to the standard. Further, let $\tilde{\lambda}_3^P(\overline{\alpha}) = \max\left\{\tilde{\lambda}_2^P(\overline{\alpha}), \tilde{\lambda}(\overline{\alpha})\right\}$, where $\tilde{\lambda}(\overline{\alpha})$ equals the maximum value of λ such that $(\tilde{\pi}_0(\lambda,\overline{\alpha}) - \tilde{\pi}_1(\lambda,\overline{\alpha}))|_{\alpha_0=\overline{\alpha},\alpha_1=\overline{\alpha}} = (\tilde{\pi}_0(\tilde{\lambda}_2^P(\overline{\alpha}),\overline{\alpha}) - \tilde{\pi}_1(\tilde{\lambda}_2^P(\overline{\alpha}),\overline{\alpha}))|_{\alpha_0=1,\alpha_1=\overline{\alpha}}$. We can verify that $\tilde{\lambda}_2^P(\overline{\alpha}) > \tilde{\lambda}_1^P(\overline{\alpha})$, which implies that $\tilde{\lambda}_3^P(\overline{\alpha}) > \tilde{\lambda}_1^P(\overline{\alpha})$. The private career CEO's optimal choice of weight $\tilde{\lambda}^P$ is given by the following Proposition.

Proposition 3. *Suppose the CEO pursues a private career.*

(i) If $\tilde{\lambda}^I \le \tilde{\lambda}_1^P(\overline{\alpha})$, $\tilde{\lambda}^P(\overline{\alpha}) = \tilde{\lambda}_1^P(\overline{\alpha})$ *and the public firm abates up to the standard* $\overline{\alpha}$ *in stage three;*

(ii) If $\tilde{\lambda}_1^P(\overline{\alpha}) < \tilde{\lambda}^I \le \tilde{\lambda}_3^P(\overline{\alpha})$, $\tilde{\lambda}^P(\overline{\alpha}) = \tilde{\lambda}^I(\overline{\alpha})$ *and the public firm abates up to the standard* $\overline{\alpha}$ *in stage three; and*

(iii) If $\tilde{\lambda}^I > \tilde{\lambda}_3^P(\overline{\alpha})$, $\tilde{\lambda}^P(\overline{\alpha}) = \tilde{\lambda}_2^P(\overline{\alpha})$ *and the public firm fully abates in stage three.*

The proof is similar to that of Proposition 1 and is omitted. Again, parallel to the case of pollution tax, the positions of the threshold weights $\tilde{\lambda}_i^P$, $i = 1,2,3$, and of $\tilde{\lambda}^I$ relative to $[\tilde{\lambda}_1^P, \tilde{\lambda}_3^P]$, depend on the parameter values including standard $\overline{\alpha}$. It is straightforward to verify that $\partial\tilde{\lambda}_1^P(\overline{\alpha})/\partial\overline{\alpha} > 0$, $\partial\tilde{\lambda}_2^P(\overline{\alpha})/\partial\overline{\alpha} > 0$, and $\tilde{\lambda}_1^P(\overline{\alpha}) < \tilde{\lambda}_2^P(\overline{\alpha}) \le 1/4 = \tilde{\lambda}_1^P(1) = \tilde{\lambda}_2^P(1)$ for all $\overline{\alpha} \le 1$. As the standard increases, not only will the values of the four threshold weights change, but also their relative positions and thus which of them will be the one chosen by the CEO. Figure 4 illustrates two possible patterns, one involving jumps in the optimal weights and the other involving smooth changes in $\tilde{\lambda}^P$ as $\overline{\alpha}$ increases.

[Insert Figure 4 Here]

In Figure 4, the three threshold curves, $\tilde{\lambda}_1^P(\overline{\alpha})$, $\tilde{\lambda}_2^P(\overline{\alpha})$, and $\tilde{\lambda}_3^P(\overline{\alpha})$, cross at $\overline{\alpha} = 1$ (taking the value of ¼), while $\tilde{\lambda}^I$ is independent of $\overline{\alpha}$. In Figure 4 (a), $\tilde{\lambda}^I(\overline{\alpha}) < 1/4$, which is equivalent to $\delta < 4c/3$, a case of low pollution damage. For low standard levels, $\tilde{\lambda}^P = \tilde{\lambda}^I(\overline{\alpha})$ and for high standard levels, $\tilde{\lambda}^P = \tilde{\lambda}_1^P(\overline{\alpha})$. In both cases the public firm abates at level $\overline{\alpha}$ in stage three. In Figure 4 (b), $\tilde{\lambda}^I(\overline{\alpha}) \geq 1/4$, which is equivalent to $\delta \geq 4c/3$, a case of high pollution damages. At low standard levels, $\tilde{\lambda}^P = \tilde{\lambda}^I(\overline{\alpha})$ and the public firm abates at level $\overline{\alpha}$ in stage three. But at high standard levels, the value of $\tilde{\lambda}^P$ jumps down to $\tilde{\lambda}^P = \tilde{\lambda}_2^P(\overline{\alpha})$ and the public firm fully abates in stage three.

The intuition again is similar to that in the case of emission taxes. Since the CEO pursues a private career, he has two conflicting incentives when choosing the optimal weight $\tilde{\lambda}^P$ to influence the firms' output and abatement decisions. (i) On the one hand, he has incentive to choose a lower level of λ to ensure that the public firm cares enough about social welfare so that it produces more and thus gains competitive advantage over the private firm. (ii) On the other hand, he has incentive to choose a higher level of λ to ensure that the public firm care enough about its own profit so that it does not abate over the standard $\overline{\alpha}$. In Figure 4(a), i.e., for the case of low pollution damages, the second incentive dominates: the CEO can choose a high enough weight so that the public firm does not abate. Further, as shown in Appendix A, when $\tilde{\lambda}^P < 1/2$ (which is satisfied since $\tilde{\lambda}^P < 1/4$ in Figure 4(a)), the public firm's output q_0 increases and the private firm's output q_1 decrease as the standard $\overline{\alpha}$ rises: while a higher standard raises the total cost of production, thereby pushing down q_1, it also means that a higher proportion of pollution is abated, so that the social welfare conscious public firm is less concerned with its output causing pollution damage. Thus, a higher standard, by raising q_0 and decreasing q_1, further reduces the CEO's incentive in (i): eventually the optimal weight $\tilde{\lambda}^P$ rises as $\overline{\alpha}$ further increases in Figure 4(a).

In Figure 4(b), i.e., when the pollution damage is higher, the CEO has to choose a much higher level of weight λ in order to induce the public firm not to abate; otherwise, its concern for social welfare coupled with high pollution damage means that the public firm will fully abate its emissions. Doing so comes at the cost of sacrifacing objective (i) of gaining competitive advantage. The cost is further aggravated by the fact that the public firm's output is already decreased relative to the private firm by the high pollution damage δ, *even for fixed levels of* λ.[8] Thus, in this case private career CEO eventually chooses a lower weight at $\tilde{\lambda}^P = \tilde{\lambda}_2^P$ and the public firm fully abates its emissions.

Similar to the case of emission taxes, the private career CEO's profit weight is non-decreasing in the standard when there are no jumps: as the government tightens the standard, the CEO responds by behaving more like a private firm, mitigating the effectiveness of the tougher standard. However, when the pollution damage is high, it is possible that a tough enough standard induces the public firm to fully abate its emissions. The effects of the standard can be discontinuous.

III.2. Effects of emission standards

Substituting the optimal choice of $\tilde{\lambda}^G = 0$ into the social welfare function $\tilde{W}(\lambda, \overline{\alpha})$, we obtain the (reduced form) optimal social welfare when the CEO pursues a public career: $\tilde{W}^*(\overline{\alpha}) \equiv \tilde{W}(\lambda^G = 0, \overline{\alpha})$. Substituting the optimal choices of $\tilde{\lambda}^P$ in Proposition 3 into the profit functions $\tilde{\pi}_i(\lambda, \overline{\alpha})$, i=0,1, we obtain the (reduced form) optimal profit functions when the CEO pursues a private career: $\tilde{\pi}_i^*(\overline{\alpha}) \equiv \tilde{\pi}_i(\lambda^P(\overline{\alpha}), \overline{\alpha})$, *i=0,1*. Based on $\tilde{W}^*(\overline{\alpha})$ and $\tilde{\pi}_i^*(\overline{\alpha})$, and the payoff functions in (4), we can study how varying emission standards affects the CEO's career choice and the subsequent emission and output levels and social welfare.

The effects of the emission standard are structurally similar to those of the emission tax. As the standard tightens, the CEO's career objective may change, and given a fixed career objective, his choice of the profit weight may also change. Both will lead to changes in output and abatement levels. Let $\overline{\alpha}_2 \equiv \{\overline{\alpha} \in [0,1]: \ \tilde{\lambda}^I = \tilde{\lambda}_1^P(\overline{\alpha}) \,|\, \delta < 4c/3\}$ be the crossing point of $\tilde{\lambda}^I$ and $\tilde{\lambda}_1^P(\overline{\alpha})$ in Figure 4(a), and $\overline{\alpha}_1 \equiv \{\overline{\alpha} \in [0,1]: \ \tilde{\lambda}^I = \tilde{\lambda}_3^P(\overline{\alpha}) \,|\, \delta \geq 4c/3\}$ be the crossing point of $\tilde{\lambda}^I$ and $\tilde{\lambda}_3^P(\overline{\alpha})$ in Figure 4(b). Proposition 4 shows how the CEO's career choice is affected by the standard.

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[8] Appendix A shows that when both firms abate only up to the standard and if $\lambda < 1$, the public firm's output q_0 is decreasing and the private firm's output q_1 is increasing in pollution damage δ: the public firm's concern for social welfare means that it decreases its polluting output when pollution damage becomes higher, and correspondingly the private firm increases its output.

Proposition 4. (i) *If* $\delta < 4c/3$ *(Figure 4(a)) and* $\bar{\alpha} > \bar{\alpha}_2$*, then* $\frac{\partial(\tilde{\pi}_0^*(\bar{\alpha}) - \tilde{\pi}_1^*(\bar{\alpha}))}{\partial\bar{\alpha}} < \frac{\partial\tilde{W}^*(\bar{\alpha})}{\partial\bar{\alpha}}$*: a stricter standard favors the public career;*

(ii) *If* $\delta \geq 4c/3$ *(Figure 4(b)) and* $\bar{\alpha} > \bar{\alpha}_1$*, then* $\frac{\partial(\tilde{\pi}_0^*(\bar{\alpha}) - \tilde{\pi}_1^*(\bar{\alpha}))}{\partial\bar{\alpha}} > \frac{\partial\tilde{W}^*(\bar{\alpha})}{\partial\bar{\alpha}}$ *: a stricter standard favors the private career;*

(iii) *In other cases, the relative effect of standard* $\bar{\alpha}$ *on profit difference* $\tilde{\pi}_0^*(\bar{\alpha}) - \tilde{\pi}_1^*(\bar{\alpha})$ *vs. on social welfare* $\tilde{W}^*(\bar{\alpha})$ *is ambiguous.*

The proof is similar to that of Proposition 2 and is omitted. Proposition 4 indicates that the effects of the standard depends on the damage level δ. When the damage is low (case (*i*)), the public firm fully abates if the CEO chooses a public career and abate only up to the standard if the CEO chooses a private career. Stricter standards improves social welfare since abatement is desirable but hurt both the public and private firms, thereby making the private career less attractive compared with the public career. When the pollution damage is high (case (*ii*)), the public firm always fully abates regardless of the CEO's career choice. Stricter standards only hurt the private firm, thereby increasing the profit difference, and thus favors private career.

Similar to the case of emission taxes, the endogeneity of the CEO's career choice can lead to non-monotonic effects of emission standards on net pollution levels. Figure 5 shows an example with $\delta \geq 4c/3$, so that as the standard tightens, the CEO switches from a public to a private career (Panel (a)). As shown in Panel (b), although the pollution level decreases as the standard tightens for a fixed career objective (bottom line for public career and top lines for private career), the switch in the CEO's career objective leads to a discontinuous increase in total emissions.

[Insert Figure 5 Here]

Figure 5(c) illustrates the effects of emission standards on social welfare. When the CEO pursues a public career, a higher standard always improves social welfare (top line in Panel (c)). Since the public firm always fully abates (since $\tilde{\lambda}^G = 0$), the only effect of raising the standard is to force the private firm to abate more. Since abatement is socially desirable, this tends to improve social welfare. Further, although the private firm reduces its output in response to the higher standard (as shown in (12) in Appendix A), the lost output is entirely (and exactly) made up by the increased production of the public firm. The total output is thus unchanged, so is the consumer surplus. As a result, the social welfare is always increasing in the stringency level of the standard. However, when the CEO pursues a private career, a higher standard might not always improve social welfare (although in the special case of Panel (c), a higher standard does always improve welfare). Even though more stringent standard always reduces pollution (from the private firm and sometimes from the public firm when $a_0 = \overline{\alpha}$), it can also reduce the total output level, aggravating the loss in consumer surplus due to imperfect competition. Finally, a key observation in Figure 5 (c) is that social welfare under the public career is always higher than that under the private career.

Given the welfare dominance of the public career over the private career, Proposition 4 and Figure 5 indicate that the socially optimal standard should induce a public career and thus might be far below the first best case of full abatement. For pollution intensive industries, the public firm already fully abates and stricter standards will hurt the private firm only, thereby driving up the profit difference between the two firms and making the private career more attractive. A relatively loose standard might thus be optimal for pollution intensive industries while a tighter standard might be optimal for less pollution intensive industries (Proposition 4(i)). What drives this counter-intuitive finding is the endogeneity of the public firm CEO's career choices: a tougher standard imposed on pollution intensive industries might hurt the private firm so much relative to the public firm and thus help the CEO send such a strong signal about his ability to compete in markets that he ends up choosing a private career and thus steering the public firm to emphasize profit over social welfare, thereby reducing overall social welfare.

IV. Comparison: Tax vs. Standard

A standard result in the environmental economics literature is that, with symmetric firms and without uncertainties, information asymmetries or transaction costs, emission taxes and standards are equivalent: for any tax, there is a standard that leads to the same pollution level and vice versa. When the firms are heterogeneous, a uniform tax is advantageous over a uniform standard since the former equates the marginal abatement costs of the firms. In our model, the public and private firms share the same abatement and production technologies. Their difference lies in the divergent objective functions arising from the nature of mixed economies, and we show in this section that the equivalence between taxes and standards breaks down. When this happens, we further identify the "better" regulatory tool, which may not always be emission taxes.

Figures 6 and 7 show two examples of "anchored" comparisons of taxes and standards for two different scenarios. On the horizontal axis, tax τ goes from zero to one, so does standard $\overline{\alpha}$. Note that there is no regulation on emissions when τ and $\overline{\alpha}$ are both zero, and there is full regulation (full abatement) when they are both one. The two end values of zero and one thus provide natural anchors when comparing the effects of the two policies. For instance, $\tau = \bar{\alpha} = 0.4$ represent regulations that are 40% stringent compared with the "full regulation" associated with each policy instrument.

Panel (a) in each of Figures 6 and 7 shows the impacts on total emission levels and Panel (b) shows the impacts on welfare as the tax or standard increases. Thick curves are associated with emission standards while thin curves are for emission taxes. Solid lines represent the realized emission levels or welfare when the CEO's career objective is endogenously chosen, while dotted lines represent the emission and welfare levels for fixed careers.

[Insert Figure 6 Here]

[Insert Figure 7 Here]

Panels (a) in both Figures 6 and 7 demonstrate the breakdown of the equivalence between taxes and standards. Total emission levels are discontinuous in the tax level in both figures and are discontinuous in standards in Figure 7(a). Further, in Figure 6(a), there are ranges of emission levels that cannot be achieved if taxes are used but can be achieved if standards are used. For instance, if the government wishes to achieve a total emission level of $E=2$, it can do so by setting a standard of $\bar{\alpha} = 0.4$. But no tax can induce this emission level due to the discontinuity of emissions in taxes.

Panels (b) in both Figures show that there is not a clear dominance relationship between taxes and standards. There are ranges of regulation levels where taxes dominate standards, and other ranges where the dominance relation is reversed. However, a consistent pattern is that, quite intuitively, a policy tends to be dominant if it induces a public career while the other policy induces a private career. For instance, in Figure 7(b), welfare associated with low levels of standards that induce a public career is higher than that associated with (higher levels of) taxes and standards that induce a private career. Similarly, welfare associated with taxes that induce a public career dominates that associated with both policies when they induce a private career. Thus, the determining factor in welfare rankings of the policies lies in the career objectives that they induce. A policy instrument tends to be effective if it induces a public career. Ultimately, the optimal policy choice in Figure 6 is a tax at the level of $\tau^* = 0.84$, while the optimal policy choice in Figure 7 is a standard at the level of $\bar{\alpha}^* = 0.81$.

V. Discussion and Conclusions

In this paper, we study environmental regulation in mixed economies where public and private firms engage in Cournot competition, and show that in these economies some fundamental results in environmental economics fail to hold, e.g., the monotonicity result of tougher taxes or standards always leading to lower emissions, and the equivalence between taxes and standards. This is important given the pervasive nature of mixed economies in developing countries and in many industrialized nations. Public firms behave differently from private firms since their behaviors are not entirely profit driven. However, as we argue and model in this paper, their objectives are not necessarily fixed. Instead, they are influenced by the CEO's career choices, and both the CEO's career choices and the public firm's objectives are affected by environmental regulation, including the stringency and specific instruments of the regulation.

The endogeneity of the public firm CEO's career choices drives much of the "non-standard" effects of environmental regulation. More stringent regulation does not necessarily lead to less pollution, since it might induce the CEO to switch from a public career to a private career, causing upward jumps in pollution levels. In fact, the optimal emission tax is typically lower than Pigouvian tax, and the optimal emission standard might be lower for emissions that cause more environmental damage compared with emissions that cause less damage. There is no clear dominance relation between taxes and standards, with the instrument that induces a public career being welfare dominant. These results highlight an important phenomenon that has not been addressed in the literature: environmental regulation can affect not only the firms' payoffs but also their objective functions. The endogenous payoff functions are similar in spirit to the endogenous preference literature (Bowles, 1998), where government regulation might alter the preferences of individuals. Our paper presents a structural model of how firm preferences can be altered through the CEO's career choices, and shows how this endogeneity can lead to questions about some "standard" conclusions in environmental economics.

Although we model strategic interactions between public and private firms as Cournot, our results are robust to other strategic interactions such as the public firm being the Stackelberg leader. This is intuitive: different career choices of the CEO will inevitably lead to discrete changes in the public firm's weighting between profit and social welfare, which in turn will lead to jumps in emission and welfare levels. The forms of strategic interactions between public and private firms might affect the magnitude and location but not the existence of the discontinuities.[9] Our results are also robust to the linear quadratic setup. Even with convex

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[9] If the firms compete in prices, we have to go beyond the most basic Bertrand setup to capture the role of market power and public firms, e.g., by introducing capacity constraints or differentiated products. Once we do so, e.g., by introducing differentiated products, our main results still hold because discrete career choices will lead to jumps in equilibrium

production costs and a nonlinear demand function, the discontinuity in policy levels and instrument choices due to the discrete career choices can still lead to jumps in emission and welfare levels. Finally, our results still hold if the public firm is more pollution intensive than the private firm due to the reasons discussed in Introduction: as long as the public firm chooses to abate more if it cares more about social welfare, discrete career choices by the public firm CEO still lead to jumps in emission levels and welfare.

Appendix A: Technical Details

Emission taxes

Given the linear quadratic setup, we are able to obtain closed form solutions of the equilibrium output and abatement levels. It is straightforward to show that

(i) If $\tau \geq c$ *, then* $\alpha_0 = \alpha_1 = 1$ *and*

$$\begin{cases} q_0 = \dfrac{a-k-c}{1+2\lambda} \\ q_1 = \lambda \dfrac{a-k-c}{1+2\lambda} \end{cases} \tag{8}$$

(ii) If $\tau < c$ *and* $\lambda < \lambda^I$ *, then* $\alpha_0 = 1,\ \alpha_1 = 0$ *and*

$$\begin{cases} q_0 = \dfrac{\tau - 2c + a - k}{1+2\lambda} \\ q_1 = \dfrac{\lambda a - \lambda k - \lambda \tau - \tau + c}{1+2\lambda} \end{cases} \tag{9}$$

(iii) *If* $\tau < c$ *and* $\lambda \geq \lambda^I$ *, then* $\alpha_0 = 0,\ \alpha_1 = 0$ *and*

$$\begin{cases} q_0 = \dfrac{2\lambda\delta - 2\lambda\tau - 2\delta + \tau + a - k}{1+2\lambda} \\ q_1 = \dfrac{-\tau + \lambda a + \delta - \lambda\delta - \lambda k}{1+2\lambda} \end{cases} \tag{10}$$

When $\lambda < 1$, the public firm differs from the private firm in two aspects due to the former's concern about social welfare: it might abate, and it tends to produce more so as to raise consumer surplus. The two firms also respond differently to changes in exogenous parameters. Proposition A1, which can be easily derived from (10), highlights the differences for the case of (iii) above.

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prices, similar to the Cournot setting.

Proposition A1 *Consider case (iii), i.e.,* $\alpha_0 = 0,\ \alpha_1 = 0$ *and* q_0 *and* q_1 *are given in* (10).

(i) Suppose $\lambda < 1$*, i.e., the public firm cares about the social welfare. As pollution damage* δ *increases, the public firm's output* q_0 *decreases but the private firm's output* q_1 *increases.*

(ii) As pollution tax τ *increases, the public firms' output* q_0 *decreases if* $\lambda \geq 1/2$ *and the private firms' output* q_1 *always decreases, and* q_1 *decreases more than* q_0 *does.*

(iii) As consumer demand parameter a increases, both firms' outputs rise, but the public firm's output rises more than that of the private firm.

(iv) As the marginal cost k rises, both firms' outputs decrease, but the public firm's output decreases more than the private firm.

(v) As λ *increases, i.e., as the public firm cares more about its profit, the public firm's output* q_0 *decreases, and the private firm's output* q_1 *increases.*

We omit the proof, which is straightforward utilizing (10). When $\lambda < 1$, the public firm cares about the social welfare. Thus, as the pollution damage δ increases, the public firm reduces its output q_0 but the private firm increases its output due to strategic substitution between q_0 and q_1. In general, the private firm produces less as tax increases, but the public firm might produce more since the tax revenue is part of the social welfare. It will produce less if it cares more about its profit than about social welfare, i.e., if $\lambda \geq 1/2$. When demand increases, both firms produce more but since the marginal consumer surplus is higher, the public firm has incentive to increase its output more than the private firm. When cost *k* rises, the fact that social welfare includes both firms' profits means that the public firm reduces its output more than the private firm. As λ increases, the public firm cares more about its profit and thus reduces its output q_0, and the private firm increases its output q_1 in response, mimicking results in the standard mixed oligopoly literature.

Proof of Proposition 1. Given $\tau < c$, it is straightforward to show that (cf. Figure 1) $(\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau))|_{\alpha_0=0,\alpha_1=0} > (\hat{\pi}_0(\lambda,\tau) - \hat{\pi}_1(\lambda,\tau))|_{\alpha_0=1,\alpha_1=0}$: at any chosen λ, the public firm obtains a higher profit when it does not abate. The definition of λ_1^P and λ_2^P then implies that $(\hat{\pi}_0(\lambda_1^P(\tau),\tau) - \hat{\pi}_1(\lambda_1^P(\tau),\tau))|_{\alpha_0=0,\alpha_1=0} > (\hat{\pi}_0(\lambda_2^P(\tau),\tau) - \hat{\pi}_1(\lambda_2^P(\tau),\tau))|_{\alpha_0=1,\alpha_1=0}$. Thus,

$$\text{f}(\hat{\pi}_0(\lambda_1^P(\tau),\tau)-\hat{\pi}_1(\lambda_1^P(\tau),\tau))|_{\alpha_0=0,\alpha_1=0} \tag{11}$$

is the highest payoff the private career CEO can obtain when choosing λ.

Under Case (i) of Proposition 1, $\lambda_1^P(\tau)>\lambda^I(\tau)$. By setting $\lambda^P=\lambda_1^P$, the CEO obtains the highest payoff in (11). Under Case (ii), the CEO has no incentive to choose $\lambda<\lambda^I$ since it induces full abatement (cf. Figure 1(b)) and since $\lambda^I(\tau)<\lambda_3^P(\tau)$ implies that choosing $\lambda\in[\lambda^I,\lambda_3^P)$ generates a payoff that exceeds the maximum payoff obtainable under full abatement (cf. the definition of $\hat{\lambda}$). Since $f(\cdot)$ is concave by assumption and $(\hat{\pi}_0(\lambda,\tau)-\hat{\pi}_1(\lambda,\tau))|_{\alpha_0=0,\alpha_1=0}$ is concave in λ (due to the linear quadratic setup), the optimal choice from $\lambda\in[\lambda^I,\lambda_3^P)$ is $\lambda^P=\lambda^I$. Under Case (iii), the definition of $\hat{\lambda}$ and the condition that $\lambda^I\geq\lambda_3^P\geq\hat{\lambda}$ imply that the CEO can obtain a higher payoff by inducing full abatement and choosing $\lambda^P=\lambda_2^P$. QED

Layout of Figure 2. The layout of the threshold profit weight functions in Figure 2 has the following properties: (i) $\lambda_1^P(\tau)<\lambda_2^P(\tau)\leq 1/4$ for all $\tau\leq c$, $\lambda_2^P(\tau=c)=1/4$, and $\partial\lambda_i^P(\tau)/\partial\tau>0$, for *i=1, 2*, and $\partial\lambda^I(\tau)/\partial\tau>0$; (ii) $\lambda^I(\tau)$ crosses $\lambda_1^P(\tau)$ only once and from below at point τ_1, defined as $\tau_1\equiv\max\left\{\tau\geq 0,\ \text{s.t. } \lambda^I(\tau)=\lambda_1^P(\tau)\right\}$ if it exists and $\tau_1=0$ otherwise; (iii) $\lambda^I(\tau)$ crosses $\lambda_3^P(\tau)$ only once and from below at point τ_2, defined as $\tau_2\equiv\max\left\{\tau\geq 0,\ \text{s.t. } \lambda^I(\tau)=\lambda_3^P(\tau)\right\}$ if it exists and $\tau_2=0$ otherwise; and (iv) $\tau_1<\tau_2<c$.

Property (i) can be established directly from equations (5), (6) and (7). From (5) and (6), $\lambda^I(\tau)$ and $\lambda_1^P(\tau)$ can cross at most twice. Figure 2 depicts a situation when they cross once where $\lambda^I(\tau)$ crosses from below. We can show that if $\lambda^I(\tau)$ ever crosses $\lambda_1^P(\tau)$ from above, it will always cross $\lambda_1^P(\tau)$ again from below because $\dfrac{\partial\lambda_1^P(\tau)}{\partial\tau}=\dfrac{9(a-k-\delta)}{2(2a-2k-3\delta+\tau)^2}$ and is bounded above but $\dfrac{\partial\lambda^I(\tau)}{\partial\tau}=\dfrac{\delta-c}{(\delta-\tau)^2}$ and goes to infinity as τ increases. That is, eventually the slope of $\lambda^I(\tau)$ will exceed that of $\lambda_1^P(\tau)$ and they will cross again. A third possibility is when $\lambda^I(\tau)$ lies entirely above $\lambda_1^P(\tau)$, in which case $\tau_1=0$. Although we only analyze the situation when they cross only once, the same methods can be used to analyze the other two situations (crossing twice or never crossing) and our main results still hold. Property (iii) can be established in a similar fashion to Property (ii). In Property (iv), $\tau_1 < \tau_2$ follows from the fact that $\lambda^I(\tau)$ is increasing, $\lambda^I(\tau)$ crosses $\lambda_1^P(\tau)$ from below, and $\lambda_1^P(\tau) < \lambda_2^P(\tau)$. Since $\lim_{\tau\to c} \lambda^I(\tau) = 1$ and $\lambda_3^P(c) < 1$, we know $\tau_2 < c$.

Proof of Proposition 2. When $\tau > c$, both firms fully abate and thus pay no pollution tax. Their profits and the social welfare are independent of τ, establishing (i) of the Proposition. For (ii), we can establish that $\partial W^* / \partial\tau - \partial(\pi_0^* - \pi_1^*) / \partial\tau = (\delta - c) - (a - k - \tau)/2$, which is negative from Assumption 2(ii), $\tau < c$, and $\delta > \tau$ (implied by Assumption 2(i)). For (iii) of the Proposition, we can show that $\partial W^* / \partial\tau - \partial(\pi_0^* - \pi_1^*) / \partial\tau = (\delta - c) + (a - k - \tau)/6$**,** which is positive from Assumption 1 and because $\delta > c$ (Assumption 2(i)). QED

<u>Emission standards</u>

Given standard $\overline{\alpha}$ and weight λ, it is straightforward to show that in Stage 3 Nash equilibrium, the private firm always abates up to the standard. Further,

(i) If $\lambda < \tilde{\lambda}^I$*, the public firm fully abates (*$\alpha_0 = 1$*) and the outputs are given by*

$$\begin{cases} q_0 = \dfrac{c\overline{\alpha} - 2c + a - k}{1 + 2\lambda} \\ q_1 = \dfrac{\lambda a - \lambda k - \lambda c\overline{\alpha} - c\overline{\alpha} + c}{1 + 2\lambda} \end{cases} \tag{12}$$

(ii) If $\lambda \geq \tilde{\lambda}^I$, $\alpha_0 = \overline{\alpha}$ *and the equilibrium outputs are*

$$\begin{cases} q_0 = \dfrac{-2\lambda\delta\overline{\alpha} - 2\delta + 2\delta\overline{\alpha} + 2\lambda\delta + a - k - c\overline{\alpha}}{1 + 2\lambda} \\ q_1 = \dfrac{\lambda\delta\overline{\alpha} + \lambda a - \lambda k - \lambda c\overline{\alpha} + \delta - \delta\overline{\alpha} - \lambda\delta}{1 + 2\lambda} \end{cases} \tag{13}$$

Similar to the case of taxes, when the public firm fully abates, further tightening of the standard (increasing

$\bar{\alpha}$) only hurts the private firm since it will have to abate more. Thus in (12), q_0 is increasing while q_1 is decreasing in standard $\bar{\alpha}$. When both firms are constrained by the standard, the private firm's output is always decreasing in the standard, again since it cares only about its profit and abatement is costly. Even though the standard is binding for the public firm, the public firm's output can still be increasing in the standard as long as its profit weight is not too high: a sufficient condition for this to be true is $\lambda \leq 1/2$. Finally, we can show that in (13), q_0 is decreasing while q_1 is increasing in pollution damage δ: $\partial q_0 / \partial\delta \propto -(1-\bar{\alpha})(1-\lambda) \leq 0$ and $\partial q_1 / \partial\delta \propto (1-\bar{\alpha})(1-\lambda) \geq 0$, where the inequalities follow from $\lambda \leq 1$ and $\bar{\alpha} \leq 1$.

References

Barros, F.: 1995. Incentive Schemes as Strategic Variables: An Application to a Mixed Duopoly, *International Journal of Industrial Organization*13: 373-386.

Baumol, W. J. and Oates W. E.: 1988. *The Theory of Environmental Policy*, Second Edition, Cambridge University Press.

Bowles, Samuel. :1998. Endogenous Preferences: The Cultural Consequences of Markets and other Economic Institutions, *Journal of Economic Literature* XXXVI: 75-111.

Cao, J. and Karplus, V.J.: 2014. Ownership and Energy Management in China's Industrial Firms, working paper, Tsinghua University.

Darnall, N. and Edwards, D. : 2006. Predicting the cost of environmental management system adoption: the role of capabilities, resources and ownership structure. *Strategic Management Journal*, 27: 301–320.

DeFraja, G. and Delbono, F.: 1989. Alternative Strategies of a Public Enterprise in Oligopoly, *Oxford Economic Papers* 41: 302-311.

Demski, J. and Sappington, D.: 1987. Hierarchical Regulatory Control, *Rand Journal of Economics*, 18: 369–383

Dewatripont, M., Jewitt, I. and Tirole, J.: 1999a. The Economics of Career Concerns, Part I: Comparing Information Structures, *Review of Economic Studies* 66: 183-198.

Dewatripont, M., Jewitt, I. and Tirole, J.: 1999b. The Economics of Career Concerns, Part II: Application to Missions and Accountability of Government Agencies, *Review of Economic Studies* 66: 199-217.

Du, N., Heywood, J. S., and Ye, G.: 2013. Strategic Delegation in an Experimental Mixed Duopoly, *Journal of Economic Behavior and Organization* 87: 91-100.

Earnhart, D. and Lizal, L.: 2006. Effects of ownership and financial performance on corporate environmental performance, *Journal of Comparative Economics* 34:111–129.

Endres, A.: 1997. Negotiating a Climate Convention - the Role of Prices and Quantities. *International Review of Law and Economics* 17: 147-156.

Endres, A. and Finus, M.: 2002. Quotas May Beat Taxes in a Global Emission Game. *International Tax and Public Finance*, 9: 687-707.

Fjell, K. and Heywood, J. S.: 2004. Mixed Oligopoly, Subsidization and the Order of Firm's Moves: The Relevance of Privatization, *Economics Letters* 83: 411-416.

García, J.H., Afsah, S. and Sterner, T.: 2009. Which Firms are More Sensitive to Public Disclosure Schemes for Pollution Control? Evidence from Indonesia's PROPER Program, *Environmental and Resource Economics*, 42: 151-168.

Gentry, B. S.: 1998. *Private Capital Flows and the Environment: Lessons from Latin America*, Edward Elgar.

Hambrick, D. C. and Finkelstein, S.: 1987. Managerial discretion: A bridge between polar views of organizational outcomes, *Research in Organizational Behavior* 9: 369–406.

Hambrick, D. C. and Abrahamson, E,: 1995. Assessing managerial discretion across industries: a multimethod approach. *Academy of Management Journal* 38: 1427-1441.

Hanh, R. W.: 2000. The Impact of Economics on Environmental Policy, *Journal of Environmental Economics and Management* 39: 375-399.

Hanley, N., Shogren, J. F. and White B.: 2007. *Environmental Economics in Theory and Practice,* second edition, Palgrave Macmillan.

Heywood, J. S., and Ye, G.: 2009. Mixed Oligopoly, Sequential Entry and Spatial Price Discrimination, *Economic Inquiry* 47: 589–597.

Jaffe, A.B. and Stavins, R.: 1995. Dynamic incentives of environmental regulations: the effects of alternative policy instruments on technology diffusion, *Journal of Environmental Economics and Management*, 29: S43-S63.

Jansen, T., Lier, A. V. and Witteloostuijn, A. V. :2007. A note on strategic delegation: The market share case," *International Journal of Industrial Organization* 25: 531-39.

Jung, C., Krutilla, K. and Boyd, R.: 1996. Incentives for advanced pollution abatement technology at the industry level: an evaluation of policy alternatives, *Journal of Environmental* Economics and Management, 30: 95-111.

Katsoulacos, Y. and Xepapadeas, A.: 1995. Environmental Policy under Oligopoly with Endogenous Market Structure, *Scandinavian Journal of Economics*, 97: 411-20.

Kikeri, S., Nellis, J. and Shirley, M.: 1992. *Privatization: the Lesson of Experience*, Washington: The World Bank.

Kofman, F. and Lawarrée, J.: 1993. Collusion in Hierarchical Agency, *Econometrica*, 61: 629-656.

Koppell, J. G.: 2007. Political Control for China's State-Owned Enterprises: Lessons from America's Experience with Hybrid Organizations, *Governance* 20: 255-278.

Mascarenhas B.:1989. Domains of state-owned, privately held, and publicly traded firms in international corporations, *Administrative Science Quarterly* 34*:* 582–597.

Matsumura, T.: 1998. Partial Privatization in Mixed Duopoly, *Journal of Public Economics*70: 473 – 483.

Matsumura, T.: 2003. Endogenous Role in Mixed Markets: a Two Production Period Model, *Southern Economic Journal* 70: 403–413.

Merrill, W.C., Schneider, N.: 1966. Government firms in oligopoly industries: a short-run analysis. *Quarterly Journal of Economics* 80: 400–412.

Montero, J. P.: 2002. Prices versus quantities with incomplete enforcement, *Journal of Public Economics* 85: 435-454.

Pal, D.: 1998. Endogenous Timing in a Mixed Oligopoly, *Economics Letters*, 61: 181–185.

Pargal, S. and Wheeler, D.: 1996. Informal Regulation of Industrial Pollution in Developing Countries: Evidence from Indonesia, *Journal of Political Economy*, 104: 1314-1327.

Requate, T.:1996. Environmental Policy under Imperfect Competition, in T. Tietenberg and H. Folmer eds, *International Yearbook of Environmental and Resource Economics 2006/07*, Edward Elgar.

Shleifer, A., Vishny, R.: 1994. Politicians and firms. *Quarterly Journal of Economics* 109: 995–1025.

Simpson, R.D.: 1995. Optimal Pollution Taxation in a Cournot Duopoly, *Environmental and Resource Economics*, 6: 59-369.

Stavins, R. N.: 2003. Experience with market-based environmental policy instruments, in Maler, K.G. and J.R. Vincent eds. *Handbook of Environmental Economics*, vol 1, Chapter 9, pp 355-435.

Talukdar, D. and Meisner, C.M.: 2001. Does the private sector help or hurt the environment? Evidence from carbon dioxide pollution in developing countries, *World Development* 29, 827-840

Tirole, J.: 1986. Hierarchies and Bureaucracies: On the Role of Collusion in Organizations, *Journal of Law, Economics and Organization*, 2: 181–214.

Wang, H. and Jin, Y.: 2007. Industrial Ownership and Environmental Performance: Evidence from China, *Environmental & Resource Economics* 36:255–273.

White, M.D.: 2001. Managerial Incentives and the Decision to Hire Managers in Markets with Public and Private Firms, *European Journal of Political Economy* 17: 877 – 896.

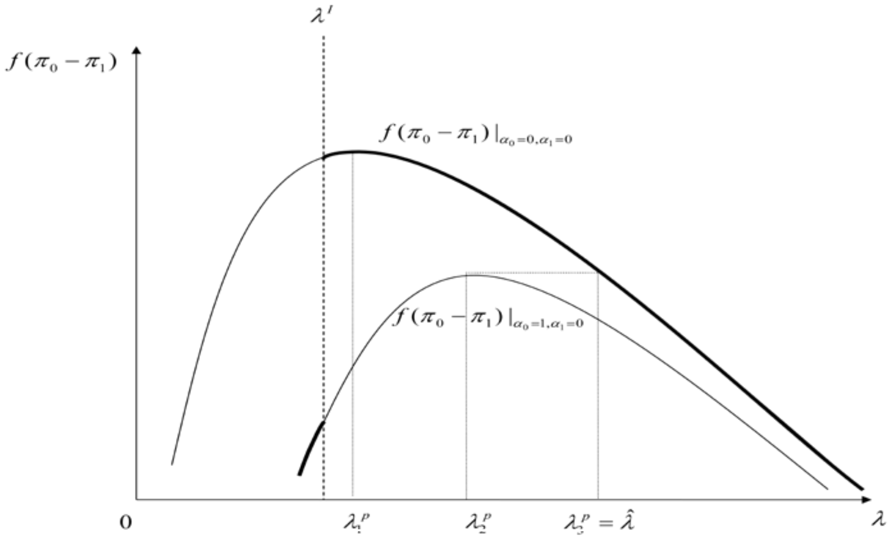
White, M.D.: 2002. Political Manipulation of A Public Firm's Objective Function, Journal of *Economic Behavior and Organization* 49: 487 – 499.

Wilson, J.Q.: 1989. *Bureaucracy: What Government Agencies Do and Why They Do It,* Basic Books.

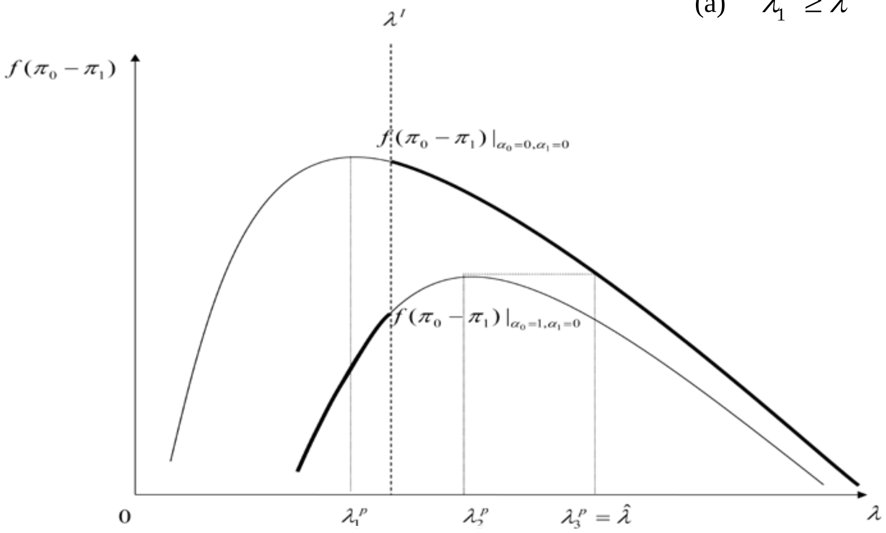
Zeckhauser, R.J., Horn, M.,: 1989. The control and performance of state-owned enterprises. In: MacAvoy, P.W., et al. (Eds.), Privatization and State-Owned Enterprises: Lessons from the United States, Great Britain and Canada. Kluwer Academic Publishers, Boston, pp. 7–57.

Zhao, J.: 2003. Irreversible Abatement Investment under Cost Uncertainties: Tradable Emission Permits and Emissions Charges, *Journal of Public Economics*, 87: 2765-2789.

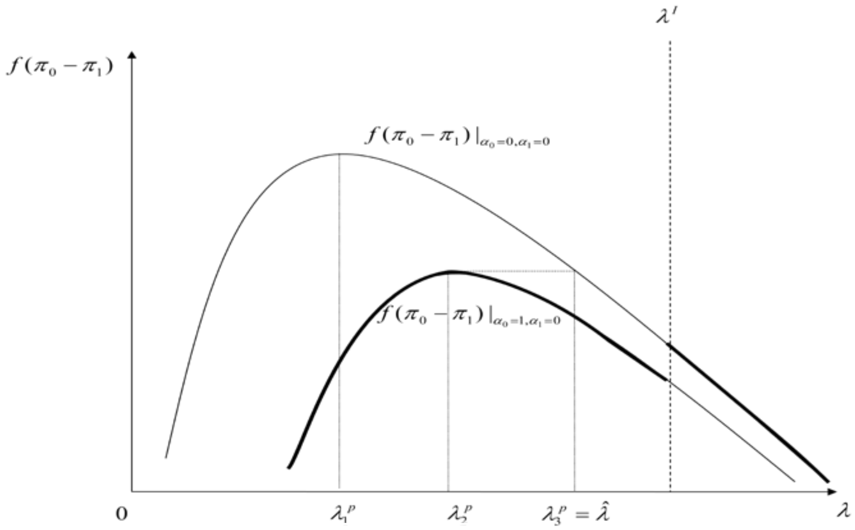
Figure 1. Optimal choice of profit weight λ^P when $\tau < c$



(a) $\lambda_1^P \geq \lambda^I$



(b) : $\lambda_1^P < \lambda^I \leq \lambda_3^P$



(c): $\lambda^I > \lambda_3^P$

Figure 2. Optimal weight λ^P as a function of tax τ

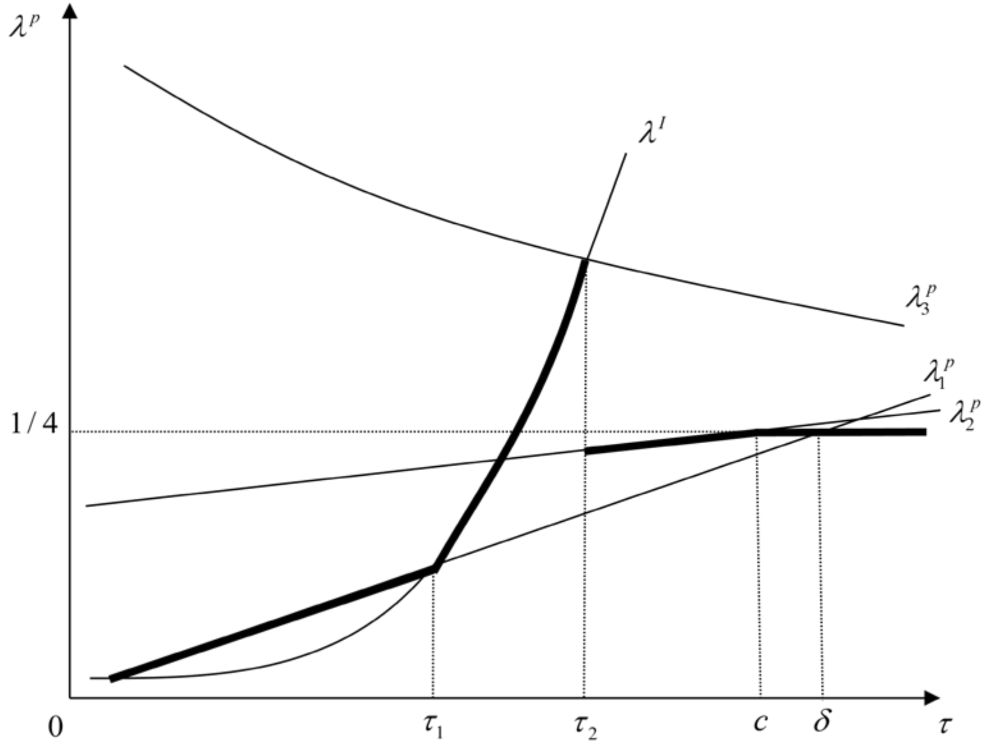
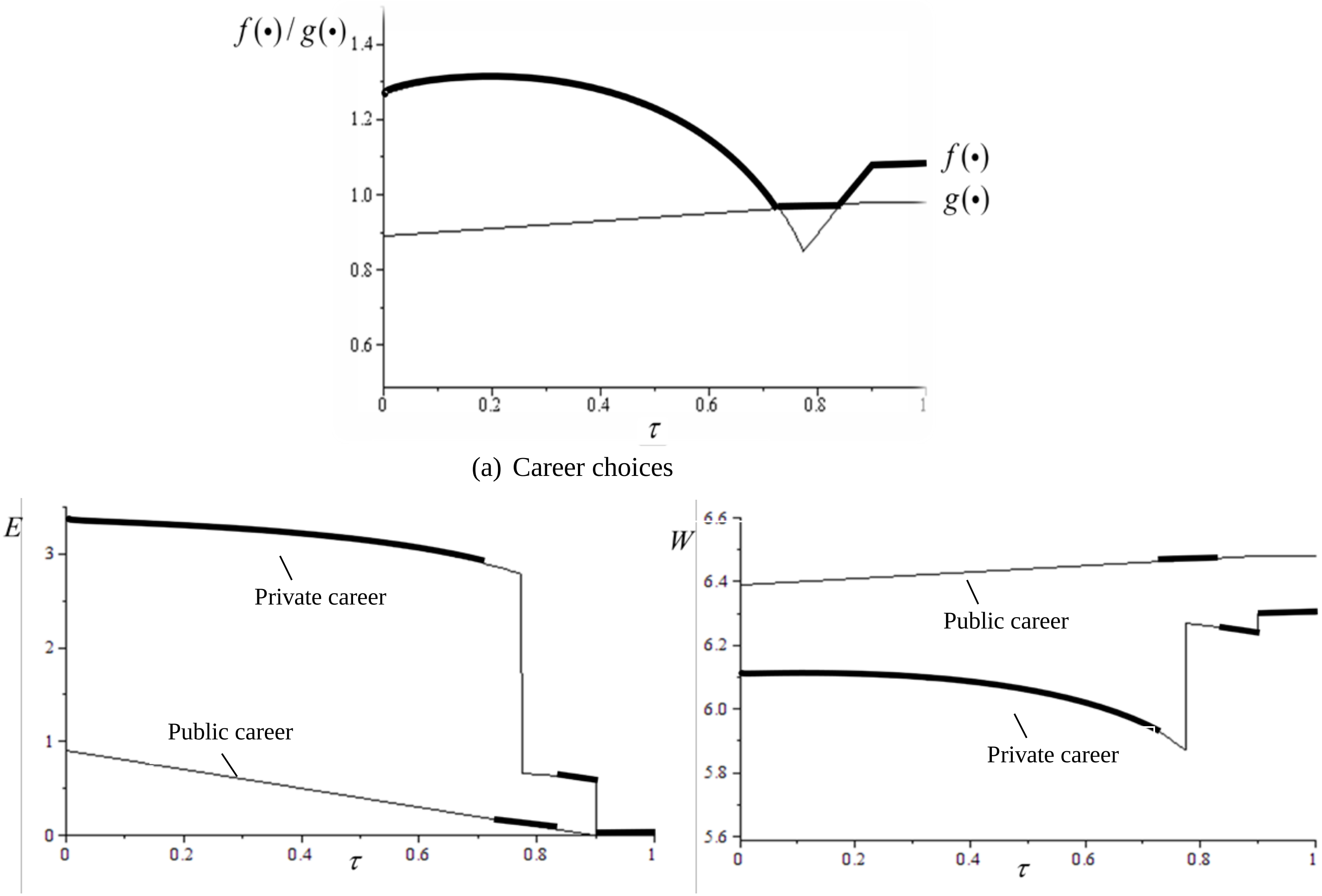


Figure 3. Effects of emission taxes



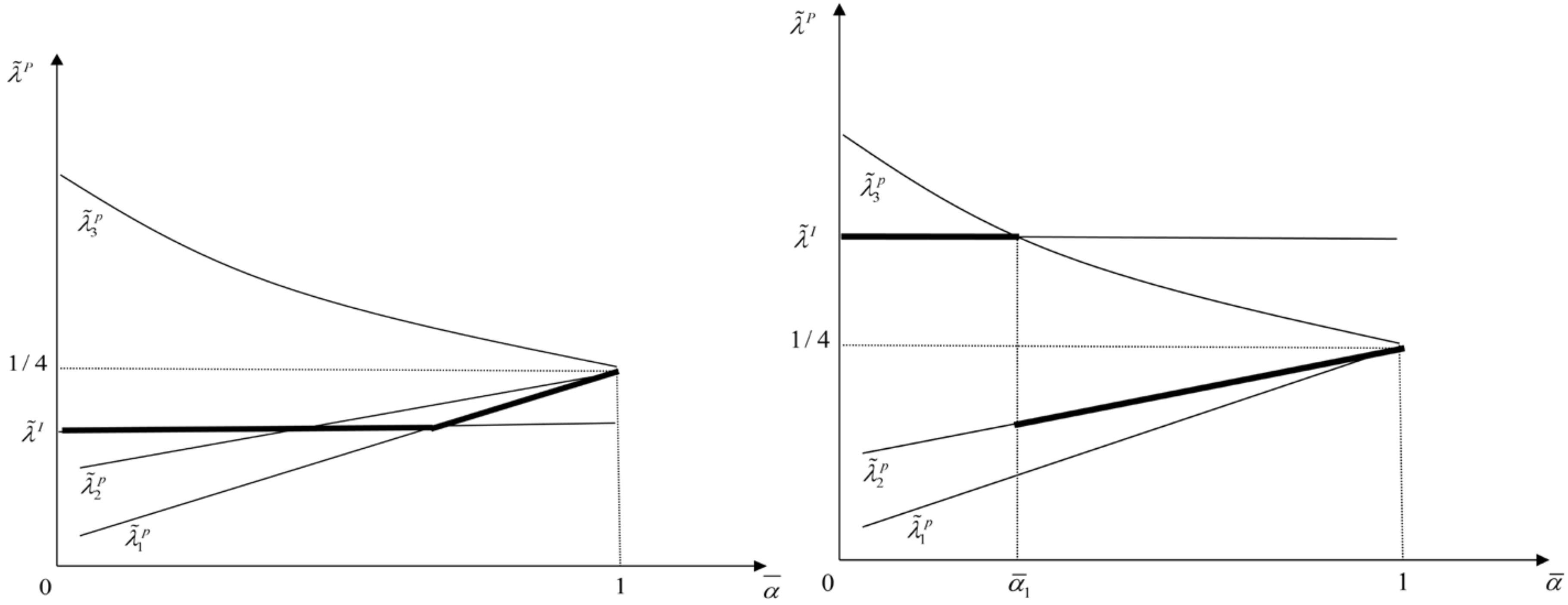
(a) Career choices

(b) Emissions

(c) Welfare

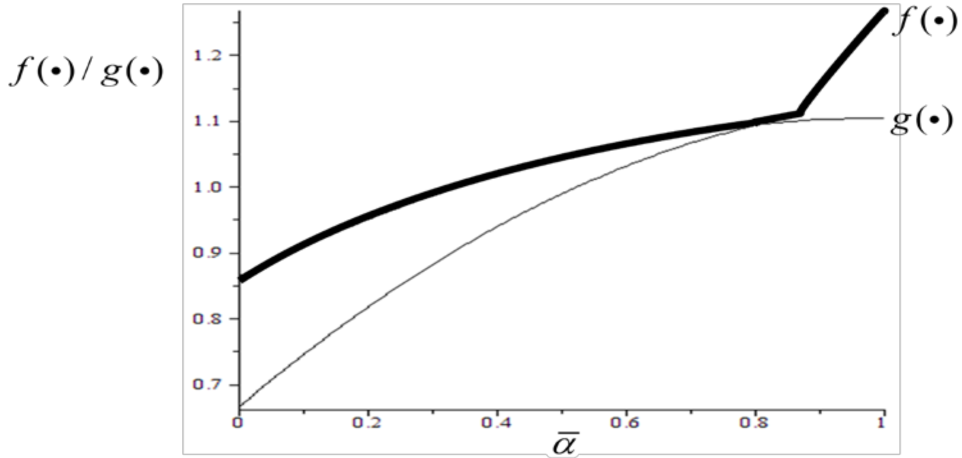
Note: parameter values used are $a = 5.5,\ k = 1,\ c = 0.9,\ \delta = 1$.

Figure 4. Effects of standard $\bar{\alpha}$ on profit weight $\tilde{\lambda}^P$

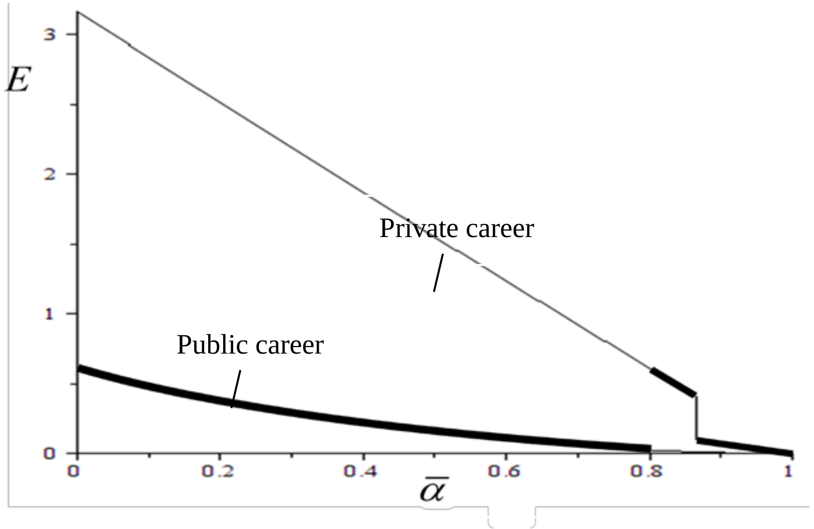


(a) $\delta < 4c/3$ (b) $\delta \geq 4c/3$

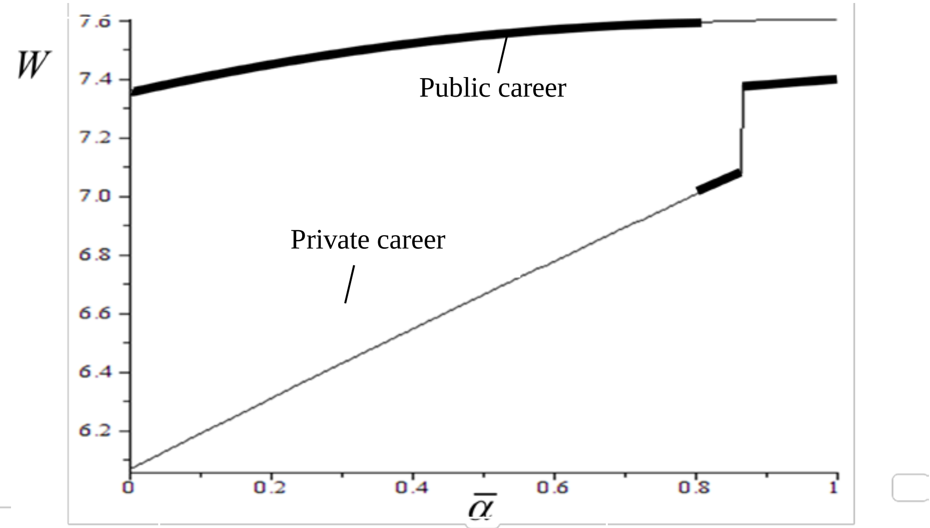
Figure 5. Effects of emission standards on career choices, pollution and welfare.



(a) Career choices



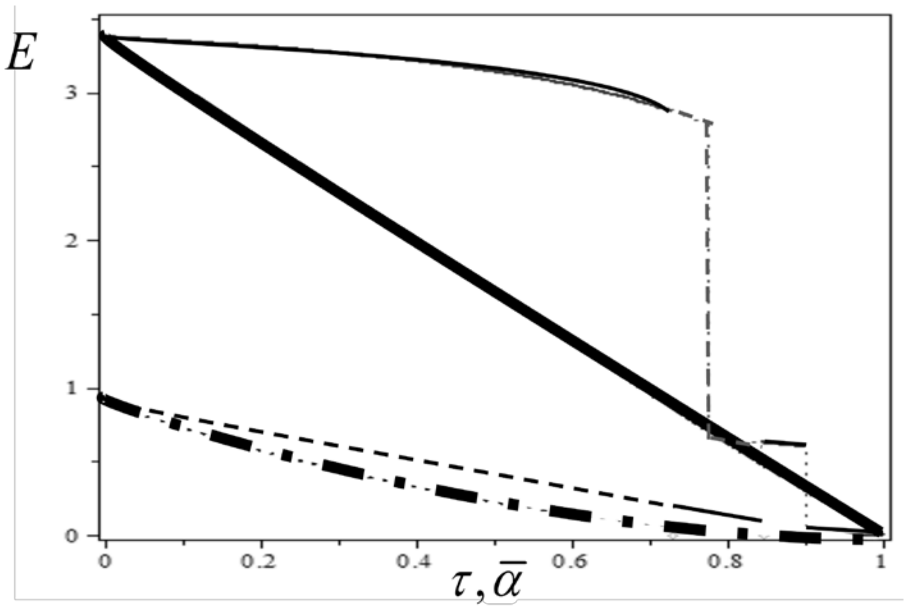
(b) Emissions

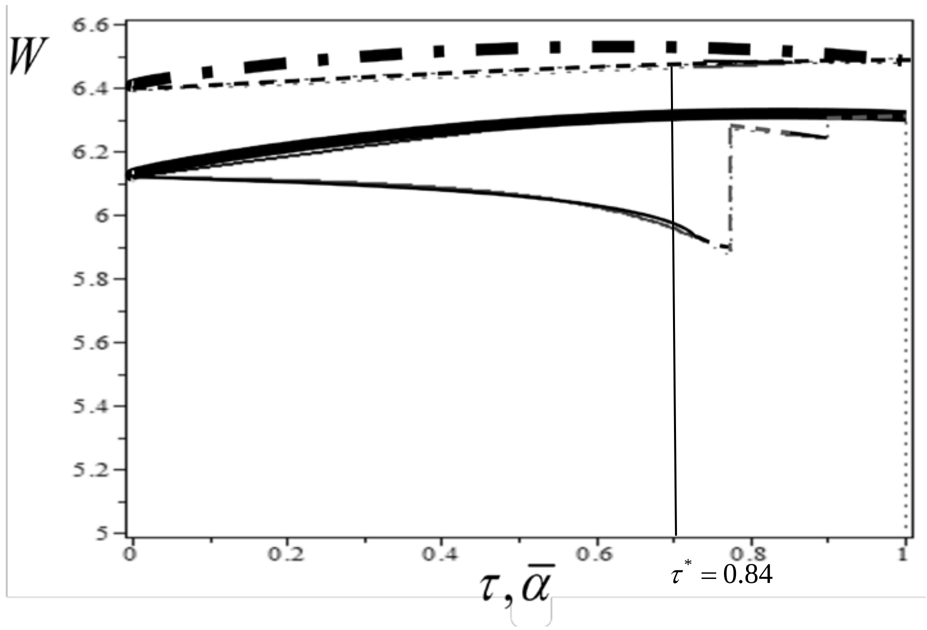


(c) Welfare

Note: parameter values used are $a = 5.5$, $k = 1$, $c = 0.6$, $\delta = 1$.

Figure 6. Comparison of taxes and standards: scenario I





(a) Impacts on total emissions

(b) Impacts on welfare

Graph Legend:

Unrealized values associated with Standard

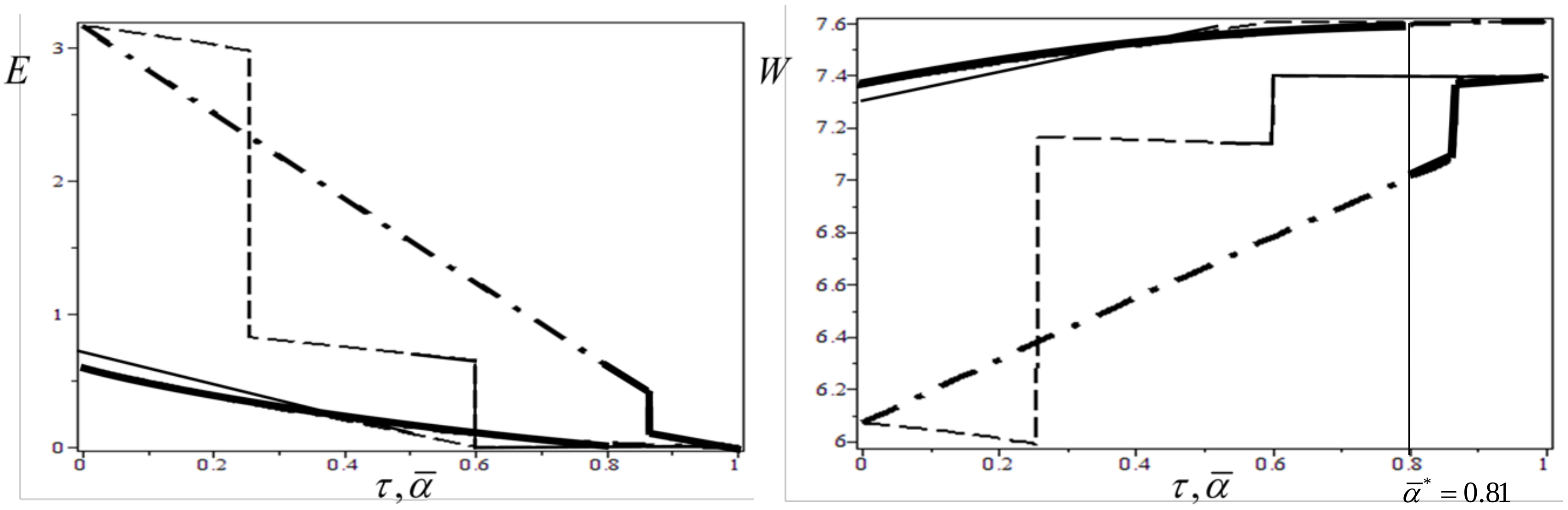
Unrealized values associated with Tax

Realized values associated with Standard

Realized values associated with Tax

Note: parameter values used are $a = 5.5,\ k = 1,\ c = 0.9,\ \delta = 1$.

Figure 7. Comparison of taxes and standards: scenario II



(a) Impacts on total emissions

(b) Impacts on welfare

Graph legend:

Unrealized values associated with Standard (thick dash-dot line)
Unrealized values associated with Tax (thin dashed line)
Realized values associated with Standard (thick solid line)
Realized values associated with Tax (thin solid line)

Note: parameter values used are $a = 5.5,\ k = 1,\ c = 0.6,\ \delta = 1$.