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The optimal fuel and emission tax combination for life-cycle emissions under imperfect competition[*]

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Abstract

This study examines the optimal combination of emission and fuel taxes for reducing greenhouse gas emissions. Greenhouse gases are emitted during both production and consumption stages. We present two cases in which a government should impose an additional fuel tax even when an optimal emission tax is introduced: the case in which consumers select the fuel consumption and case in which a producer selects fuel efficiency endogenously. In other words, we show that a government should maintain fuel taxes even after introducing an effective emission tax.

Keywords: fuel tax, emission tax, carbon pricing, heterogeneous consumers, vehicle industry

JEL Classification: Q58, Q48, H23, L51

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Highlights

- The optimal combination of fuel and emission taxes is investigated.
- Life-cycle emissions and heterogeneity among consumers are introduced.
- Under perfect competition, the optimal fuel tax rate is zero.
- Under imperfect competition, the optimal fuel tax rate is positive.
- The government should impose both emission and fuel taxes.

1 Introduction

Global economy faces the risk of climate change and vulnerability in the supply of fossil fuels, and moving away from fossil fuels and decarbonization has become increasingly critical for sustainable economy (Victor, 2022). The European Union (EU) continues to lead the mission for a low emission society.[1] Although the US, China, and Japan had been logging into it, they have recently declared that they will pursue the goal of a zero-emission society by 2050 (the US and Japan) and 2060 (China).[2] US President Joe Biden signed a new executive order on the commitment to reach net zero emissions nationally by 2050.[3] In February 2022, the Japanese Ministry of Economy, Trade and Industry (METI) announced the GX (green transformation) League Basic Concept and invited companies to endorse it.[4] Carbon pricing is one of the most natural policy measures to reduce CO2 emissions and promote decarbonization, and the Japanese government plans to introduce effective carbon pricing.

On one hand, the current carbon tax rate in Japan is extremely low (¥ 289 per ton). It is apparent that this tax is insufficient to induce substantial emission reductions. Therefore, the Japanese government is discussing a new carbon pricing system. On the other hand, the current gasoline tax rate is high (¥ 53.8 per litter, which is equivalent to ¥ 24000 per ton carbon tax).[5] Therefore, it is often insisted that gasoline taxes should be abolished upon introducing an effective carbon tax to avoid double taxation.

This study discusses whether the government should abolish fuel taxes such as a gasoline

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[1] Despite facing an energy crisis, the EU has declared its commitment. It presented a new report in May 2022 entitled REPowerEU (`https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131`).

[2] Reuters, `https://jp.reuters.com/article/japan-politics-suga/japan-aims-for-zero-emissions-carbon-neutral-society-by-2050-pm-idUSKBN27B0FB`

[3] Energy live news, `https://www.energylivenews.com/2021/01/28/biden-wants-carbon-free-electricity-by-2035/`

[4] METI, `https://www.meti.go.jp/english/press/2022/0201_001.html`

[5] Gasoline taxes exist worldwide. In the US, both federal and state governments impose gasoline taxes. In the EU, the Netherlands has the highest gasoline tax at €0.82 per liter; Italy applies the second highest rate at €0.73 per liter. Hungary has the lowest gasoline tax, at €0.34 per liter (`https://taxfoundation.org/gas-taxes-in-europe-2022/`). In China, a refined oil excise tax is applied to gasoline. (`https://www.oecd.org/tax/tax-policy/taxing-energy-use-china.pdf`). If we consider an EV instead of a gasoline vehicle, then electricity taxes should be considered. In Japan, the sum of the electricity consumption tax and levy is ¥ 3.875 per kWh, and is significantly higher than the carbon tax rate.

tax when an effective carbon tax is introduced. The government should indeed impose additional fuel taxes even in the presence of an effective emission tax, to cover the cost of road construction (tax revenue purpose) or if the consumption of gasoline yields other negative externalities (such as the emissions of SOx and NOx). In this study, by considering life-cycle CO2 emissions generated at both the production and consumption stages (life-cycle emissions), we show that even if there is no tax revenue purpose or other negative externality than CO2 emissions, the government should maintain strictly positive fuel tax rates in imperfectly competitive markets.

Since Pigou's (1932) seminal work, it is well known that in perfectly competitive markets, the optimal emission tax rate for harmful emissions is equal to the marginal environmental damage caused by emissions, and that this tax policy leads to first-best optimality. The tax that internalizes the negative externality of emissions is known as "Pigovian tax." This implies that the government need not impose fuel taxes, and only a carbon tax is required to reduce CO2 optimally.

However, in imperfectly competitive markets, the Pigovian tax is not optimal (Buchanan, 1969; Barnett, 1980; Misiolek, 1980; Baumol and Oates, 1988). In a monopoly market, the monopolist's production level falls below the optimal level. To mitigate welfare losses owing to suboptimal production levels, the emission tax rate in the monopoly market should be lower than the Pigovian rate. However, this low tax rate distorts the incentive for monopolists' emission abatement activities, and thus, reduces welfare. Therefore, the first-best optimality is not achieved by an emission tax (second-best optimality).[6]

In this study, we discuss the optimal combination of fuel and emission taxes. In contrast to the discussions on the emission tax in monopoly markets mentioned above, we focus on how to achieve first-best optimality in the presence of life-cycle emissions. As Fowlie et al. (2016) and Preonas (2017) empirically show, welfare loss caused by Pigovian tax in an imperfectly competitive market is significant. This implies that modifying the Pigovian

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[6] For discussions on oligopolies, see Levin (1985), Simpson (1995), Katsoulacos and Xepapadeas (1995), Lee (1999), and Xu et al. (2022). They also show that the emission tax policy does not achieve the first-best optimality.

tax policy and mitigating or eliminating this problem using alternative first-best policies may bring about significant welfare gains. We show that the strictly positive fuel tax plus emission tax, the latter being lower than the Pigovian rate, achieve the first-best optimality.

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

In regard to the vehicle industry, Fullerton and West (2002, 2010) adopt a consumption structure that is similar to ours, and investigate the policy mix including gasoline tax. They consider heterogeneous consumers who can choose miles and other car characteristics. We consider cases where heterogeneous consumers endogenously choose consumption (miles) and where the producer chooses fuel efficiency endogenously. Fullerton and West (2002, 2010) focus on emissions at the consumption stage and confirm first-best optimality of the emission tax under perfect competition. Moreover, their main interest is in investigating alternative policies driven by car characteristics, provided the emission tax is absent. By contrast, we show first-best optimality of the combination of the tax on life-cycle emissions and fuel tax under imperfect competition.

The remainder of this paper is organized as follows. Section 2 formulates the basic model with heterogeneous consumers and a monopolistic producer. Section 3 extends the basic model by endogenizing the fuel efficiency of the product. Both sections show that the optimal fuel tax rate is strictly positive. Finally, Section 4 concludes the paper.

2 Model 1: Endogenous consumption levels

We construct a partial equilibrium model in which emissions (greenhouse gas) are generated in production and consumption during the life-cycle of products. The vehicle market is a good example of this scenario.

Consider a monopolistic producer for simplification. $C(q)$ is its cost function with $C' > 0$ and $C'' \geq 0$, where q represents the quantity of production. $E(q)$ is the emission function in the production process, with $E' > 0$ and $E'' \geq 0$.

Consumers are continuum of mass 1. Each consumer decides whether to purchase one product (vehicle) and chooses the degree of use of a product (mileage) when they purchases it. $x(\theta) \geq 0$ is the degree of use that Type θ chooses, where $\theta \in [0, 1]$ denotes the valuation parameter (type) of consumers. θ is distributed as $\theta \sim F(\theta)$ and the density function corresponding to F is denoted as $f(\theta)$. We assume that the hazard rate $f(\theta)/(1 - F(\theta))$ is strictly increasing, which is a standard assumption in the literature. $u(x, \theta)$ represents the valuation (willingness to pay) of type θ for one product, which is strictly concave in (x, θ) and satisfies $u_x > 0$ and $u_\theta > 0$.[7]

One unit of consumption (use) requires α units of fuel (gasoline), and one unit of fuel emits one unit of emission.[8] Thus, $\alpha > 0$ represents the fuel (in)efficiency. In this section, we suppose that α is exogenously given and $\alpha = 1$. In the next section, we provide a model in which the producer can choose α endogenously.

The environmental damage is

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

where X is the total consumption (use). We assume $D' \geq 0$ and $D'' \geq 0$.

2.1 Market equilibrium

Suppose a consumer purchases a product. Then, type θ consumer solves

$$\max_x \; u(x, \theta) - \gamma x,$$

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[7] In this study, the subscripts of functions denote partial derivatives. For example, $u_x \equiv \partial u / \partial x$.

[8] If we consider an EV, an electricity consumption tax must be considered instead of a gasoline tax. We also observe electricity consumption tax are levied globally.

where γ represents the unit cost of fuel (gasoline), which is given by

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

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.

The first-order condition for each consumer is,

$$u_x(x, \theta) - \gamma = 0, \tag{1}$$

from which we obtain the fuel consumption level for type θ, $x^*(\theta)$.[9]

Given the product price, $p > 0$, each consumer purchases a product if and only if $u(x^*(\theta), \theta) - \gamma x^*(\theta) \geq p$. With equality, we obtain[10] the marginal consumer who purchases, $\bar{\theta}(p)$, that is,

$$u(x^*(\bar{\theta}), \bar{\theta}) - \gamma x^*(\bar{\theta}) = p. \tag{2}$$

We focus on the interior case satisfying $0 < \bar{\theta} < 1$. Because consumers whose type satisfies $\theta \geq \bar{\theta}$ purchase the products, market demand for products is given by $Q(p) \equiv 1 - F(\bar{\theta}(p))$. Thus, the inverse demand function is described as

$$P(q) \equiv Q^{-1}(q),$$

where the superscript -1 represents an inverse function and[11]

$$P'(q) = -\frac{1}{F'(\bar{\theta})\partial\bar{\theta}/\partial p} = -\frac{u_\theta}{f(\bar{\theta})} < 0.$$

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[9] Differentiating (1) with respect to θ yields

$$\frac{\partial x^*}{\partial \theta} = -\frac{u_{x\theta}}{u_{xx}}.$$

Thus, while the effect of γ on x^* is always negative, the effect of θ on x^* depends on the sign of $u_{x\theta}$.

[10] Note that the surplus for purchasing a product (left-hand side) is strictly increasing in θ because differentiating it with respect to θ yields

$$u_\theta + (u_x - \gamma)\frac{\partial x^*}{\partial \theta} = u_\theta > 0,$$

where we use (1).

[11] Differentiating (2) with respect to p yields:

$$u_\theta \frac{\partial \bar{\theta}}{\partial p} = 1 \;\therefore\; \frac{\partial \bar{\theta}}{\partial p} = \frac{1}{u_\theta},$$

where we use the equation in footnote 10.

The producer solves

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

The first-order condition for this problem is

$$P(q) + P'(q)q - C'(q) - t_e E'(q) = 0. \tag{3}$$

This condition uniquely determines the market equilibrium q, and thus, equilibrium $\bar{\theta}$, as q and $\bar{\theta}$ have a one-to-one relationship through $q = 1 - F(\bar{\theta})$.[12]

2.2 Optimal tax combination

Let $x(\theta)$ be an arbitrary level of type θ's consumption contingent on the purchase of $\theta \in [0, 1]$. Then, the welfare-maximizing problem is

$$\max_{x(\theta),\bar{\theta}}\ W \equiv \int_{\bar{\theta}}^{1} u(x(\theta), \theta) f(\theta)\ d\theta - C(q) - cX - D(E(q) + X),$$

where $q = 1 - F(\bar{\theta})$ and total emissions from fuel consumption (gasoline) are

$$X \equiv \int_{\bar{\theta}}^{1} x(\theta) f(\theta)\ d\theta.$$

The first-order condition with respect to $x(\theta)$ is

$$u_x(x(\theta), \theta) - c - D'(E(q) + X) = 0 \tag{4}$$

for all $\theta \in [0, 1]$, and that with respect to $\bar{\theta}$ is

$$u(x(\bar{\theta}), \bar{\theta}) - cx(\bar{\theta}) - C'(q) - [E'(q) + x(\bar{\theta})]D'(E(q) + X) = 0. \tag{5}$$

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[12] Because of this one-to-one relationship, the problem can be stated as maximization with respect to $\bar{\theta}$, instead of that with respect to q as

$$\max_{\bar{\theta}}\ P(1 - F(\bar{\theta}))(1 - F(\bar{\theta})) - C(1 - F(\bar{\theta})) - t_e E(1 - F(\bar{\theta})).$$

The first-order condition is

$$-f(\bar{\theta}) \left[P - \frac{1 - F(\bar{\theta})}{f(\bar{\theta})} u_\theta - C' - t_e E' \right] = 0.$$

As the left-hand side is strictly decreasing in $\bar{\theta}$ under our assumptions, the second-order condition is satisfied globally. Here, we used

$$\frac{\partial}{\partial \bar{\theta}} \frac{[1 - F(\bar{\theta})] u_\theta(x^*(\bar{\theta}), \bar{\theta})}{f(\bar{\theta})} = u_\theta \frac{\partial}{\partial \bar{\theta}} \frac{1 - F}{f} + \frac{1 - F}{f} \left[\frac{u_{xx} u_{\theta\theta} - (u_{x\theta})^2}{u_{xx}} \right] < 0$$

because the hazard rate $f/(1 - F)$ is strictly increasing and u is strictly concave ($u_{xx} u_{\theta\theta} - (u_{x\theta})^2 > 0$).

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

As a benchmark, suppose the producer is a price taker. In this case, the first-order condition of the producer is $p - C'(q) - t_e E'(q) = 0$ where $p = u(x^*(\bar{\theta}), \bar{\theta}) - \gamma x^*(\bar{\theta})$ from (2). Therefore, together with (1), and comparing with (4) and (5), we find that Pigovian tax $t_e = D'(E_L^o)$ and $t_f = 0$ attain optimal outcomes. Under perfect competition, to correct the externality of life-cycle emissions, the government need not impose fuel taxes; only an emission tax is required.[13]

In the presence of market power, by comparing market conditions (1), (2), and (3) with optimal conditions (4) and (5), we can identify the optimal tax combination (t_e^o, t_f^o) as in the following proposition.

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

$$\begin{aligned} t_e^o &= D'(E_L^o) + \frac{P'(q^o)q^o}{E'(q^o)} < D'(E_L^o), \\ t_f^o &= -\frac{P'(q^o)q^o}{E'(Q^o)} > 0. \end{aligned}$$

Proof. For necessity, suppose that $x(\theta) = x^*(\theta) = x^o(\theta)$ for all θ and $\bar{\theta} = \bar{\theta}^o$ $(q = q^o)$ at market equilibrium. Then, substituting (4) into (1) yields

$$D' - (t_e + t_f) = 0.$$

Subtracting (5) from (3) yields

$$-(t_e + t_f)x + P'q - t_e E' + (E' + x)D' = 0,$$

where we use $P = u(x(\bar{\theta}), \bar{\theta}) - \gamma x(\bar{\theta})$ from (2). Solving these two equations derives $t_e = t_e^o$ and $t_f = t_f^o$.

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[13] This result holds true because a single externality from greenhouse gases is considered and an emission tax is imposed on emissions from both consumption and production properly. Walls and Palmer (2001) show that if several types of pollution are considered during a product's life-cycle, the same number of pollution taxes as the number of pollution types is required to attain the optimum.

For sufficiency, suppose that $t_e = t_e^o$ and $t_f = t_f^o$. Then, substituting $\gamma = c + t_e^o + t_f^o$ into (1) yields

$$u_x(x^*(\theta), \theta) - c - D'(E_L^o) = 0, \tag{6}$$

for all θ. Also, substituting $t_e = t_e^o$ into (3) yields

$$P(q) + P'(q)q - C'(q) - \left[D'(E_L^o) + \frac{P'(q^o)q^o}{E'(q^o)} \right] E'(q) = 0. \tag{7}$$

Because $P(q) = u(x^*(\bar{\theta}), \bar{\theta}) - \gamma x^*(\bar{\theta})$ from (2), (7) is rearranged as

$$u(x^*(\bar{\theta}), \bar{\theta}) - cx^*(\bar{\theta}) - C'(q) - [E'(q) + x^*(\bar{\theta})]D'(E_L^o) \\ + \left[P'(q)q - P'(q^o)q^o \frac{E'(q)}{E'(q^o)} \right] = 0.$$

As the last term on the left-hand side vanishes when $q = q^o$, (6) and (7) must be satisfied when $x^*(\theta) = x^o(\theta)$ for all θ and $\bar{\theta} = \bar{\theta}^o$ $(q = q^o)$ using (4) and (5). **Q.E.D.**

For the producer, the derived formula of t_e^o matches the well-known optimal emission tax for monopolies (Misiolek, 1980; Barnett, 1980). To correct the undersupply resulting from the market power, the emission tax should be lower than the marginal damage. However, such a low emission tax level does not make consumers sufficiently reduce their fuel consumption. Therefore, a positive fuel tax t_f^o should be used such that $t_e^o + t_f^o = D'$.

It is worth emphasizing that life-cycle emissions are important for implementing this optimal tax policy. If E' is close to zero, that is, most of the emissions are generated at the consumption stage, t_e^o becomes negative.[14] Introducing such explicit subsidies for polluters will be politically difficult. However, when E' is not too small, that is, there are also substantial emissions at the production stage, we can attain the first-best optimality by combining taxes for polluters instead of any explicit subsidies. This may be an acceptable policy.

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[14] The traditional second-best emission tax derived by Misiolek (1980) and Barnett (1980) can be negative as well.

3 Model 2: Endogenous fuel efficiency

We extend the model by endogenizing fuel efficiency, $\alpha > 0$. A lower α indicates a higher fuel efficiency. The producer's cost function is $C(q, \alpha)$, where C is convex and satisfies $C_q > 0$ and $C_\alpha < 0$.

To clarify the effect of producer's investment, we simplify the structure of the consumer side by specifying u as

$$u(x, \theta) \equiv \begin{cases} vx \text{ if } x \leq \theta \\ v\theta \text{ if } x \geq \theta, \end{cases}$$

where $v > 0$ is sufficiently large, such that $x^*(\theta) = \theta$. In other words, the degree of use is exogenously given by types θ and we can directly represent the distribution of use of a product by $x \sim F(x)$ on $x \in [0, 1]$. Therefore, we express the consumer type hereafter by x instead of by θ.

3.1 Market equilibrium

Type x consumer purchases a product if and only if $vx - \gamma\alpha x \geq p$. The marginal consumer who purchases $\bar{x}(p, \alpha)$ is obtained by

$$v\bar{x} - \gamma\alpha\bar{x} = p, \quad \therefore \bar{x} = \frac{p}{v - \alpha\gamma}. \tag{8}$$

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

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

$$P(q, \alpha) \equiv Q^{-1}(p, \alpha),$$

respectively.

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

$$P(q, \alpha) + P_q(q, \alpha)q - C_q(q, \alpha) - t_e E'(q) = 0, \tag{9}$$

$$P_\alpha(q, \alpha)q - C_\alpha(q, \alpha) = 0, \tag{10}$$

where

$$P_q(q,\alpha) = -\frac{v-\alpha\gamma}{f(\bar{x}(q,\alpha))} < 0, \tag{11}$$

$$P_\alpha(q,\alpha) = -\gamma\bar{x}(q,\alpha) < 0 \tag{12}$$

hold.[15] Note that $\bar{x}(q,\alpha)$ is obtained by substituting $p = P(q,\alpha)$ into $\bar{x}$ in (8).

3.2 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 (gasoline) is

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

The first-order conditions are

$$v\bar{x} - c\alpha\bar{x} - C_q(q,\alpha) - [E'(q) + \alpha\bar{x}]D'(E(q)+\alpha X) = 0, \tag{13}$$

$$-[c + D'(E(q)+\alpha X)]X - C_\alpha(q,\alpha) = 0. \tag{14}$$

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

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[15] P_q and P_α are derived as follows. Because $\bar{x} = p/(v-\alpha\gamma)$ from (8), 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

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

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

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

At market equilibrium, by substituting (10) into the left-hand side of (14), 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 relation

$$SMC \cdot \mu_X \gtreqless -P_\alpha(q, \alpha) \;\Leftrightarrow\; \frac{\partial W}{\partial \alpha} \lesseqgtr 0, \tag{15}$$

where $SMC = c + D'(E(q) + \alpha X)$ is the marginal social cost of fuel at market equilibrium. Thus, the left-hand side, $SMC \cdot \mu_X$, is the average saving in social costs with a decrease in α (i.e., improvement in fuel efficiency). The right-hand side, $-P_\alpha$, is the marginal market valuation of the decrease in α. Relation (15) indicates that when the former social benefit is greater (less) than the latter private benefit, a marginal decrease (increase) in α improves welfare: the market under invests (over invests) in fuel efficiency.

This market failure in fuel efficiency is related to market failure in choosing product quality, as discussed by Spence (1975). To demonstrate this, let $\gamma = SMC$ ($t_e + t_f = D'$) (i.e., environmental damage is fully internalized into the fuel cost).[16] In this case, because $P_\alpha = -\gamma \bar{x}$ from (12), (15) is reduced to

$$\mu_X \gtreqless \bar{x} \;\Leftrightarrow\; \frac{\partial W}{\partial \alpha} \lesseqgtr 0. \tag{16}$$

Indeed, $\mu_X > \bar{x}$ always holds true in our model.[17] Thus, the market forces lead to underinvestment ($\partial W / \partial \alpha < 0$) even if environmental damage is fully internalized. When a monopoly sets the product quality (in our context, 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 (8) and (9), and (10) with optimal conditions (13) and (14).

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[16] Another way to see this is to consider the case in which $D' = 0$ and $t_e + t_f = 0$: environmental damage and the associated taxes are zero. As $P_\alpha = -c\bar{x}$, (15) is also reduced to (16).

[17] See the third paragraph of the proof of Proposition 2.

Proposition 2 *The socially optimal outcomes are achieved if and only if*

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

Proof. For necessity, suppose that $\bar{x} = \bar{x}^o$ ($q = q^o$) and $\alpha = \alpha^o$ at market equilibrium. Substituting (14) into (10) yields

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

By subtracting (13) from (9), 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 (8). 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 (more precisely, similar to the latter half of the proof of Proposition 1), (9) and (10) must be satisfied when $q = q^o$ and $\alpha = \alpha^o$ under the conditions of optimal outcomes (13) and (14).

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

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

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 (Misiolek, 1980; Barnett, 1980), 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. As in the previous section, the terms correcting for market power are positive in t_f^o and negative in t_e^o. Because $\mu_X^o > \bar{x}^o$ as shown in the proof, 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 always positive and that of the emission tax t_e^o is always lower than the Pigovian level D'.

We explain why the optimal policy has this structure. Even if environmental damage is fully internalized ($\gamma = SMC$), fuel efficiency chosen by the producer is suboptimal. Thus, to encourage an improvement in fuel efficiency, 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

$$\gamma^o = SMC^o \frac{\mu_X^o}{\bar{x}^o} > SMC^o, \quad \text{or} \quad t_e^o + t_f^o > D'(E_L^o),$$

where the equality stems from Proposition 2. 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 Pigovian level.[18]

4 Concluding remarks

This study investigates the optimal combination of emission and fuel taxes in a monopoly. We consider life-cycle emissions and heterogeneity among consumers. We present two stories in which optimal fuel tax is strictly positive. In other words, heavier taxes should be imposed at the fuel consumption stage than at the production stage. In the first scenario, consumers choose the mileage of vehicles. In the second scenario, the producer chooses fuel efficiency. We believe that both are realistic in the vehicle industry, which is one of major sources of CO2 emissions.

If a production subsidy is available, the first-best outcome is also achieved by the combination of the subsidy and emission tax. However, it is politically difficult to introduce direct subsidies to polluters. By contrast, the combination of taxes for polluters may be more acceptable. Therefore, we believe that our analysis has practical policy implications in this respect.

To elucidate each function, we endogenized the consumption levels and fuel efficiency

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[18] See Proposition 2 and the last terms of t_e^o and t_f^o, which correct product quality. Their magnitudes are larger in t_f^o than in t_e^o.

separately. If we endogenize both simultaneously, the first-best outcome cannot be implemented by combining fuel and emission taxes. However, if we introduce additional policy tools, such as the regulation of energy efficiency, we can show that fuel tax is strictly positive.[19]

In this study, we focus only on emission and fuel taxes, and do not investigate other policy measures. The fuel taxes we investigate may promote the switch from grey products to green products, and thus, may substitute for a green portfolio standard, such as a zero-emission vehicle program.[20] How other environmental policy measures affect the optimal combination of emission and fuel taxes should be investigated in future research.

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[19] Energy efficiency is globally regulated by energy conservation laws (Matsumura and Yamagishi, 2017).

[20] See Ino and Matsumura (2021a) and the studies cited therein.

References

Barnett, A.H. (1980) ‘The Pigovian tax rule under monopoly’, *American Economic Review* 70, 1037–1041.
https://www.jstor.org/stable/1805784

Baumol, W.J. and Oates, W.E. (1988) *The Theory of Environmental Policy* (second edition), Cambridge University Press, Cambridge.

Buchanan, J.M. (1969) ‘External diseconomies, corrective taxes, and market structure’, *American Economic Review* 59, 174–177.
https://www.jstor.org/stable/1811104

Fowlie, M., Reguant, M., and Ryan, S.P. (2016) ‘Market-based emissions regulation and industry dynamics’, *Journal of Political Economy* 124, 249-302.
https://doi.org/10.1086/684484

Fullerton, D. and West, S.E. (2002) ‘Can taxes on cars and on gasoline mimic an unavailable tax on emissions?’, *Journal of Environmental Economic and Management* 43(1), 135–157.
https://doi.org/10.1006/jeem.2000.1169

Fullerton, D. and West, S.E. (2010) ‘Tax and subsidy combinations for the control of car pollution’ *B.E. Journal of Economic Analysis & Policy* 10(1), Advances, Article 8.
https://doi.org/10.2202/1935-1682.2467

Ino, H. and Matsumura, T. (2021a) ‘Promoting green or restricting gray? An analysis of green portfolio standards’, *Economics Letters* 198, 109650.
https://doi.org/10.1016/j.econlet.2020.109650

Ino, H. and Matsumura, T. (2021b) ‘Optimality of emission pricing policies based on emission intensity targets under imperfect competition’, *Energy Economics* 98, 105238.
https://doi.org/10.1016/j.eneco.2021.105238

Katsoulacos, Y. and Xepapadeas, A. (1995) ‘Environmental policy under oligopoly with endogenous market structure’, *Scandinavian Journal of Economics* 97, 411–420.
https://doi.org/10.2307/3440871

Lee, S.-H. (1999) ‘Optimal taxation for polluting oligopolists with endogenous market structure’, *Journal of Regulatory Economics* 15, 293–308.
https://doi.org/10.1023/A:1008034415251

Levin, D. (1985) ‘Taxation within Cournot oligopoly’, *Journal of Public Economics* 27(3), 281–290.
https://doi.org/10.1016/0047-2727(85)90052-0

Matsumura, T. and Yamagishi, A. (2017) ‘Long-run welfare effect of energy conservation regulation’, *Economics Letters* 154, 64–68.
https://doi.org/10.1016/j.econlet.2017.02.030

Misiolek, S. (1980) ‘Effluent taxation in monopoly markets’, *Journal of Environmental Economic and Management* 7(2), 103–107.
https://doi.org/10.1016/0095-0696(80)90012-1

Pigou, A. C. (1932) *The Economics of Welfare* (fourth edition), MacMillan, London.

Preonas, L. (2017) ‘Market power in coal shipping and implications for us climate policy’, Energy Institute at Hass Working Paper 285.

Simpson, R.D. (1995) ‘Optimal pollution taxation in a Cournot duopoly’, *Environmental and Resource Economics* 6(4), 359–369.
https://doi.org/10.1007/BF00691819

Spence, A.M. (1975) ‘Monopoly, quality, and regulation’, *Bell Journal of Economics* 6(2), 417–429.
https://doi.org/10.2307/3003237

Walls, M. and Palmer, K. (2001) ‘Upstream pollution, downstream waste disposal, and the design of comprehensive environmental policies’, *Journal of Environmental Economic and Management* 41(1), 94–108.
https://doi.org/10.1006/jeem.2000.1135

Victor, P.A. (2022) The macroeconomics of a green transformation: the role of green investment. in Making the Great Turnaround Work Economic Policy for a Green and just Transition, edited by the Heinrich Böll Foundation, ZOE–Institute for Future-Fit Economies, and Finanzwende Recherche,
https://eu.boell.org/en/person/peter-victor

Xu, L., Chen, Y., and Lee, S.H. (2022) Emission tax and strategic environmental corporate social responsibility in a Cournot-Bertrand comparison. *Energy Economics* 107,105846
https://doi.org/10.1016/j.eneco.2022.105846