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Are fuel taxes redundant when an emission tax is introduced for life-cycle emissions?*

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Abstract

This study examines the optimal combination of emission and fuel taxes for reducing greenhouse gas emissions in a monopoly market. Greenhouse gases are emitted during both production and consumption stages (life-cycle emissions). We show that when a producer selects fuel efficiency endogenously, an additional strictly positive fuel tax should be imposed even if an optimal emission tax is introduced. Remarkably, the unit cost of fuel should be larger than the marginal social cost of fuel. The results imply that a government may maintain fuel taxes even after introducing an effective emission tax.

Keywords: fuel tax, emission tax, optimal taxation, carbon pricing, vehicle industry, fuel efficiency

JEL Classification: Q58, Q48, H23, L51

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1 Introduction

Many countries levy both carbon and fuel taxes. For example, the Japanese carbon tax rate is significantly low (¥ 289 per ton), thus implying that this tax is insufficient to induce substantial emission reduction. Conversely, the current gasoline tax rate is high (¥ 53.8 per liter, which is equivalent to ¥ 24000 per ton carbon tax).[1] Therefore, abolishment of gasoline taxes is often insisted while introducing an effective carbon tax, to avoid double taxation.

This study discusses whether the government should abolish fuel taxes like gasoline tax, when an effective carbon tax is introduced. Considering life-cycle CO2 emissions generated at both the production and consumption stages, we show that the government should maintain strictly positive fuel tax rates in imperfectly competitive markets.

Although we believe that the insights have much broader generality, our model is a good representation of the vehicle market,[2] which is usually imperfectly competitive. In a car's lifecycle, CO2 is emitted not only while it is manufactured, but also when a consumer drives it. The emissions from the consumption process depend also on fuel efficiency of cars. We show that a fuel tax should be imposed additionally to the effective carbon tax if producers endogenously select fuel efficiency, whereas the fuel tax is redundant if it is exogenous.

Barnett (1980) shows that in a monopoly market, the first-best optimality is not achieved by an emission tax and the second-best tax is lower than Pigovian. Fowlie et al. (2016) empirically show the significance of welfare loss caused by Pigovian tax in an imperfectly competitive market. This implies that, modifying the Pigovian tax policy and mitigating or eliminating this problem might cause significant welfare gains. We focus on how to achieve

[1] Gasoline taxes exist worldwide. In the US, both federal and state governments impose these taxes, in EU, the Netherlands has the highest gasoline tax at €0.82 per litter, Italy applies the second highest rate at €0.73 per litter, and Hungary has the lowest gasoline tax, at €0.34 per litter (`https://taxfoundation.org/gas-taxes-in-europe-2022`, accessed June 18, 2023). On electric vehicles instead of gasoline vehicles, electricity taxes should be addressed. In Japan, the total electricity consumption tax and levy is ¥ 3.875 per kWh, and is significantly higher than the carbon tax rate.

[2] Regarding the vehicle industry, Fullerton and West (2002) investigate the policy mix including gasoline tax as ours. However, they focus on emissions at the consumption stage (i.e., they do not consider the life-cycle emissions) and confirm first-best optimality of the emission tax under perfect competition. Moreover, their primary interest is to investigate alternative policies driven by car characteristics, in the absence of the emission tax.

first-best optimality under monopoly in the presence of life-cycle emissions. We show that the combination of the strictly positive fuel tax and the emission tax that is lower than the Pigovian rate achieve the optimality. In other words, the strictly positive fuel tax is indispensable, even in the presence of emission tax.

Ino and Matsumura (2021a) also investigate first-best optimality under imperfect competition, portraying that an emission pricing policy based on emission intensity targets yields the first-best solution.[3] However, our analysis differs from this approach. Our study shows that a combination of existing taxes yields the first-best solution, instead of proposing a new scheme. It also shows that the optimal emission tax rate is lower than the Pigovian tax rate, whereas in Ino and Matsumura (2021a), the optimal tax rate is the Pigovian rate. Thus, our analysis is a natural extension of the literature on emission taxes in monopoly markets.

2 The Model

We construct a partial equilibrium model in which emissions are generated, both in production and consumption processes during the products' life-cycle. The vehicle market is a good example of this scenario.

Consumers are a continuum of mass 1 and price takers. Each consumer decides whether to purchase one product (vehicle), and if purchases it, the degree of usage x depends on the type of consumer and the distribution of x is given by $x \sim F(x)$ on $x \in [0, 1]$. Type x consumer's gross utility is given by vx.

Letting $f(x) = F'(x)$, we assume that the hazard rate $f(x)/(1-F(x))$ is strictly increasing, which is a standard assumption in the literature. One unit of use (mileage) requires $\alpha > 0$ units of fuel and one unit of fuel emits one unit of emission. Thus, α represents the fuel (in)efficiency of the product.

Consider a monopolistic producer for simplification. Emission (CO2) is also generated

[3] This is because the production expansion yielded by the intensity target can correct the market power of imperfectly competitive firms. More specifically, Ino and Matsumura (2021b) show that a green portfolio standard between two differentiated (green and gray) products can attain first-best optimality. Both of these works do not consider the life-cycle emissions.

when the producer manufactures its products. $E(q)$ is the emission function in the production process, with $E' > 0$ and $E'' \geq 0$, where q represents the quantity of production. A second-order continuously differentiable function $C(q, \alpha)$ represents the producer's cost function, where C is convex and satisfies $C_q > 0$ and $C_\alpha < 0$ and the subscripts of functions denote partial derivatives. $C_\alpha < 0$ because a lower α indicates a higher fuel efficiency.

The environmental damage is

$$D(E(q) + \alpha X),$$

where X is the total usage. Note that $E(q)$ and αX are the emissions generated in different processes. $E(q)$ is generated in the production process, and αX is in the consumption process while using the products. Thus, the total emission is $E(q) + \alpha X$. We assume $D' \geq 0$ and $D'' \geq 0$.

3 With a binding regulation on fuel efficiency

We begin with a benchmark case of exogenously provided fuel efficiency. A possible interpretation of this case is a setting where a producer is given a binding fuel efficiency mandate.

Type x consumer purchases a product if and only if

$$vx - \gamma\alpha x \geq p \tag{1}$$

where $p > 0$ is the price of one product. γ represents the unit cost of fuel given by

$$\gamma = c + t_e + t_f,$$

where $t_e \geq 0$ is the emission tax, $t_f \geq 0$ is the fuel tax, and $c \geq 0$ is the marginal cost of fuel production. Assuming a perfectly competitive fuel market, γ represents the fuel price.

Being (1) with equality, we obtain the marginal consumer who purchases, $\bar{x}(p; \alpha)$, as

$$\bar{x} = \frac{p}{v - \alpha\gamma}. \tag{2}$$

We focus on the interior case that satisfies $0 < \bar{x} < 1$. The demand and inverse demand for the product are

$$Q(p;\alpha) \equiv 1 - F(\bar{x}(p;\alpha)), \tag{3}$$

$$P(q;\alpha) \equiv Q^{-1}(p;\alpha). \tag{4}$$

The superscript -1 represents an inverse function that corresponds q to p. Since α is exogenous, in this subsection we express the demand by omitting α as $P(q) = P(q;\alpha)$ with $P' = P_q$ and $P'' = P_{qq}$.

The producer's profit maximization problem is

$$\max_q \; P(q)q - C(q) - t_e E(q).$$

The first-order condition is

$$P(q) + P'(q)q - C'(q) - t_e E'(q) = 0, \tag{5}$$

where

$$P'(q) = -\frac{v - \alpha\gamma}{f(\bar{x}(q))} < 0 \tag{6}$$

hold.[4] Note that $\bar{x}(q)$ is obtained by substituting $p = P(q)$ into $\bar{x}$ in (2).

The welfare-maximizing problem is

$$\max_{\bar{x}} \; W = \int_{\bar{x}}^{1} vxf(x)\, dx - C(q) - c\alpha X - D(E(q) + \alpha X),$$

where $q = 1 - F(\bar{x})$ and total emission from fuel consumption is

$$\alpha X = \alpha \int_{\bar{x}}^{1} xf(x)\, dx.$$

Since q and $\bar{x}$ have a one-to-one relationship through $q = 1 - F(\bar{x})$, we can state the welfare-maximizing problem with respect to $\bar{x}$ instead of q. The first-order condition for this problem is

$$v\bar{x} - c\alpha\bar{x} - C'(q) - [E'(q) + \alpha\bar{x}]D'(E(q) + \alpha X) = 0. \tag{7}$$

[4] See the appendix for the derivation of (6).

Let the superscript o denote the socially optimal outcomes. We denote the optimal total life-cycle emissions as $E_L^o = E(q^o) + \alpha X^o$.

By comparing the market conditions (2) and (5) with the optimal condition (7), we find that the socially optimal outcome is achieved if t_e and t_f satisfies

$$t_e = D'(E_L^o) - \frac{\alpha \bar{x}^o t_f - P'(q^o)q^o}{E'(q^o) + \alpha \bar{x}^o}.$$

This clarifies that the fuel tax is perfectly substitutable to the emission tax. In particular, even when $t_f = 0$, the optimality can be attained by the emission tax alone as

$$t_e = D'(E_L^o) + \frac{P'(q^o)q^o}{E'(q^o) + \alpha \bar{x}^o}.$$

4 Endogenous fuel efficiency

We endogenize fuel efficiency α.

4.1 Market equilibrium

The marginal consumer $\bar{x}(p; \alpha)$ is obtained by (2), and the demand $Q(p; \alpha)$ and inverse demand $P(q; \alpha)$ are given by (3) and (4).

The producer's profit maximization problem is

$$\max_{q,\alpha} \; P(q; \alpha)q - C(q, \alpha) - t_e E(q).$$

The first-order conditions are

$$P(q; \alpha) + P_q(q; \alpha)q - C_q(q, \alpha) - t_e E'(q) = 0, \tag{8}$$

$$P_\alpha(q; \alpha)q - C_\alpha(q, \alpha) = 0, \tag{9}$$

where

$$P_q(q; \alpha) = -\frac{v - \alpha\gamma}{f(\bar{x}(q; \alpha))} < 0, \tag{10}$$

$$P_\alpha(q; \alpha) = -\gamma \bar{x}(q; \alpha) < 0 \tag{11}$$

hold.[5] Note that $\bar{x}(q; \alpha)$ is obtained by substituting $p = P(q; \alpha)$ into $\bar{x}$ in (2).

[5] See the appendix for the derivation of (10) and (11).

4.2 The optimal tax combination

The welfare-maximizing problem is

$$\max_{\bar{x},\alpha} \ W \equiv \int_{\bar{x}}^{1} vxf(x)\ dx - C(q,\alpha) - c\alpha X - D(E(q) + \alpha X),$$

where $q = 1 - F(\bar{x})$ and the total emission from fuel consumption is

$$\alpha X \equiv \alpha \int_{\bar{x}}^{1} xf(x)\ dx.$$

The first-order conditions are

$$v\bar{x} - c\alpha\bar{x} - C_q(q,\alpha) - [E'(q) + \alpha\bar{x}]D'(E(q) + \alpha X) = 0, \tag{12}$$

$$-[c + D'(E(q) + \alpha X)]X - C_\alpha(q,\alpha) = 0. \tag{13}$$

Let the superscript o denote socially optimal outcomes. We denote optimal total life-cycle emissions as $E_L^o \equiv E(q^o) + \alpha^o X^o$.

At market equilibrium, by substituting (9) into the left-hand side of (13), we obtain

$$\frac{\partial W}{\partial \alpha} = -[c + D'(E(q) + \alpha X)]X - P_\alpha(q;\alpha)q.$$

Therefore, denoting the average use per product as $\mu_X \equiv X/q$, we obtain the following relation:

$$SMC \cdot \mu_X \gtreqless -P_\alpha(q;\alpha) \ \Leftrightarrow \ \frac{\partial W}{\partial \alpha} \lesseqgtr 0. \tag{14}$$

Here, $SMC = c + D'(E(q) + \alpha X)$ is the marginal social cost of fuel at market equilibrium. Thus, the left-hand side denoting $SMC \cdot \mu_X$ is the average saving in social costs with a decrease in α (i.e., improvement in fuel efficiency). The right-hand side depicting $-P_\alpha$ is the marginal market valuation of the decrease in α. Relation (14) indicates that when the former social benefit is greater (less) than the latter private benefit, a marginal decrease (increase) in α improves welfare, implying that the market under invests (over invests) in fuel efficiency.

This market failure in fuel efficiency is related to market failure in choosing product quality (Spence, 1975). To demonstrate this, let $\gamma = SMC$ ($t_e + t_f = D'$) (i.e., environmental damage is completely internalized into the fuel cost).[6] In this case, because $P_\alpha = -\gamma\bar{x}$ from (11), (14) is reduced to

$$\mu_X \gtreqless \bar{x} \;\Leftrightarrow\; \frac{\partial W}{\partial \alpha} \lesseqgtr 0. \tag{15}$$

Indeed, $\mu_X > \bar{x}$ always holds true in our model. Thus, the market forces cause underinvestment ($\partial W/\partial\alpha < 0$), despite completely internalizing environmental damages. When a monopoly sets the product quality (here, fuel efficiency), "the social benefits correspond to the increase in the revenues of the firm only if the marginal consumer is average or representative," but "there is nothing at all intrinsic to the market that guarantees that the marginal purchaser is representative," argues Spence (1975, p.418).

The optimal tax combination (t_e^o, t_f^o) is identified by comparing market conditions (2), (8), and (9) with optimal conditions (12) and (13).

Proposition 1 *The socially optimal outcomes are achieved if and only if*

$$\begin{aligned} t_e^o &= D'(E_L^o) + \frac{P_q(q^o;\alpha^o)q^o}{E'(q^o)} - \frac{\alpha^o}{E'(q^o)}(c + D'(E_L^o))(\mu_X^o - \bar{x}^o) < D'(E_L^o), \\ t_f^o &= -\frac{P_q(q^o;\alpha^o)q^o}{E'(q^o)} + \frac{\alpha^o\bar{x}^o + E'(q^o)}{E'(q^o)\bar{x}^o}(c + D'(E_L^o))(\mu_X^o - \bar{x}^o) > 0. \end{aligned}$$

Thus, $t_e^o + t_f^o > D'(E_L^o)$ *holds.*

Proof. For necessity, suppose $\bar{x} = \bar{x}^o$ ($q = q^o$) and $\alpha = \alpha^o$ at market equilibrium. Substituting (13) into (9) yields

$$-(c + t_e + t_f)\bar{x}q + [c + D']X = 0.$$

By subtracting (12) from (8), we obtain

$$-(t_e + t_f)\alpha\bar{x} + P_q q - t_e E' + [E' + \alpha\bar{x}]D' = 0,$$

where we use $P = v\bar{x} - \gamma\alpha\bar{x}$ from (2). Solving these two equations yields $t_e = t_e^o$ and $t_f = t_f^o$.

For sufficiency, suppose $t_e = t_e^o$ and $t_f = t_f^o$. Then, owing to the construction of t_e^o and t_f^o (8) and (9) must be satisfied when $q = q^o$ and $\alpha = \alpha^o$ under the optimal outcome conditions (12) and (13).

[6] Another perspective is to consider the case where $D' = 0$ and $t_e + t_f = 0$, with zero environmental damage and the associated taxes. As $P_\alpha = -c\bar{x}$, (14) is also reduced to (15).

The inequalities are obtained because $\mu_X > \bar{x}$ always holds true. This is because

$$\mu_X = \frac{X}{q} = \frac{\int_{\bar{x}}^{1} x f(x) dx}{1 - F(\bar{x})} > \frac{\int_{\bar{x}}^{1} \bar{x} f(x) dx}{1 - F(\bar{x})} = \frac{\bar{x} \int_{\bar{x}}^{1} f(x) dx}{\int_{\bar{x}}^{1} f(x) dx} = \bar{x},$$

where the inequality is obtained because $x > \bar{x}$ in the integration interval. **Q.E.D.**

The optimal fuel tax t_f^o is composed of two terms: the first term relates to distortion due to market power and the second term relates to the market failures associated with product quality (Spence, 1975). Regarding the optimal emission tax t_e^o, the deviation from the Pigovian level D' is similarly composed of two terms. The terms correcting for market power are positive in t_f^o and negative in t_e^o. Because $\mu_X^o > \bar{x}^o$ holds, the terms correcting for product quality are also positive in t_f^o and negative in t_e^o. Thus, the optimal fuel tax level t_f^o is positive and that of the emission tax t_e^o is lower than the Pigovian level D'.

We explain why the optimal policy has this structure. Even if environmental damage is completely internalized ($\gamma = SMC$), the producer's choice of fuel efficiency is suboptimal. Thus, to encourage fuel efficiency improvement, the unit cost of fuel, $\gamma^o = c + t_e^o + t_f^o$, should be larger than the marginal social cost of fuel, $SMC^o = c + D'(E_L^o)$, as $t_e^o + t_f^o > D'(E_L^o)$. A higher fuel price increases consumers' valuation of a fuel-efficient car. Therefore, an increase in γ increases the producer's incentive to improve the fuel efficiency of the product. However, if such an increase in fuel price is implemented with an increase in the emission tax, it raises the firm's production cost and accelerates welfare loss due to suboptimal production. Therefore, the government should set a positive fuel tax and choose an emission tax rate lower than the Pigovian level.

5 Concluding remarks

This study investigates the optimal combination of emission and fuel taxes in a monopoly, considering life-cycle emissions. We present a story portraying a strictly positive optimal fuel tax in the case where a producer endogenously selects fuel efficiency of its products. In other words, heavier taxes should be imposed during fuel consumption than during production.

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Appendix

Derivation of (6), (10), and (11)

Derivation of P_q is perfectly similar for (6) and (10). Because $\bar{x} = p/(v - \alpha\gamma)$ from (2), differentiating $Q(p;\alpha) = 1 - F(\bar{x})$ yields

$$\frac{\partial Q}{\partial p} = -\frac{F'}{v - \alpha\gamma}, \quad \frac{\partial Q}{\partial \alpha} = -\frac{\gamma p F'}{(v - \alpha\gamma)^2}.$$

Because $P = Q^{-1}$, we obtain

$$\frac{\partial P}{\partial q} = \frac{1}{\partial Q/\partial p} = -\frac{v - \alpha\gamma}{F'}.$$

P_α in (11) is derived as follows. Because $p = P(Q(p;\alpha);\alpha)$ by definition, differentiating this with respect to α yields

$$0 = \frac{\partial P}{\partial q}\frac{\partial Q}{\partial \alpha} + \frac{\partial P}{\partial \alpha} \quad \therefore \frac{\partial P}{\partial \alpha} = -\frac{\partial Q/\partial \alpha}{\partial Q/\partial p}.$$

Then, by substituting the derived expressions, we obtain

$$\frac{\partial P}{\partial \alpha} = -\frac{\gamma p}{v - \alpha\gamma} = -\gamma\bar{x}.$$