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Dynamic analysis of bribery firms' environmental tax evasion in an emissions trading market[☆]

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ABSTRACT

Using an R&D-based growth model with dual regulation, we analyse how environmental policies influence pollution, corruption, a growth rate, and welfare. Considering that polluting firms bribe bureaucrats to evade paying environmental tax, we find that a stricter environmental tax leads to a decrease in growth rate via a decrease in the permit rent as well as an increase in pollution and corruption per firm and results in worsening households' welfare and in improving the bureaucrats' welfare. Thus, tax evasion with corruption improves households' welfare and worsens the bureaucrats' welfare. Our findings imply that tax evasion under dual regulation improves social welfare.

1. Introduction

With worsening climate, more EU member states are participating in the European Union Emissions Trading System (EU-ETS). Thus, a dual regulation problem is created, whereby firms emitting greenhouse gases are subjected to overlapping regulations: environmental taxes and emissions permit trading. However, industries in the EU have resisted these regulations because such overlapping regulations for the same pollution impose additional costs on firms (Sorrel, 2002). The additional costs from dual regulation may incentivise firms to evade environmental taxes through corruption. The government suffers from corruption, which damages the efficiency of environmental policies. This is because the weakening of environmental regulations as a result of corruption may inhibit economic development and increase pollution (Pellegrini and Gerlagh, 2006). In developing countries, corrupt officials demand bribes from firms in return for overlooking the under-reporting of pollution emissions. Previous studies show that polluting firms evade environmental tax via corruption (i.e. Damania, 2002; Iskandar et al., 2014). Thus, tax evasion with corruption may slow economic development and worsen environmental quality if there is tax evasion in developed countries.

Environmental tax evasion is not expected in developed countries. However, European Union (EU) member states such as the United Kingdom (Customs, 2011) report that polluting firms do engage in environmental tax evasion. Thus, in contrast to developing

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countries, dual regulation in developed countries detrimentally affects the efficiency of emissions permit-trading via tax evasion with corruption. This damage via dual regulation on developed countries has not been addressed in previous literature (e.g. Damania, 2002; Lapatinas et al., 2011; Liu, 2013; Cerqueti and Coppier, 2016; Iskandar et al., 2014). The examination of this point is important because it provides clues to the improvement of the emissions permit-trading system under dual regulation. Moreover, this study provides clues to preventing tax evasion with corruption from inhibiting economic development via environmental policies. Our research goal is to analyse how additional costs under dual regulation influence emissions permit trading and economic development via environmental tax evasion with corruption.

Here, we aim at *the distribution effect*, which implies that an allocation rent increases the polluting firms' profit (Smale et al., 2006) and their value (Bovenberg and Goulder, 2006; Oestreich and Tsiakas, 2015). This distribution effect promotes the entry of new polluting firms, which aim to obtain more rents and, thus, may increase the number of firms participating in the EU-ETS. The total permit level allocated by the government fixes the total pollution level and, thus, an increase in the number of firms leads to a change in the average pollution in the long run. Moreover, this increase also leads to a change in the average corruption because each firm bribes officials to evade tax. Under dual regulation, environmental tax evasion influences the market permit price. Thus, environmental tax evasion may have some effects on the long-term relationship between pollution and corruption via the distribution effect.

To study this point of argument, we apply Nash bargaining between the firms and officials, as considered by Harstad and Svensson (2011), to the variety expansion model developed by Romer (1990) and Grossman and Helpman (1991). Then, we regard the government's regulation motivation as pollution reduction and consider *i*) emissions permit trading and *ii*) endogenous changes in the number of polluting firms via innovation. This model setting expands Harstad and Svensson (2011)'s model. In this setting, we investigate the effects that changes in the grandfathered permit level, environmental tax rate, and penalty rate have on permit price, growth rate, pollution and corruption per firm, and on the welfare of a household and a bureaucrat. Our analysis shows the following: A decrease in the grandfathered permit level stimulates the growth rate via an increase in permit price, reduces the pollution and corruption per firm, and results in improving the household's welfare and worsening the bureaucrat's welfare. By contrast, stricter environmental tax and penalty rates reduce the growth rate via a decrease in permit price, expand pollution and corruption per firm, and result in worsening households' welfare and improving the bureaucrat's welfare. These findings imply that tax evasion improves social welfare under dual regulation.

Our findings add several insights to the literature. The first finding is that the permit price is determined by environmental tax. In the present model, the government imposes overlapping regulations for the same pollution on polluting firms. Thus, under the framework of the general equilibrium model, environmental tax influences the permit price via the emissions permit market clearing condition. This result will provide beneficial suggestions to the discussion on the equivalence between environmental tax and emissions permit trading. Additionally, our study states that the effect of environmental tax on permit price changes according to tax evasion. In the present model, the government imposes a penalty rate on corrupt officials to prevent polluting firms from evading tax via corruption. This enables us to analyse how the permit price changes according to the degree of quality of the political system, which depends on political factors such as the penalty rate and the officials' bargaining power. Previous studies on dual regulation focus on environmental and cost efficiencies and ignore the effect of environmental tax evasion with corruption on permit price (e.g. Böhringer et al., 2008; Mandell, 2008; Eichner and Pethig, 2007). Thus, our finding suggests that the permit price is influenced under dual regulation via environmental tax, corruption, and so on.

The second finding is a growth-enhancing effect via the distribution effect. In this model, increasing the permit price via a decreased grandfathered permit level leads to an increase in the firms' profits because it expands the permit allocation rents. This leads to an increase in the economic growth rate because it stimulates the incentive of innovation via the no-arbitrage condition between assets and shares. This result is contrary to Ono, 2002, who shows that a decrease in equilibrium employment enhances the growth-reducing effect of permit level. Previous studies find the growth-enhancing effect of environmental policy to be via substitution of education for leisure (Hettich, 1998), substitution of innovation for leisure (Hamaguchi, 2019b), a general equilibrium effect via markup (Nakada, 2004), a substitution effect via social status preference (Hamaguchi, 2019c), an indeterminacy of equilibrium (Itaya, 2008), a generation turnover effect (Pautrel, 2008), and an externality effect of pollution on lifespan (Pautrel, 2009). Additionally, Hamaguchi (2019a) shows that the growth-enhancing effect via the distribution effect leads to tourism-led growth in an agglomeration model. We add the distribution effect to the literature. Additionally, although the literature of public economics has shown that tax evasion has a positive supply-side effect on output (e.g. Chang et al., 1999; Peacock and Shaw, 1982) and economic growth (e.g. Chen, 2003), the literature of environmental economics ignores the effect of tax evasion and corruption on the economic growth rate. We find that tax evasion with corruption stimulates the economic growth rate via an increased permit price whereas a stricter penalty leads to a decrease in the growth rate via a decreased permit price. These results imply that, under dual regulation, economic growth accelerates via environmental tax evasion. Thus, we combine the growth-enhancing effect via environmental policy with the political factor not considered in previous studies.

The third finding is corruption per firm in proportion to the pollution per firm. This positive relationship between pollution and corruption is confirmed by recent empirical studies (e.g. Welsch, 2004; Farzin and Bond, 2006; Pellegrini and Gerlagh, 2006; Fredriksson and Wollscheid, 2008). Thus, our study provides a rationale for this empirical relationship. Moreover, we find positive effects of environmental tax and penalty rates on the pollution and corruption per firm. The key to finding this relationship and its effects is endogenous changes in the number of polluting firms in the long run. In this model, a decrease in the economic growth rate via the distribution effect implies a decrease in the number of polluting firms. Under the total pollution level fixed by the total permit level, the decrease in the number of firms leads to an increase in the pollution and corruption per firm. By contrast, analysis of previous studies is static and assumes a constant number of polluting firms. For example, Damania (2002) shows that an environmental tax prompts polluting firms to under-report their pollution emissions, whereas a higher penalty prevents firms from evading the tax. Iskandar et al. (2014) also find that corruption prompts polluting firms to evade environmental tax depending on the tax rate and confirms that the results obtained by their model analysis apply to the economic experience in Indonesia. Therefore, it is difficult for previous studies to investigate how the long-term effect influences the relationship between pollution and corruption in the static framework of their analyses. Thus, our dynamic analysis adds to the literature on the long-term effect of endogenous changes in the number of firms on the relationship between pollution and corruption.

The fourth finding is that tax evasion itself improves social welfare under dual regulation. We observe that tax evasion improves the household's welfare and worsens the bureaucrat's, while a higher penalty rate worsens the household's welfare and improves the bureaucrat's. The welfare-improving effect of tax evasion is counter to *the tax evasion effect* found by Liu (2013). This effect implies that welfare improves via a cost reduction of tax evasion because firms substitute their existing low-cost tax evasion for high-cost environmental tax evasion. In the present model, the key to improving social welfare via tax evasion is dual regulation because the welfare effect depends on the effect of environmental tax on permit price. Thus, our finding suggests to previous studies that the welfare effect of tax evasion may change according to the regulation system.

The remainder of the paper is structured as follows: We describe a dynamic general equilibrium model in Section 2 and then define the equilibrium in Section 3. In Section 4, we investigate how environmental policies affect pollution, corruption, and the economic growth rate. We conduct a welfare analysis of the environmental policies in Section 5. Finally, Section 6 concludes the paper.

2. The model

We consider an economy with households, an agricultural good sector, a manufacturing goods sector, bureaucrats, and a research and development (R&D) sector. Households inelastically supply labour to acquire positive utility from consumption of manufactured goods and agricultural good and negative utility from the externalities of pollution.

2.1. Household

The number of households is normalised to one and the households exist in the economy indefinitely. A representative household has the following instantaneous utility function:

$$U(t) = \int_0^\infty e^{-\rho t} \log[M(t)^\mu A(t)^{1-\mu} D(t)^{-\chi}]dt, \tag{1}$$

where $\rho \in (0, 1)$, $\mu \in (0, 1)$, and $\chi \in (0, 1)$ represent the subjective discount rate, share of expenditure devoted to manufactured goods, and weight of the utility devoted to the total pollution, respectively. $A(t)$ is agricultural good and $D(t)$ is the aggregate pollution. Following Dixit and Stiglitz (1977), $M(t)$ denotes a composite good comprising a large number of varieties:

$$M(t) = \left[\int_0^{n(t)} m_i(t)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where $n(t)$ represents the total number of varieties and $\sigma > 1$ is the elasticity of substitution between any two varieties. The aggregate pollution becomes

$$D(t) = \left[\int_0^{n(t)} d_i(t) di \right], \tag{3}$$

where $d_i(t)$ states the pollution emitted by firm i.

The household's flow budget constraint is given by:

$$E(t) = \int_0^{n(t)} p_i(t) m_i(t) di + P_A(t) A(t) - T(t), \tag{4}$$

where $E(t)$ is household's expenditure, $T(t)$ is the lump sum transfer, and, $p_i(t)$ and $P_A(t)$ denote the price of a variety and the price of agricultural good, respectively.

Solving the static optimisation problem yields the following usual consumer's demands:

$$m_i(t) = p_i(t)^{-\sigma} P(t)^{\sigma-1} \mu E(t), \tag{5}$$

where $P(t)$ is the price index. This price index corresponds to the composite good and, thus, we obtain the following:

$$P(t) = \left(\int_0^{n_t} p_i(t)^{1-\sigma} di \right)^{\frac{1}{1-\sigma}}. \tag{6}$$

Taking prices and expenditure as given, the dynamic optimisation problem yields the following Euler equation: $\dot{E}(t)/E(t) = R(t) - \rho$, where $R(t)$ is the interest rate. Under constant nominal expenditure, $R = \rho$ holds at equilibrium. Thus, we omit the time notation from the remainder of the paper unless required. Using the expenditure per period determined by the Euler equation, we obtain the following: $PM = \mu E$ and $A = (1 - \mu)E$, where the agricultural good is the numeraire. The agricultural good is produced by employing only labour under constant returns to scale technology. Thus, $P_A = w = 1$ holds.

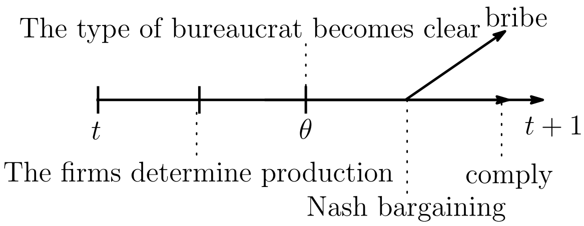

Fig. 1. Timing.

2.2. Timing

Fig. 1 presents the following timeline of the game between a manufacturing good firm and a bureaucrat: Each manufacturing good firm determines their production without knowledge of the qualities of the bureaucrats dispatched by the government. After the production determination, each firm observes the qualities of the bureaucrats. Then, the firm determines whether to bribe the bureaucrats to evade an environmental tax or to comply with the payment of the tax, according to the bureaucrats' qualities. Depending on this decision, each manufacturing good firm begins to negotiate with the bureaucrats about bribes. If the firm reaches a deal with them, it can evade the environmental tax by bribing the bureaucrats. Otherwise, the firm complies with the payment of the tax. In every period, new bureaucrats are dispatched by the government to each firm and, thus, this procedure is repeated in every period.

2.3. Manufacturing sector

Following Gradus and Smulders (1993), we assume that net pollution is generated by the following mechanism:

$$d(i) = \frac{q(i)}{a(i)} \tag{7}$$

where $q(i)$ and $a(i)$ represent firm i's production scale and abatement technology level, respectively. The net flow of pollution decreases by improving the abatement technology whereas the net flow increases by expanding the firm's production scale.

As an environmental policy, the government implements grandfathered permits and an environmental tax.[1] Manufacturing goods firm i receives a quota of the grandfathered permit $s(i)$ from the government. The quota amount distributed to manufacturing goods firm i is $s(i) \equiv S/N$, where S represents the total grandfathered permit level allocated by the government. Each firm freely trades the distributed quota in the competitive market for the permit. The unit price of the permit is denoted by $p^e(t)$. A manufacturing goods firm generating pollution over the quota, that is if $d(i) > s(i)$, must purchase a permit for $d(i) - s(i) > 0$ in the market at price $p^e(t)$. On the other hand, the manufacturing goods firm generating pollution under the quota $d(i) < s(i)$ can sell the permit $s(i) - d(i) > 0$ at price $p^e(t)$. The emissions trading market must be cleared.

A unit of pollution generated by the manufacturing goods firm is also uniformly subject to the environmental taxation. The firm participates in an emissions trading market and, thus, the imposition of the environmental tax implies dual regulation. This setting is based on the experiences of several EU member states because their governments have overlapped the domestic environmental tax with EU-ETS by introducing emissions-related taxes since the early1990's (OECD, 2001; Anderson et al., 2006). In fact, previous studies analyse the environmental and cost efficiencies of dual regulation (e.g. Böhringer et al., 2008; Mandell, 2008; Eichner and Pethig, 2007). Based on these previous studies and facts, we consider dual regulation, which means that the government implements two different environmental policies to regulate the pollution emitted by the manufacturing goods firm.

Additionally, we consider that the manufacturing goods firm evades the imposed environmental tax to reduce the additional cost of permit trading under dual regulation. For example, in EU member states such as the United Kingdom (Customs, 2011), there are firms that evade environmental taxes. Therefore, an overlapping regulation for the same pollution may prompt polluting firms to evade environmental taxes to escape the additional cost.[2] Thus, we introduce tax evasion through corruption in the present model.[3] The environmental tax rate is denoted by τ. To monitor the pollution emitted by each manufacturing goods firm, a bureaucrat is dispatched to the firm by the government. The firms do not know the type of bureaucrats until the end of their production activities and have two alternatives. First, a firm can comply with the environmental policy and pay the environmental tax. Second, the firm may bribe the bureaucrat to evade the tax. That is, firm i can pay a bribe $b(k)$ to bureaucrat k to evade the tax. As will be described

[1] To make it simple to analyse the present model, we assume the following interior solution: $p^e > 0$ and $\tau > 0$.

[2] We assume that the firms can evade environmental tax by under-report their actual emission to bureaucrats but the firms cannot do emission permits trading. It is interesting to analyse how effect the under-report their actual emission have on emission permits trading. However, considering the effect makes our analysis in the present model more difficult and complicated. Thus, we analyse only the case of evaded environmental tax to simplify the analysis of the present model.

[3] Instead of tax evasion, polluting firms may lobby the government to reduce the regulation level (e.g. with allocation of more grandfathered permits). This lobbying game is analysed by Harstad and Svensson (2011). However, analysing both tax evasion and lobbying highly complicates the present model. Thus, we consider only firms' tax evasion through corruption to simplify the analysis of the present model.

later, the size of $b(k)$ is negotiated between the manufacturing goods firm and the bureaucrat.

Following Dixit and Stiglitz (1977), the manufacturing firms produce horizontally differentiated varieties by competing monopolistically with each other. Thus, each firm produces a single, unique variety. Before the firms learn the bureaucrats' type, they maximise the following current expected profit by taking the inverse demand function for their manufactured goods and pollution as given:

$$\max_{p(i)} \mathbb{E}[\pi(i)] = p(i)q(i) - q(i) - \mathbb{E}\min[\tau d(i), b(k)] - p^e(d(i) - s(i)), \tag{8}$$

where $0 < \tau < \omega(k)$, and $0 < \omega(k) < 1$ denotes the penalty rate. The first-order conditions of profit maximisation are given by

$$\mathbb{E}[p(i)] = \frac{\sigma}{\sigma - 1}\left[1 - \left(\frac{p(i)}{\sigma q(i)}\right)\frac{\partial \mathbb{E}[\tau d(i), b(k)]}{\partial p(i)} + \frac{p^e}{a(i)}\right]. \tag{9}$$

Eq. (9) represents the expected markup over a marginal cost pricing rule. We obtain the following optimal expected operating profit:

$$\mathbb{E}[\pi(i)] = \frac{\sigma q(i)}{\sigma - 1}\left[\frac{1}{\sigma} - \left(\frac{p(i)}{\sigma q(i)}\right)\frac{\partial \mathbb{E}[\tau d(i), b(k)]}{\partial p(i)} + \frac{p^e}{\sigma a(i)}\right] - \mathbb{E}[\tau d(i), b(k)] + p^e s. \tag{10}$$

2.4. Bureaucrat

We apply the firm's tax evasion activity considered by Harstad and Svensson (2011) to the present model.[4] Suppose bureaucrat k is dispatched to manufacturing goods firm i by the government. We define bureaucrat k's utility as $b(k) - e(k)d(i)$, where $e(k)$ measures the degree of externality of non-compliance. Bureaucrat k acquires the positive utility of the bribe received from the firm i, but he/she acquires a negative utility from the pollution emitted by firm i, which does not comply with a payment of the environmental tax. Here, $e(k)$ is bureaucrat k's expected penalty based on the following mechanism: bureaucrat k fears not the negative externality of pollution but the non-compliance of the manufacturing goods firm that he/she monitors. This is because the government recognises bureaucrat k receives a bribe from the non-compliant firm in compensation for overlooking the firm's tax evasion and, therefore, removes bureaucrat k from the firm with removal probability $\theta(i)$. The $\theta(i)$s vary across by bureaucrats and are uniformly i.i.d. over $[0, 1]$. The government imposes a penalty on the corrupt bureaucrat k based on the pollution emitted by the non-compliant firm i. As a result, $e(k) = \theta(k)\omega(k)$, where $\omega(k)$ represents the penalty rate. The penalty payed by bureaucrat k is $\theta(k)\omega(k)d(i)$, which is proportional to the pollution emitted by the non-compliant firm i and to the degree of non-compliance. This penalty is a bureaucrat's cost for overlooking the manufacturing goods firm's tax evasion.

In the present model without private information, we assume that manufacturing goods firm i observes $\theta(k)$ before negotiating with bureaucrat k. Thus, we can define $\tau \in (0, \omega(k))$ as the following threshold for the bureaucrats' corruption: bureaucrats for whom $\theta(k) < \tau/\omega(k)$ are corrupt, whereas the ones for whom $\theta(k) \geq \tau/\omega(k)$ are not. The negotiation determines a bribe amount and the bargaining solution is efficient by assumption. Under the current environmental regulatory level, with the payment of a bribe $b(k) \in (\theta(k)\omega(k)d(i), d(i))$ from manufacturing good firm i to the bureaucrat k, both of them can be better off when $\theta(k) < \tau/\omega(k)$.

By negotiating with firm i, bureaucrat k maximises the bribe, as follows:

$$\max_{b(k)} (b(k) - \theta(i)\omega(k)d(i))^{\beta}(\tau d(i) - b(k))^{1-\beta},$$

where $\beta \in [0, 1]$ represents the bureaucrat's share of the bargaining surplus.[5] Thus, the first-order condition becomes

$$b(k) = \beta\tau d(i) + (1 - \beta)\theta(k)\omega(k)d(i). \tag{11}$$

Bribe $b(k)$ increases proportionally to $d(i)$ because manufacturing goods firm i must bribe bureaucrat k with a higher amount as its compliance cost increases depending on $d(i)$. Moreover, bureaucrat k demands a larger bribe from firm i based on $d(i)$ because he/she must incur a larger cost for overlooking the firm's tax evasion. For the same reason, he/she also demands a higher bribe from the firm i, depending on $\theta(k)$ and τ.

Then, the probability that $\theta(k)\omega(k) < \tau$ is $\tau/\omega(k)$, implying that manufacturing good firm i bribes bureaucrat k with probability $\tau/\omega(k)$, whereas it complies with probability $1 - \tau/\omega(k)$. In other words, the smaller the penalty, the more manufacturing good firms prefer to bribe instead of complying. Thus, manufacturing good firm i's current expected cost of bribing or complying becomes

$$\mathbb{E}[\tau d(i), b(k)] = \left(1 - \frac{\tau}{\omega(k)}\right)\tau d(i) + \frac{\tau}{\omega(k)}b(k) = \hat{\tau}(\tau, \omega(k), \beta, \theta(k))d(i),$$
$$\hat{\tau}(\tau, \omega(k), \beta, \theta(k)) \equiv \tau\left[1 - (1 - \beta)\left(\frac{\tau}{\omega(k)} - \theta(k)\right)\right], \tag{12}$$

where $\hat{\tau}(\tau, \omega(k), \beta, \theta(k))$ represent firm i's expected efficiency tax rate.

[4] See Harstad and Svensson (2011), for more details on the Nash bargaining process.

[5] Following Harstad and Svensson (2011), we assume that firms do not pay bribes to bureaucrats to simplify the analysis of the present model. See Harstad and Svensson (2011, p.48, footnote.8), for more details.

Differentiating (12) with respect to $p(i)$ yields the following:

$$\frac{\partial \mathbb{E}[\tau d(i), b(k)]}{\partial p(i)} = -\frac{\tau}{a(i)}\left[1-(1-\beta)\left(\frac{\tau}{\omega(k)}-\theta(k)\right)\right]\left(\frac{\sigma\mu E}{p(i)^{1+\sigma}P^{1+\sigma}}\right). \tag{13}$$

Because $\theta(k)$ is uniformly distributed on [0,1], we define the average removal probability as $\theta(k) = \theta = \tau/(2\omega)$. Thus, the current expected cost of bribing or complying becomes the same for all manufacturing good firms. By using the average removal probability, we rewrite (12) as follows:

$$\begin{aligned} &\mathbb{E}[\tau d, b] = \hat{\tau}(\tau, \omega, \beta)d, \ \hat{\tau}(\tau, \omega, \beta) \equiv \tau\left[1-\frac{(1-\beta)\tau}{2\omega}\right] > 0, \ for\ \bar{\tau} \equiv \frac{2\omega}{1-\beta} > \tau, \\ &\frac{\partial \hat{\tau}(\tau, \omega, \beta)}{\partial \omega} > 0, \ \frac{\partial \hat{\tau}(\tau, \omega, \beta)}{\partial \beta} > 0, \ \frac{\partial \hat{\tau}(\tau, \omega, \beta)}{\partial \tau} > 0, \end{aligned} \tag{14}$$

where all firms become symmetric at equilibrium, and thus, we omit subscript i from the remainder of paper. Note that $\tau = \hat{\tau}$ holds if $\beta = 1$ holds in (14). This indicates the case of environmental tax rate without tax evasion. We assume that $b = 0$ holds in the case.

Eq. (14) states each firm's expected cost of bribing or complying. We call $\hat{\tau}(\tau, \omega, \beta)$ the efficiency tax rate. Following Harstad and Svensson (2011), Eq. (14) implies that an increase in the environmental tax and penalty rates leads to a rise in the efficiency tax rate. In the present model, a polluting firm escapes the environmental tax burden of $(1-\beta)\tau^2/(2\omega)$ by bribing a bureaucrat. This implies a substantial decrease in the environmental tax rate through tax evasion but a substantial increase in the tax rate through the stricter penalty.

Using (13) and $\theta = \tau/(2\omega)$, we rewrite (9) as follows:

$$p = \frac{\sigma}{\sigma-1}(1+\phi), \ for\ \phi \equiv \frac{\hat{\tau}+p^e}{a}, \tag{15}$$

where we define ϕ as the environmental regulation cost. An increase in the markup via ϕ represents the markup effect. Using (13)–(15) and $\theta = \tau/(2\omega)$, we rewrite (10) as follows:

$$\pi = \left(\frac{1+\phi}{\sigma-1}\right)q + p^e s, \tag{16}$$

where the second term in (8) is the permit allocation rent. The effect of the rent on each economic variable is called *distribution effect*. Using (5) and (15) yields the following:

$$q = \frac{\mu L(\sigma-1)}{\sigma(1+\phi)}\left(\frac{E}{n}\right), \tag{17}$$

where q is the scale of production.

2.5. R&D sector

Following Romer (1990) and Grossman and Helpman (1991), we assume that a new variety of manufactured good develops via the following technology:

$$\dot{n} = \frac{\iota}{\eta}n, \tag{18}$$

where ι states an effective labour employed firms in the R&D sector and $\eta > 0$ is the productivity of innovation.[6] Firms in the R&D sector compete perfectly in the market and, thus, $v = \eta/n$ holds via condition of free entry to the sector. A firm's value in the stock market is equal to the following, based on the present stream of profits: $v(t) = \int_0^\infty e^{-R(\varepsilon-t)}d\varepsilon$. Differentiating this equation with respect to time yields the following no-arbitrage condition:

$$\pi + \dot{v} = Rv. \tag{19}$$

2.6. Market

In the labour market, the following holds:

$$\iota + L\left[(1-\mu) + \frac{\mu(\sigma-1)}{\sigma(1+\phi)}\right]E = L. \tag{20}$$

The emissions trading market is cleared when $p^e(nd - ns) = 0$, which implies that, in equilibrium, $d = s$. Combining (7) and $s = S/n$ with (17), we rewrite this emissions market clearing condition as:

[6] See Romer (1990) and Grossman and Helpman (1991), for more detail innovation process.

$$S = \left[\frac{\mu L(\sigma - 1)}{a\sigma(1 + \phi)}\right]E. \tag{21}$$

Eq. (21) implies that changes in the environmental tax and penalty rates influence the emissions market clearing condition via the effect of these policies on the markup.

Finally, the government transfers environmental tax revenue to households as a lump sum transfer. Thus, $T = \hat{\tau}nd = \hat{\tau}([\mu L(\sigma - 1)]/[a\sigma(1 + \phi)])E$ holds.

3. Equilibrium

In this section, we derive the level of expenditure per capita, the permit price, and the economic growth rate at equilibrium and conduct an analysis of stability in the dynamic system.

In equilibrium, a balanced growth path $g = \dot{n}/n$ exists because $R = \rho$ holds. Differentiating $v = \eta/n$ with respect to time yields $\dot{v}/v = -g$. Using (16) and (19) yields $-\ \dot{v}/v = [(1 + \phi)/(\sigma - 1)](q/v) + p^e(s/v) - R$. Substituting this equation for $R = \rho$, $v = \eta/n$, and $\dot{v}/v = -g$, we obtain $g = [(1 + \phi)/(\sigma - 1)](nq)/\eta + (p^e ns)/\eta - \rho$. Further, combining this equation with (17) and $s = S/n$ yields the following:

$$g = \frac{\mu L}{\sigma\eta}E + \frac{S}{\eta}p^e - \rho. \tag{22}$$

Using (18), (20), and (21) yields the following:

$$g = \frac{L}{\eta} - \frac{aS}{\eta} - \frac{L(1 - \mu)}{\eta}E. \tag{23}$$

Substituting (23) for (22), we obtain the following level of expenditure per capita:

$$E = \frac{\sigma[L + \eta\rho - S(a + p^e)]}{L[\mu + \sigma(1 - \mu)]}. \tag{24}$$

Eq. (24) implies that an increase in permit price decreases the level of expenditure per capita, ceteris paribus, because a rise in p^e via environmental policies leads to an in increase in the markup and results in reducing the household's expenditure on manufacturing goods; see (15). This shows the income effect via the permit price.

Substituting (24) for (22) yields the following:

$$g = \frac{L}{\sigma}\left[\frac{\mu}{\eta} - (\mu + \sigma(1 - \mu))\right]E + (L + \eta\rho) - aS, \tag{25}$$

Note that we can easily show the growth effect of S, using (23) and (25).

Using (21) and (24), we obtain the following:

$$\hat{\tau} + p^e + a = \frac{\mu(\sigma - 1)[L + \eta\rho - S(a + p^e)]}{\mu + \sigma(1 - \mu)}. \tag{26}$$

Rewriting (26) yields the following permit price in equilibrium:

$$p^e = \frac{\mu(\sigma - 1)(L + \eta\rho - aS) - (a + \hat{\tau})[\mu + \sigma(1 - \mu)]}{\sigma + \mu(\sigma - 1)(S - 1)}. \tag{27}$$

Eq. (27) implies that changes in the grandfathered permit level and in the environmental tax and penalty rates influence the permit price because S, τ, and ω have an effect on the household's expenditure per capita via markup; see (15) and (24).

Using (16), (17), and (21) yields the following dividend per share price at equilibrium:

$$\frac{\pi}{v} = \frac{\mu}{\eta[\mu + \sigma(1 - \mu)]}\left[L + \eta\rho - aS + \left(\frac{\sigma S(1 - \mu)}{\mu}\right)p^e\right]. \tag{28}$$

Equation (28) implies that environmental policies influence R&D activity via π/v because these policies have an effect on the no-arbitrage condition between assets and shares; see (19).

Taking (27) into account, we discuss the phase diagram of (22) and (23). Suppose that there exists a steady state at the initial point. If the steady state diverges from the initial point along (23), the economy immediately jumps to the original steady state. Therefore, the dynamic system in (22) and (23) is unstable and the steady state is determinate at equilibrium.

Substituting (21) for (22) yields the following economic growth rate:

$$g = \frac{\mu}{\eta[\mu + \sigma(1 - \mu)]}\left[L + \eta\rho - aS + \left(\frac{\sigma S(1 - \mu)}{\mu}\right)p^e\right] - \rho. \tag{29}$$

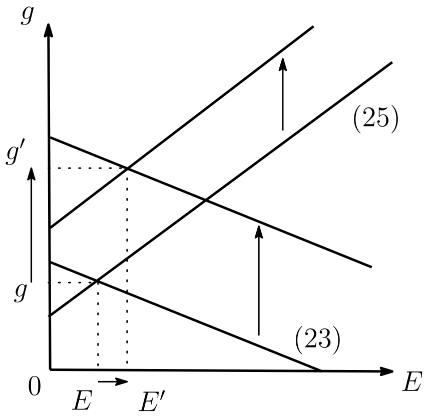

Fig. 2. Growth effect of decreased permits level.

Eq. (29) implies that the environmental tax and a penalty rates influence the economic growth rate through the effect of these policies on the permit price. This shows the growth effect via the permit price.[7]

4. Comparative statics

In this section, we analytically investigate how changes in the grandfathered permit level, the environmental tax rate, and the penalty rate influence the permit price, economic growth rate, pollution per firm, and corruption per firm.

4.1. Permit price and economic growth rate

Differentiating (14) and (27) with respect to the variable representing each policy, we obtain $\partial p^e/\partial S < 0, [\partial p^e/\partial \hat{\tau}][\partial \hat{\tau}/\partial \tau] < 0$, and $[\partial p^e/\partial \hat{\tau}][\partial \hat{\tau}/\partial \omega] < 0$. This leads to the following proposition:

Proposition 1 (*Effect of environmental policies on permit price:*). *A decrease in the total grandfathered permit level raises the permit price whereas an increase in the environmental tax and penalty rates lowers the permit price. Moreover, environmental tax evasion leads to a rise in the permit price.*

A decrease in the grandfathered permit level leads to an increase in the firm's permit demand via the emissions market clearing condition in (21) and results in increasing the permit price.

By contrast, environmental tax leads to a decrease in the permit price. Suppose that $\tau = \hat{\tau}$ holds in the case of environmental tax without tax evasion, the environmental tax rate imposes an additional cost on the firm participating in the emissions permit trading market. This additional cost increases the markup and, thus, the environmental policy leads to a reduction in the scale of production with pollution, ceteris paribus; see (15) and (17). Thus, firms become less pollution intensive, selling permits in the market. Consequently, an increase in the environmental tax decreases the permit price. This result implies that, under dual regulation, environmental tax determines the permit price in an emissions permit system.

In the case of environmental tax with tax evasion, $\tau > \hat{\tau}$ holds because a polluting firm escapes the environmental tax burden of $(1-\beta)\tau^2/(2\omega)$ by bribing a bureaucrat. Thus, the efficiency tax rate with tax evasion is lower than the environmental tax rate without tax evasion. The lower efficiency tax rate via tax evasion leads to an increase in the permit price via the following: Firms reduce the environmental tax burden via tax evasion, and thus, their mark-up rises, ceteris paribus; see (15). This leads to an expansion in the scale of production with pollution, ceteris paribus; see (17). Thus, firms become more pollution intensive and buy permits in the market. Consequently, the lower efficiency tax rate via tax evasion increases the permit price. Moreover, an increase in the penalty rate leads to a decrease in the permit price via an efficiency tax rate because the policy leads to a reduction in firms' environmental tax evasion. These results imply that, under dual regulation, environmental tax evasion may disturb the permit price in an emissions permit system.

Differentiating (29) with respect to τ and ω, we obtain $\partial g/\partial \tau < 0$ and $\partial g/\partial \omega < 0$ because $[\partial g/\partial p^e][\partial p^e/\partial \tau] < 0$ and $[\partial g/\partial p^e][\partial p^e/\partial \omega] < 0$. Additionally, using (23) and (25), we can easily illustrate the growth effect of S in Fig. 2. This leads us to the following proposition.

Proposition 2 (*Effect of environmental policies on growth rate:*). *A decrease in the total grandfathered permit level raises the economic growth rate whereas an increase in the environmental tax and penalty rates lowers the economic growth rate. Moreover, environmental tax*

[7] Our main results depend on a negative effect of $\hat{\tau}$ on p^e, and thus, the growth effect of environmental tax evasion may vanish if we assume $\mu = 1$. This implies that a non-polluting sector such as agricultural good sector may play an important role in growth and welfare effects of environmental policy. We analyse the present model expecting for $\mu = 1$ to obtain fruitful implications.

evasion leads to an increase in the economic growth rate.

We explain the growth effect of S via Fig. 2. A decrease in the grandfathered permit level leads to an increase in g in (25) via the following: An increase in the permit price via the decreased grandfathered permit level leads to an increase in the mark-up p and permit allocation rent sp^e, ceteris paribus; see (15) and (16). Thus, each firm's profit increases. The increase in profit leads to an increase in the dividend per share price; see (28). This stimulates R&D activity via the no-arbitrage condition in (19) and thus g in (25) increases. Additionally, the environmental policy leads to an increase g in (23) via the following: A decreased grandfathered permit level leads to a reduction in the scale of production with pollution via the emissions market clearing condition in (21), ceteris paribus; see (17). Thus, the reduced production scale decreases firms' labour demand in the manufacturing goods sector. This leads to labour transference from firms in the manufacturing goods sector to the R&D sector. Innovation expands via labour transference and thus g in (23) increases. As a result, a decrease in the grandfathered permit level leads to an increase in the economic growth rate via increases in (23) and (25)

By contrast, a decrease in the permit price via the environmental tax rate leads to a decrease in the markup and permit allocation rent, ceteris paribus, and results in a reduction in each firm's profit. The decrease in profit leads to a decrease in the dividend per share price. This inhibits R&D activity via the no-arbitrage condition and, thus, the economic growth rate decreases. Moreover, using proposition 2, we can state that the lower efficiency tax rate via tax evasion stimulates the economic growth rate via an increased permit price whereas a stricter penalty leads to a fall in the growth rate via a decreased permit price. These results imply that, under dual regulation, economic growth becomes faster via environmental tax evasion. On the other hand, Chen (2003) shows a positive supply-side effect of tax evasion on economic growth, using a standard AK model with public capital. Thus, we can state that the present model applies the supply-side effect of tax evasion to environmental policy under dual regulation. Our findings compliment the growth effect of tax evasion shown by Chen (2003).

4.2. Pollution and corruption

Using (7), (17), and (21) yields the following pollution per firm: $d = S/n$. Taking the log of both sides of $d = S/n$ yields the following logarithmic pollution per firm:

$$\log d = \log S - \log n_0 - g, \tag{30}$$

where we assume $t = 1$ in the remainder of this paper.[8] Eq. (30) implies that the logarithmic pollution per firm increases with the total pollution S and decreases with the number of polluting firms at the initial time n_0 and the economic growth rate g.

Using (7), (11), (17), (21), and the average removal probability $\theta = \tau/(2\omega)$, we obtain the following corruption per firm and aggregate corruption:

$$b = \left(\frac{1+\beta}{2}\right)\frac{\tau S}{n}, \tag{31}$$

$$B \equiv nb = \left(\frac{1+\beta}{2}\right)\tau S. \tag{32}$$

Eq. (31) and (32) imply that the bribe amount is proportional to the environmental tax rate τ and total pollution S because the firm must bribe the bureaucrat with a higher amount to evade the environmental tax, depending on τ and S. An increase in the number of polluting firms reduces the corruption per firm and the aggregate corruption.

Taking the log of both sides of (31) yields the following logarithmic bribe per firm:

$$\log b = \log\left(\frac{1+\beta}{2}\right) + \log\tau + \log S - \log n_0 - g. \tag{33}$$

Eq. (33) implies that the logarithmic corruption per firm increases with the total pollution S and environmental tax rate τ and decreases with the number of polluting firms at initial time n_0 and the economic growth rate g. This is because a firm must bribe the bureaucrat with a higher amount, depending on τ and S.

Differentiating (30) and (33) with respect to the variable representing each policy, we obtain the following proposition:

Proposition 3 (*Effect of environmental policies on pollution and corruption:*). *A decrease in the total grandfathered permit level reduces the pollution per firm and the corruption per firm. On the other hand, an increase in the environmental tax and penalty rates raises the pollution per firm and corruption per firm.*

Proof. Differentiating (30) and (33) with respect to the variable representing each policy, we obtain the following:

[8] Note that n expands infinitely as t approaches infinity. This implies that the pollution per firm asymptotically approaches 0. However, this is not a realistic case. Moreover, when Hamaguchi (2019c) conducts numerical analysis of the welfare effect of pollution permits, he implicitly assumes $t = 1$ to make the implications of the welfare effect more clean. Thus, we assume $t = 1$ to exclude unrealistic cases and simplify the comparative statics of pollution, corruption, and welfare.

$$\frac{\partial \log d}{\partial S} = \frac{1}{S} - \frac{\partial g}{\partial S} > 0, \quad \frac{\partial \log d}{\partial \tau} = -\frac{\partial g}{\partial \tau} > 0, \quad \frac{\partial \log d}{\partial \omega} = -\frac{\partial g}{\partial \omega} > 0,$$
$$\frac{\partial \log b}{\partial S} = \frac{1}{S} - \frac{\partial g}{\partial S} > 0, \quad \frac{\partial \log b}{\partial \tau} = \frac{1}{\tau} - \frac{\partial g}{\partial \tau} > 0, \quad \frac{\partial \log b}{\partial \omega} = -\frac{\partial g}{\partial \omega} > 0.$$

The above inequalities prove the results of Proposition 3. □

Pollution per firm and corruption per firm are positively proportional to total pollution and negatively proportional to the number of polluting firms whereas only corruption per firm is proportional to the environmental tax rate. Here, the direct effect of the grandfathered permit level on total pollution and the indirect effect on the number of polluting firms lead to a reduction in the pollution per firm, which also leads to a decrease in the corruption per firm.

By contrast, a decrease in the number of polluting firms via environmental tax leads to an increase in the pollution per firm. Moreover, a polluting firm must bribe the bureaucrat with a higher amount, depending on the environmental tax rate and, thus, the environmental policy results in increasing the corruption per firm. An increase in the penalty rate also leads to an increase in the pollution and corruption per firm via a decrease in the number of polluting firms.

5. Welfare

In this section, we investigate how changes in the grandfathered permit level, environmental tax rate, and penalty rate influence the household's and the bureaucrat's welfare.

Using (6) and (15) yields the following: $P = [\sigma(1+\phi)/(\sigma-1)]n^{1/(1-\sigma)}$. Using this equation, $nd = S$, (2), (5), and (14), we rewrite (1) as follows:

$$\begin{aligned} U &= \frac{1}{\rho}\log[X(L+\eta\rho - S(a+p^e))] + \frac{\mu}{\rho^2(\sigma-1)}g, \\ X &\equiv \mu^\mu(1-\mu)^{1-\mu}\left[\frac{\sigma}{L[\mu+\sigma(1-\mu)]}\right]\left(\frac{a}{\hat{\tau}+p^e+a}\right)^\mu \frac{n_0^\mu}{S^\chi}, \end{aligned} \tag{34}$$

where the first term is the welfare obtained by the household via the consumption of manufactured and agricultural goods and the second term is the welfare obtained via the economic growth rate.

Using (7), (11), (17), (21), and $\theta = \tau/(2\omega)$, we rewrite the bureaucrat's utility $[b - \theta\omega d]$ as follows:

$$U_b \equiv \left(\frac{1-\beta}{2}\right)\frac{\tau S}{n} \Longrightarrow \log U_b = \log\left(\frac{1+\beta}{2}\right) + \log\tau + \log S - \log n_0 - g, \tag{35}$$

Eq. (35) states that the bureaucrat' welfare is proportional to the amount of corruption.

Differentiating (34) and (35) with respect to the variable representing each policy, we obtain the following proposition:

Proposition 4 (*Effect of environmental policies on welfare:*). *A decrease in the total grandfathered permit level improves the household's welfare but the environmental policy deteriorates the bureaucrat' welfare. On the other hand, an increase in the environmental tax and penalty rates deteriorates the household's welfare whereas these policies improve the bureaucrat's welfare.*

Proof. See the online appendix.[9] □

The welfare effect of the grandfathered permit level in (34) depends on the direct effect of S and three indirect effects: a markup effect, an income effect, and a growth effect. A decrease in S leads to an improvement in welfare via a decrease in the total pollution and a positive growth effect. On the other hand, the income effect of decreasing S in (24) depends on a positive direct effect and the negative indirect effect via the increase in p^e. The indirect effect implies a negative income effect via the following markup effect: the increase in p^e via the decrease in S leads to an increase in the markup and, thus, the consumption of manufacturing goods decreases. The direct effect dominates the indirect effect and the markup effect when $\sigma - 1 \geq 1/[\mu(1-\mu)]$. Thus, a decrease in S results in improving welfare.

The welfare effect of the environmental tax rate and the penalty rate in (34) depends on three indirect effects: a markup effect, an income effect, and a growth effect. An increase in τ and ω leads to a deterioration in welfare via three negative indirect effects. The markup effect implies that the increase in p^e via an increase in τ and ω leads to a rise in the markup and, thus, the consumption of manufacturing goods is reduced via a decrease in household's expenditure; see (15) and (24). This effect leads to the negative income effect. Thus, an increase in τ and ω results in deteriorating welfare via the markup effect, the income effect, and the negative growth effect.

The welfare effect of the grandfathered permit level and the environmental tax rate in (35) depend on a direct effect and an indirect effect via a growth effect. A decrease in S inhibits a polluting firm's incentive to bribe the bureaucrat because the firm's regulation burden is reduced. Moreover, the corruption per firm decreases proportionally to the increase in the number of bribing firms. Thus, a decrease in S deteriorates the bureaucrat's welfare via a decrease in corruption. On the other hand, an increase in τ stimulates a polluting firm's incentive to bribe the bureaucrat because the firm's regulation burden increases. Moreover, the

[9] This appendix is to be found, in the online version, at 10.1016/j.jmacro.2019.103169.

corruption per firm rises proportionally to the decrease in the number of bribing firms. Thus, an increase in τ improves the bureaucrat's welfare via an increase in the corruption. An increase in ω also improves the bureaucrat's welfare via an increase in the corruption per firm.

Using proposition 1–4, we can state that a lower efficiency tax rate via tax evasion leads to an improvement in a household's welfare and a deterioration in a bureaucrat's welfare whereas a stricter penalty leads to deterioration of a household's welfare and improvement of a bureaucrat's welfare. These results imply that, under dual regulation, social welfare worsens via a transparent political system, namely, a higher penalty rate. Conversely, under dual regulation, social welfare improves via environmental tax evasion. Thus, the welfare effect of tax evasion may change according to the regulation system.

6. Conclusion

We analyse how environmental policies influence pollution, corruption, the economic growth rate, and welfare, using an R&D-based growth model with dual regulation. We apply the Nash bargaining between firms and bureaucrats employed by Harstad and Svensson (2011) to the present model. Then, we regard the government's regulation motivation to be pollution reduction and consider *i*) emissions permit trading and *ii*) endogenous changes in the number of polluting firms via innovation. We show the following: A decrease in the grandfathered permit level stimulates the growth rate via an increase in the permit price, reduces the pollution and corruption per firm, and results in improving a household's welfare and worsening a bureaucrat's welfare. By contrast, a stricter environmental tax rate and penalty rate reduce the growth rate via a decrease in the permit price, increase the pollution and corruption per firm, and result in worsening a household's welfare and in improving a bureaucrat's welfare. Thus, our findings suggest that, under dual regulation, environmental tax evasion leads to improved social welfare.

Our findings have several implications. First, under dual regulation, environmental tax determines the permit price in an emissions permit system. Sorrel (2002) indicates that some additional costs under dual regulation lead to unchanged aggregate pollution emissions and a decrease in permit price. Thus, our study provides a rationale for this indication. Second, environmental tax evasion may disturb the permit price under dual regulation. The different qualities of political systems across countries are likely to influence the permit price. This is because environmental tax is generally only imposed on domestic firms and exposing tax evasion depends on the quality of a country's political system. Our finding indicates that political factors may contribute to explaining the high permit price volatility. Third, an expropriation of the permit rent via environmental tax leads to worsening social welfare under dual regulation. This result implies that a transition from dual regulation to single regulation of the emissions trading system is desirable for a society from the social welfare perspective. Thus, we suggest that policy makers transition from dual to single regulation.

However, our study has several limitations. First, we do not consider the polluting firms' lobbying for grandfathered permits investigated by Fredriksson et al. (2005). This lobbying for more allocation rents leads to over-allocated permits in EU-ETS (Svendsen 1999; Markussen and Sevendsen, 2005). Thus, adding this lobbying to the present model is likely to allow new insights, such as an interaction effect between lobbying and tax evasion. Second, we analyse only the welfare effect and do not investigate the optimal pollution level and the first best regulation with cost efficiency. Thus, we cannot add to the literature on inefficiency via political factors under dual regulation (e.g. Böhringer et al., 2008; Mandell, 2008; Eichner and Pethig, 2007. Finally, we do not analyse how effect the under-report firms' actual emission have on emission permits trading. This analysis leads to enhance validity of the present model and create interesting implications. These remain as future research questions.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jmacro.2019.103169 .

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