Environmental Policy and the Energy Efficiency of Vertically Differentiated Consumer Products*

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Abstract

We analyse optimal environmental policies in a market that is vertically differentiated in terms of the energy efficiency of products. Considering energy taxes, subsidies to firms for investment in more eco-friendly products, and product standards, we are particularly interested in how distributional goals in addition to environmental goals shape the choice of policy instruments. We find that an industry-friendly government levies an energy tax to supplement a lax product standard, but shies away from subsidies to firms. By contrast, a consumer-friendly government relies heavily on a strict product standard and additionally implements a moderate subsidy to firms, but avoids energy taxes.

JEL-Classifications: Q58, Q48, L13

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1 Motivation

Consumption activities, such as using washing machines, refrigerators, computers, TV sets and vehicles, are an integral part of everyday life. As the complementary energy consumption of the households substantially contributes to environmental pollution, reducing the energy consumption of these activities is a key goal of governments. More energy efficient household appliances and vehicles have indeed become a prime target of environmental policies around the world. For instance, Japan's Top Runner Programme has set out efficiency targets not only for refrigerators and television sets but also for rice cookers, DVD recorders, and many more appliances (METI, 2010). Similarly, the European Eco-Design Directive (EU, 2005) aims at enhancing energy efficiency of a wide range of household appliances. Also, the US has an extensive system of mandatory efficiency standards for electrical appliances (IEA, 2003).

Energy and water efficiency gains have indeed significantly contributed to limiting the negative impact of consumption activities on the environment. In the EU, the average energy consumption of washing machines per kg of capacity decreased by 37% between 1992 and 2005, and average water consumption went down by 31% between 1997 and 2005 (Faberi et al., 2007). In the US, refrigerators consumed, on average, in 2001 only 25% of the energy used in 1972. Compared to the hypothetical energy consumption at the old level of efficiency, this improvement saves the US 200 billion kWh, which is about the annual energy consumption of California (Rosenfeld et al., 2004).[1]

Thus, in this paper, we focus on environmental policy as a means to improving energy efficiency (or likewise water efficiency). In this context, we consider energy taxes, subsidies for investments in more energy efficient products, and energy efficiency standards. We are particularly interested in how the government's distributional goals, in addition to its environmental goals, shape the choice of policy instruments and the extent to which different instruments are used.

These issues are analysed in a model with vertical product differentiation. Two firms first invest in the energy efficiency of their products and then are engaged in price competition. Households buy one of the products and complementary energy. They differ in the intensity with which they use these goods, and thus in their need for energy, which is produced in a separate sector. The government chooses its optimal policy mix, and may be biased towards industry or consumers. It balances its budget by taxes on or transfers to households.

[1] Further improvements are possible even with today's technologies. For instance, Fraunhofer IZM (2007) estimates that the average on-mode energy consumption of a 32" LCD TV set can be reduced by 15% to 30%, simply by applying available technologies.

In equilibrium, each firm invests in a product with a distinct level of quality, defined here in terms of energy efficiency, to differentiate itself from its competitor and thus weaken price competition.[2] As a consequence of imperfect competition, the government must employ two instruments to achieve optimal energy efficiency levels of both high quality and low quality products. First, it needs a subsidy to firms *or* an energy tax to induce the high quality firm to improve the energy efficiency of its product. Second, the government has to additionally implement a minimum energy efficiency standard for products that consume energy, since the low quality firm is insensitive to pecuniary incentives.

Distributional preferences matter when it comes to the optimal choice of the policy instruments. We find that an industry-friendly government levies an energy tax to supplement a lax efficiency standard, but shies away from subsidies to firms. An industry-friendly government relies heavily on an energy tax, as such a tax increases the energy cost differential between the products of the two firms. An energy tax thus accentuates the quality differential between the products, thereby weakening price competition and ultimately increasing the profits of the two firms. Also, an industry-friendly government introduces only a lax minimum energy efficiency standard. The reason is that such a standard narrows the quality gap between the products, thereby reinforcing price competition and thus reducing profits.

In contrast, a consumer-friendly government heavily relies on a strict efficiency standard and additionally implements a subsidy to firms, but avoids energy taxes. From the perspective of households, a subsidy increases energy efficiency at lower cost to consumers than an energy tax, even though the subsidy is financed by households and tax revenues are ultimately given back to households. In contrast to an energy tax, however, a subsidy does not directly weaken price competition between firms and thus keeps product prices down.

Our paper shows that the distributional consequences of environmental policy can be counter-intuitive. At first glance, it is surprising that the industry gains more from an energy tax than from a direct subsidy. Likewise, it is far from obvious that households benefit more from paying for subsidies to firms than from implementing an energy tax, given that tax revenues are handed back to households. Moreover, our paper provides a justification for a sensible use of command-and-control instruments as a supplement to market-based instruments. Independent of the government's distributional preferences, standards are necessary in addition to taxes or subsidies.

Several papers have analysed the impact of government policy on firms, con-

[2] Vertical product differentiation has been well analysed in the literature on industrial economics. Seminal papers include, for example, Gabszewicz and Thisse (1979), Shaked and Sutton (1982), Cremer and Thisse (1994), and Crampes and Hollander (1995). These contributions, however, do not consider environmental issues.

sumers, and vertically differentiated markets in an environmental context. For instance, Lombardini-Riipinen (2005) considers a model in which production causes pollution and two firms choose different pollution levels per output unit in response to green preferences of consumers. Maximising aggregate welfare, the government implements an ad valorem tax in addition to either an emission tax or a subsidy to consumers who buy the eco-friendlier produced good (but there is no endogenous instrument choice). She concludes that both policy bundles can achieve the optimal allocation, and that the optimal emission tax overinternalises the externality. In a similar framework, Bansal (2008) separately examines and then compares the use of a uniform ad valorem tax and of an emission tax. She shows, for instance, that an ad valorem tax dominates an emission tax in terms of aggregate welfare if pollution causes only small damage (see, e.g., Ronnen, 1991; Arora and Gangopadhyay, 1995; Cremer and Thisse, 1999; Moraga-González and Padrón-Fumero, 2002; Bansal and Gangopadhyay, 2003, for further contributions).

The current paper has three key features that set it apart from previous contributions. First, we analyse systematically how (i) the choice of the policy instruments and (ii) the extent to which the chosen instruments are employed vary with the distributional preferences of the government. Our analysis is important because most policy decisions are indeed at least partly driven by concerns about distribution, and not merely by efficiency considerations. For a variety of reasons, governments carry out redistributive measures not only directly but also indirectly and in basically all policy areas, including environmental policy.

Second, and unlike the papers referred to above, we focus on the joint consumption of vertically differentiated goods and energy. Our approach enables us to analyse the impacts of an energy tax in addition to those of an energy efficiency standard and a direct subsidy to firms. A major characteristic of an energy tax is that it affects the 'consumption costs' of different households consuming the very same product very differently, depending on the intensity with which households use the specific product. This 'differentiated' impact of an energy tax on 'consumption costs' is exactly the reason why this instrument so effectively curbs price competition and turns out to be so attractive to an industry-friendly government.

Third, households buy eco-friendly goods in our framework because it pays for them in terms of lower energy costs. Our results do not rely on altruistic or 'green' sentiments. By contrast, previous contributions refer to 'green' preferences of consumers (see also Eriksson, 2004, and Rodriguez-Ibeas, 2007, besides the papers referred to above) and ignore the role of energy taxes, and likewise water charges.

Our paper is organised as follows. In Section 2, we present our model. Section 3 explores the quality and price competition between the firms. We then analyse the optimal environmental policy and how this policy depends on the government's distributional preferences in Section 4. Section 5 discusses alternative policy instruments and extensions of the model. Finally, Section 6 summarises the paper.

2 Firms, Households, and the Government

We start by explaining the different components of our model with vertically differentiated products, energy consumption, and environmental damage.

Firms and Technology There are two firms, H and L, each of them producing one variant of a vertically differentiated product (where H and L are mnemonics for high quality and low quality, respectively, as will be clarified below). The goods can be used with different intensities z, and their consumption requires a complementary energy consumption $(\bar{e} - e_i)$ per intensity unit. For example, each washing machine can be used once or ten times a week, and each washing cycle needs a machine-specific amount of energy.

Each firm chooses its product's energy efficiency e_i, which reduces the energy consumption per intensity unit below the exogenously given basic level $\bar{e}$.[3] A cost function $a(e_i)$, which is identical for the two firms, relates the energy efficiency e_i to the fixed investment costs a_i of inventing a product with this level of energy efficiency.

This function is twice continuously differentiable and strictly convex. It also fulfils the properties (i) $a(0) = 0$, (ii) $\partial a(0)/\partial e_i = 0$, and (iii) $\partial a(\bar{e})/\partial e_i = \infty$. That is, reducing energy consumption to zero will not be economically sensible because of infinitely high marginal investment costs for $e_i = \bar{e}$. By contrast, small improvements in energy efficiency, starting from $e_i = 0$, can be achieved at rather low costs. Without loss of generality, we assume that firm H (L) produces a more (less) energy efficient good, i.e., $e_H > e_L$.

The energy-efficiency investment costs might be subsidised by the government with rate s, yielding private investment costs $(1 - s)\, a_i$. For simplicity, there are no further production costs. Each firm chooses energy efficiency e_i and price p_i for its product such that it maximises its profit $\pi_i = p_i y_i - (1 - s)\, a_i$, where y_i denotes output. It thereby takes the decisions of its rival as given.

[3] Typically, energy efficiency is defined as energy services generated per unit of energy input (Gillingham et al., 2009). In the current framework with constant energy input per service unit of z, this would mean that energy efficiency is simply $1/(\bar{e} - e_i)$. For notational convenience, however, energy efficiency refers to e_i in our paper.

Households Each household purchases exactly one good, either from firm H or L.[4] Households differ in their exogenous consumption intensities z. For instance, all households buy a washing machine, but while families use their machines very frequently (high z), singles use theirs far less often (low z). The household characteristic z is distributed over the interval $[\underline{z}, \overline{z}]$, $\overline{z} > \underline{z} > 0$, according to a twice-continuously differentiable distribution function $F(z)$ with the properties: (i) $F(\underline{z}) = 0$ and $F(\overline{z}) = 1$, (ii) $F'(z) > 0$ for all $z \in (\underline{z}, \overline{z})$, (iii) $\underline{z}F'(\underline{z}) < 1$, and (iv) $F''(z) \in \left(-2\left(F'(z)\right)^2 / \left(1 - F(z)\right), 2\left(F'(z)\right)^2 / F(z)\right)$ for all $z \in (\underline{z}, \overline{z})$.

The first two properties are obvious. The third property restricts the consumption intensity and number of low intensity households. As a result, the high quality firm will not find it attractive to price the low quality firm out of the market, and both firms will sell their products at a positive price in equilibrium. The fourth property is sufficient for the second order conditions of profit maximisation to be satisfied. It imposes a limit on the slope of the density function. This property is fulfilled, for instance, by a uniform distribution and various specifications of the Beta distribution, which are routinely used when the domain is finite (see Appendix B for details).

Denoting by t the gross price of energy (including energy tax), household h's total costs of consuming good i with intensity z_h amount to $p_i + t\left(\overline{e} - e_i\right) z_h$, where $\left(\overline{e} - e_i\right) z_h$ captures the household's energy consumption. Each household then chooses the good—either H or L—that minimises its total consumption costs. Equivalently, we can say that each household maximises its 'residual' income $m_h = x - p_i - t\left(\overline{e} - e_i\right) z_h + b$, where x stands for a household's gross income and b for the lump-sum transfer from, or tax to, the government. We assume that income x is sufficiently high to pay a possible tax and for one of the products and a household's need for energy. Finally, we normalise the number of households to one.

Energy and the Environment Profit-maximising firms in a competitive sector generate energy at constant marginal costs c. Perfect competition implies that the net energy price households have to pay (i.e., excluding energy tax) equals marginal costs c. Adding up individual energy consumption $\left(\overline{e} - e_i\right) z_h$ yields aggregate energy consumption E, which in turn causes environmental damage $D(E)$. This twice continuously differentiable function expresses damage in pecuniary terms. It is, as usual, assumed to be convex, i.e., $\partial D/\partial E > 0$ and $\partial^2 D/\partial E^2 \geq 0$.

[4] In some papers on vertically differentiated markets, the households' decisions of whether or not to purchase a good are endogenised (see, for instance, Moraga-Gonzáles and Padrón-Fumero, 2002, and Bansal and Gangopadhyay, 2003). In contrast, we assume that all consumers buy one product, as Cremer and Thisse (1999), Eriksson (2004) and Bansal (2008), among others, do.

As discussed below, consumer welfare suffers from environmental damage. Nevertheless, the negative externality of energy consumption has no effect on an individual purchasing decision, since a household has no impact on overall environmental damage.

Government The government has three environmental policy instruments at its disposal, an energy tax rate $\tau \geq 0$, a subsidy rate $s \in [0, 1)$, and a minimum energy efficiency standard e_{min}. This standard e_{min} defines the minimum energy efficiency e_i that products have to achieve. It is limited to e_{lim}, i.e., $e_{min} \leq e_{lim}$. The limit e_{lim} is sufficiently low so that both firms ultimately stay in business; that is, each of them makes a non-negative profit. In this sense, we only allow non-drastic standards. This constraint reflects the fact that 'historical' production rights and legal fidelity—apart from political-economic reasons—prevent the government from implementing drastic regulations that would drive firms out of the market.

The government aims at maximising the weighted aggregate welfare

$$W = \alpha \underbrace{(\pi_H + \pi_L)}_{\text{Industry welfare}} + (1 - \alpha) \underbrace{[M - D(E)]}_{\text{Consumer welfare}}. \tag{1}$$

The government's objective (1) can be decomposed into consumer welfare, which consists of aggregate 'residual' income M net of environmental damage $D(E)$, and industry welfare, which is equal to aggregate profits $\pi_H + \pi_L$.[5] The parameter α, which assigns a weight to industry profits, is given exogenously, with $\alpha \in [\underline{\alpha}, \overline{\alpha}]$ and $0 < \underline{\alpha} < 1/2 < \overline{\alpha} < 1$. We refer to a government with $\alpha > 1/2$ ($\alpha < 1/2$) as industry-friendly (consumer-friendly). The borderline case $\alpha = 1/2$ constitutes our benchmark. In this case, we label the government as neutral.[6]

As usual, the government has to balance its budget. Therefore, it implements a lump-sum transfer $b > 0$ to households, or levies a lump-sum tax $b < 0$ on households, to close the gap between energy tax revenues τcE and subsidy payments $s\,(a_H + a_L)$; that is,

$$b = \tau cE - s\,(a_H + a_L). \tag{2}$$

[5] Since demand and consumption intensity are considered to be exogenous, we can omit the associated household utility without affecting our results. Instead, individual consumer welfare is simply measured by residual income m_h net of environmental damage. Thus, aggregate consumer welfare is $M - D(E)$.

[6] The government's objective function can be interpreted as a political support function, which can be derived from more sophisticated models of public decision making. See Peltzman (1976) for a seminal paper on political support functions and Rauscher (1997), chapter 7, for an application to environmental issues.

Timing Decisions take place in three stages. In the first stage, the government sets energy tax rate τ, subsidy rate s, and energy efficiency standard e_{min}. In the second stage, the two non-cooperative firms decide simultaneously on the energy efficiency of their goods, e_H and e_L. In the third stage, the firms choose again simultaneously their prices, p_H and p_L. Households decide which product they purchase, and buy the corresponding amount of energy.

Remark The assumption of fixed consumption intensities applies best to household appliances such as washing machines, television sets, refrigerators, and computers. Whether households wash their clothes, watch television, and surf the internet is hardly affected by energy prices. Instead, consumption intensities are determined to a large degree by household characteristics (e.g., household size) and price-inelastic consumer habits (e.g., using social network sites). However, the assumption of fixed consumption intensities is less appropriate for products such as vehicles. Therefore, Section 5 explores an extension of our model that allows for endogenously determined consumption intensities. In Section 5, we also discuss the implications of alternative policy instruments, a larger number of firms, and some other modifications of our model.

3 Market Equilibrium

As usual, we solve our model by backward induction and look for the subgame-perfect equilibrium. In this section, the market outcome is analysed for a given environmental policy.

3.1 Price Competition

In the third stage, each household h decides on whether one unit of either product H or product L is purchased. The corresponding total consumption costs are either $p_H + t\,(\overline{e} - e_H)\,z_h$ or $p_L + t\,(\overline{e} - e_L)\,z_h$, where $t = (1+\tau)\,c$. Comparing the two values reveals that a household prefers good H (L) if and only if its consumption intensity z_h is above (strictly below) the threshold level

$$\widetilde{z} = \frac{p_H - p_L}{(1+\tau)\,c(e_H - e_L)}. \tag{3}$$

This threshold level is determined by the ratio of the price differential $p_H - p_L$ to energy cost differential $(1+\tau)\,c(e_H - e_L)$. Obviously, all households would go for the more energy efficient product if its price p_H were equal or lower than its rival's price p_L. (We exclude the case $e_H = e_L$, since this can never be a subgame-perfect equilibrium, as discussed below.) For $p_H > p_L$, only households with a high consumption intensity $z_h \geq \widetilde{z}$ purchase the more energy efficient good, since their savings in energy costs more than compensate them for the higher product price. The other households prefer the less energy efficient good, since the lower product price more than offsets their higher energy costs.

Consequently, the two demand functions for goods H and L are $y_H = 1 - F(\widetilde{z})$ and $y_L = F(\widetilde{z})$, respectively. Then the profits of the two firms are

$$\pi_H = p_H [1 - F(\widetilde{z})] - (1-s)\, a_H \quad \text{and} \quad \pi_L = p_L F(\widetilde{z}) - (1-s)\, a_L. \tag{4}$$

At this stage, the energy efficiency levels e_H and e_L are given, and the corresponding investment costs a_H and a_L are sunk. Also, the energy tax rate τ is already determined, and the net energy price is equal to c (which follows from constant marginal costs c of energy generation and perfect competition in the energy sector). Then, each firm maximises its profit (4) with respect to its price, taking the choice of its competitor as given. This maximisation implies the usual trade-off. A higher price reduces demand, but increases the revenues from the remaining customers. Firms balance these two opposing effects, and rearranging the first order conditions for an interior solution yields[7]

$$p_H = (1+\tau)\, c\, (e_H - e_L) \frac{1 - F(\widetilde{z})}{F'(\widetilde{z})} \quad \text{and} \quad p_L = (1+\tau)\, c\, (e_H - e_L) \frac{F(\widetilde{z})}{F'(\widetilde{z})}. \tag{5}$$

These conditions determine the two product prices only implicitly (and not explicitly), since the right-hand sides also depend on prices.

Calculating the price differential $p_H - p_L$ and inserting the resulting expression into the threshold condition (3) then leads to

$$\widetilde{z} = \frac{1 - 2F(\widetilde{z})}{F'(\widetilde{z})}, \tag{6}$$

which implicitly determines the equilibrium threshold level.

Assuming that $e_H > e_L$, we first use the equations (5) and (6) to characterise the price competition equilibrium in Lemma 1, and then provide an economic interpretation of these equations and our preliminary conclusions.

Lemma 1 *Price Competition*
(i) A price competition equilibrium $(p_H, p_L, \widetilde{z})$ *exists and is unique. Both product prices are positive and satisfy condition (5), with* $p_H > p_L$. *Threshold* $\widetilde{z}$ *lies in the*

[7]The second order condition for profit maximisation is satisfied for both firms under property (iv) of the distribution function.

open interval $(\underline{z}, \overline{z})$ *and satisfies condition (6).*
(ii) The product prices p_H *and* p_L *increase (decrease) with energy efficiency* e_H (e_L)*. They also increase with energy tax rate* τ*. That is,* $\partial p_i/\partial e_H > 0$*,* $\partial p_i/\partial e_L < 0$*, and* $\partial p_i/\partial \tau > 0$*.*
(iii) Threshold $\widetilde{z}$ *and the resulting positive output levels* $y_H = 1 - F(\widetilde{z})$ *and* $y_L = F(\widetilde{z})$ *are independent of energy tax rate* τ *and energy efficiency levels* e_H *and* e_L*.*
Proof. *See Appendix A.*

Part (i) confirms that the product prices (5) and the threshold value (6) indeed define a unique equilibrium. The intuition behind part (ii) is straightforward. A more energy efficient good H widens the quality gap. Since the products then become more differentiated, price competition is weakened and both firms raise their prices. By contrast, a higher energy efficiency of good L narrows the quality gap, yielding less differentiated products. Consequently, price competition is intensified and both firms lower their prices.[8]

More interestingly, a higher tax allows both firms to raise their prices. The reason is that a higher tax increases the energy cost differential $(1+\tau)\, c(e_H - e_L)$, thus generating more *economically* differentiated goods H and L. Since greater *economic* differentiation alleviates price competition, both firms increase their prices. By contrast, a lower energy tax implies less economically differentiated goods, leading to intensified price competition. Thus, both firms decrease their product prices.

Let us finally explain part (iii), which follows directly from the threshold value (6). Consider, for instance, a rise in the energy tax rate. Such a change yields more *economically* differentiated goods H and L and raises the consumers' benefits from the more energy efficient product. It thus increases the competitive edge of firm H over its rival L. For given prices, the market share of firm H would obviously rise. However, firm H exploits its enhanced market position to substantially raise its price so that the equilibrium price differential $p_H - p_L$ increases proportionally to the energy cost differential $(1+\tau)\, c(e_H - e_L)$. The induced price response prevents an increase in the market share of firm H. Overall, the threshold $\widetilde{z}$ and equilibrium demand for each good remains unchanged.[9]

Similarly, a change in the energy efficiency e_H or e_L has no impact on the firms' market shares in equilibrium, since the equilibrium price differential increases, or decreases, proportionally to the quality gap $e_H - e_L$. Importantly, the fact that

[8] This kind of result is well known from the literature on vertically differentiated markets. See, for instance, Ronnen (1991) and Moraga-González and Padrón-Fumero (2002).

[9] Part (iii) of Lemma 1 does not hinge on the specific properties of the distribution function. However, this result would no longer hold if there were more than two firms in the market, or if markets were not fully covered. We discuss the case of more than two firms in Section 5.

changes in the tax rate and energy efficiency levels leave market shares unaltered does not indicate a lack of competition. In contrast, this results from price competition and the strategic interaction between the two firms.

3.2 Energy Efficiency Competition

In the second stage, the two firms determine their products' energy efficiency levels e_H and e_L. Each firm again takes the decision of its competitor and the implemented environmental policy as given. Moreover, it anticipates the impact of its choice of quality on the outcome of the succeeding price competition stage. Taking optimal prices (5) and part (iii) of Lemma 1 into account, the marginal effects of the products' energy efficiency levels on the firms' profits are

$$\frac{\partial \pi_H}{\partial e_H} = (1+\tau) c \frac{[1-F(\widetilde{z})]^2}{F'(\widetilde{z})} - (1-s) \frac{\partial a_H}{\partial e_H} \quad \text{and} \tag{7}$$

$$\frac{\partial \pi_L}{\partial e_L} = -(1+\tau) c \frac{[F(\widetilde{z})]^2}{F'(\widetilde{z})} - (1-s) \frac{\partial a_L}{\partial e_L} \tag{8}$$

for firm H and firm L, respectively. Consider first the situation of the high quality firm H (see (7)). On the one hand, a greater energy efficiency e_H widens the quality gap between the products and thus softens price competition. Consequently, prices, revenues and profits increase, as captured by the first term on the RHS. On the other hand, a greater energy efficiency goes along with greater private investment costs, as shown by the second term on the RHS. Since this effect depresses profits, firm H has to balance two opposing effects. The profit-maximising energy efficiency is thus characterised by the first order condition[10]

$$\frac{\partial a_H}{\partial e_H} = \frac{(1+\tau)}{(1-s)} \frac{c [1-F(\widetilde{z})]^2}{F'(\widetilde{z})}. \tag{9}$$

The situation of the low quality firm L is slightly different (see (8)). A greater energy efficiency e_L obviously means higher fixed costs, as in the case of its competitor. This effect is again captured by the second term on the RHS. In addition, a greater energy efficiency closes the quality gap, and thus reinforces price competition. In response, prices, revenues and profits decline, as reflected in the first term on the RHS. Since both effects work into the same direction, firm L chooses the lowest possible energy efficiency level, given the environmental standard e_{min}.[11] That is,

$$e_L = e_{min}. \tag{10}$$

[10] The second order condition $\partial^2 \pi_H / \partial e_H^2 = -(1-s) \partial^2 a_H / \partial e_H^2 < 0$ is fulfilled.

[11] Recall that the market is assumed to be fully covered. That is, the highest possible energy consumption per intensity unit $\bar{e}$ is sufficiently low so that all households find it beneficial to purchase the product. If this condition were not fulfilled, the low quality firm might indeed

For sufficiently small e_{min}, both firms can make non-negative profits, and the resulting quality competition equilibrium is characterised in Lemma 2.

Lemma 2 *Energy Efficiency Competition*
(i) An energy efficiency competition equilibrium (e_H, e_L) *exists. It is unique up to the permutation of the two firms across the two indices, and the energy efficiency levels satisfy* $e_H > e_L = e_{min}$ *and condition (9).*
(ii) Energy efficiency e_H *strictly increases with energy tax rate* τ *and subsidy rate* s*, i.e.,* $de_H/d\tau > 0$ *and* $de_H/ds > 0$*. It does not respond to changes in standard* e_{min}*.*
Proof. *See Appendix A.*

The arguments behind lemma 2 run as follows. Firms use energy efficiency as a means of vertically differentiating their goods from those of their rivals. A larger energy cost differential $(1+\tau)\,c\,(e_H - e_L)$ between the products of the two firms weakens price competition and allows both firms to charge higher prices. The marginal impact of a rise in the physical quality gap $e_H - e_L$ on the energy cost differential, and thus on prices, is greater the higher the energy tax τ. In this record, the energy tax reinforces the importance of the physical quality gap. Consequently, a higher tax increases the incentives to differentiate products. The more eco-friendly firm H invests even more in increasing energy efficiency e_H, while firm L sticks to the lowest possible level of quality e_L to ensure maximum product differentiation.

In contrast to the energy tax, the subsidy provides a direct incentive to invest more in a product's energy efficiency by lowering a firm's investment costs. This positive effect, however, only induces the high quality firm to improve the energy efficiency of its product. As a subsidy cannot sufficiently alter the benefits of vertical product differentiation, it cannot affect firm L's quality decision (as long as the subsidy rate is below one).

As explained above, the energy efficiency of the low quality good only fulfils the standard e_{min} and thus varies in line with this standard. The energy efficiency standard, however, does not affect the decision of the high quality firm in the second stage. Instead of changing the quality of its product, firm H cuts its prices in the third stage in response to a higher energy efficiency of its rival's product.

The choices of firms and households in the second and third stages lead to the equilibrium energy consumption

$$E = (\bar{e} - e_L)\, Z_L^{agg} + (\bar{e} - e_H)\, Z_H^{agg}, \tag{11}$$

where $Z_L^{agg} = \int_{\underline{z}}^{\tilde{z}} zF'(z)dz$ and $Z_H^{agg} = \int_{\tilde{z}}^{\overline{z}} zF'(z)dz$.

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improve the energy efficiency of its product above the minimum standard to avoid losing some customers who might otherwise not buy a good at all. Also, lax environmental standards might not be binding in the case of more than two firms, which is discussed in Section 5.

4 Environmental Policy

In the first stage, the government chooses the policy that maximises its objective function subject to a balanced budget. It anticipates the impact of its decision on market equilibrium and environmental damage.

4.1 Welfare

Since the government gives tax revenues back to households in a lump-sum fashion, energy tax payments have no direct impact on aggregate residual income M. The net tax burden of the households only results from subsidy payments to firms. Thus aggregate residual income M is equal to $x - p_H y_H - p_L y_L - cE - s\,(a_H + a_L)$. Then reformulating welfare (1) yields

$$W = (2\alpha - 1)\underbrace{(\pi_H + \pi_L)}_{\text{Industrial component}} + (1 - \alpha)\underbrace{[x - cE - D(E) - a_H - a_L]}_{\text{Traditional component}}, \tag{12}$$

where π_H, π_L, a_H a_L, and E are defined by (4), (5), (6), (9), (10), and (11). That is, welfare can be decomposed into a traditional and an industrial component. The traditional component is simply equal to the sum of consumer welfare $M - D(E)$ and firms' profits $\pi_H + \pi_L$. The industrial component contains the firms' profits $\pi_H + \pi_L$, revalued by the 'net' weight $(2\alpha - 1)$. It adds concerns about the distribution of benefits between firms and consumers to the government's objective function.

For $\alpha = 1/2$, the government pays no attention to this issue of distribution and maximises only the traditional welfare component. This captures the 'traditional', efficiency-oriented welfare maximising scenario. For $\alpha > 1/2$, the government is industry-friendly and places a positive net weight $(2\alpha - 1)$ on aggregate profits, in addition to taking into account the traditional objective; that is, profits count more than consumers' residual income (cf. (1)). By contrast, for $\alpha < 1/2$, the government is consumer-friendly and assigns a negative net weight $(2\alpha - 1)$ to profits; that is, profits count less than consumers' residual income.

4.2 Choice of Policy Instruments

The distributional preferences of the government are important, as they drive the choice of policy instruments. In exploring these preferences, we apply Definition 1.

Definition 1 *Energy Efficiency Equivalent Tax-Subsidy Bundles*
Consider two tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2). They are said to be energy efficiency equivalent (for short, ee-equivalent) if and only if they induce the same energy efficiency e_H in equilibrium; that is, if and only if $e_H(\tau_1, s_1) = e_H(\tau_2, s_2)$.

The optimality condition (9) implies that two tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2) are ee-equivalent if and only if

$$\frac{1+\tau_1}{1-s_1} = \frac{1+\tau_2}{1-s_2}. \tag{13}$$

This equivalence condition simply reflects the fact that there is an infinite number of tax-subsidy bundles that provide the same incentives for firm H to invest in energy efficiency. Despite their equivalence, however, the government is not necessarily indifferent between these tax-subsidy bundles, as summarised in Proposition 1.

Proposition 1 *Preferences over Policy Instruments*
Consider the ee-equivalent tax-subsidy bundles (τ_1, s_1) *and* (τ_2, s_2) *with* $\tau_1 \neq \tau_2$ *and* $s_1 \neq s_2$. *The standard* e_{min} *is given. Then:*
(i) A neutral government ($\alpha = 1/2$) *is indifferent between two ee-equivalent tax-subsidy bundles* (τ_1, s_1) *and* (τ_2, s_2). *That is,* $W(\tau_1, s_1, e_{min}) = W(\tau_2, s_2, e_{min})$.
(ii) A consumer-friendly government ($\alpha < 1/2$) *prefers tax-subsidy bundle* $(0, s_1)$ *to every ee-equivalent bundle* (τ_2, s_2). *That is,* $W(0, s_1, e_{min}) > W(\tau_2, s_2, e_{min})$, *including the special case* $W(0, s_1, e_{min}) > W(\tau_2, 0, e_{min})$.
(iii) An industry-friendly government ($\alpha > 1/2$) *prefers tax-subsidy bundle* $(\tau_1, 0)$ *to every ee-equivalent bundle* (τ_2, s_2). *That is,* $W(\tau_1, 0, e_{min}) > W(\tau_2, s_2, e_{min})$, *including the special case* $W(\tau_1, 0, e_{min}) > W(0, s_2, e_{min})$.
Proof. *See Appendix A.*

For a given standard e_{min}, two ee-equivalent tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2) yield the same equilibrium allocation (e_H, e_L, E), and thus the same investment costs a_H and a_L as well as the same environmental damage $D(E)$. In this allocative sense, the two market-oriented instruments are perfect substitutes in combating environmental damage. Not surprisingly, a neutral government, which cares only about the overall outcome in terms of costs and benefits of a cleaner environment, is indifferent between ee-equivalent policy bundles, as part (i) of Proposition 1 states.

The intuition for the conclusions in parts (ii) and (iii) of Proposition 1 is less obvious. Surprisingly, an industry-friendly government prefers an energy tax to an ee-equivalent subsidy or tax-subsidy mix, although the financial implications of the two instruments seem to favour a subsidy from the firms' perspective. While the subsidy implies direct payments to the firms, the energy tax entails no immediate benefit to the industrial sector. Just as surprisingly, a consumer-friendly government goes for a subsidy to the firms rather than an ee-equivalent energy tax or tax-subsidy mix, despite the fact that the financial implications for households seem to favour the energy tax. While the subsidy payments have to be fully covered by the households' tax payments, the emission tax does not cause a net tax burden on households at the aggregate level, since the tax revenues are handed back to them.

The key difference between the energy tax and the subsidy, however, is not the direct redistribution effect via the tax-transfer system, but the indirect one via market mechanisms. An energy tax induces firm H to invest more in its product's energy efficiency, since the tax reinforces the positive impact of a rise in the physical quality gap $e_H - e_L$ on product prices, as discussed above. As a consequence of the tax, the prices of *both* firms increase *directly* and *indirectly*; that is, $\partial p_i/\partial \tau > 0$ and $(\partial p_i/\partial e_H)(\partial e_H/\partial \tau) > 0$ (see Lemmas 1 and 2 and equilibrium prices (5)). The twofold rise in *both* product prices raises the revenues and profits of *both* firms at the expense of consumers, who end up with a lower residual income at the aggregate level. The induced redistribution through the product market makes such a tax attractive for an industry-friendly government and unattractive for a consumer-friendly government.

A subsidy, in contrast, increases energy efficiency e_H because it reduces the costs of product quality. Since this instrument rewards investment in the energy efficiency of a product in a more targeted fashion, a subsidy increases prices only *indirectly*, but not directly. That is, $(\partial p_i/\partial e_H)(\partial e_H/\partial s) > 0$, but $\partial p_i/\partial s = 0$. Consequently, a subsidy limits redistribution from households to firms more effectively than an energy tax. For this reason, a consumer-friendly government favours a subsidy over an emission tax, whereas an industry-friendly government does exactly the opposite.

4.3 Optimal Emission Taxes, Subsidies, and Standards

So far, we have discussed the preferences of different government types over ee-equivalent tax-subsidy bundles. Now, we explore the optimal energy tax, subsidy and standard. To this end, we derive the marginal impact of changes in the three policy instruments:

$$\frac{dW}{d\tau} = (2\alpha - 1)\, c \left[(e_H - e_L) \frac{[1 - F(\widetilde{z})]^2 + [F(\widetilde{z})]^2}{F'(\widetilde{z})} + (1+\tau) \frac{de_H}{d\tau} \frac{[F(\widetilde{z})]^2}{F'(\widetilde{z})} \right] + (1-\alpha) \left[\left(\frac{\partial D}{\partial E} + c \right) Z_H^{agg} - \frac{\partial a_H}{\partial e_H} \right] \frac{de_H}{d\tau}, \quad (14)$$

$$\frac{dW}{ds} = (2\alpha - 1) \left[(1+\tau)\, c \frac{de_H}{ds} \frac{[F(\widetilde{z})]^2}{F'(\widetilde{z})} + a_H + a_L \right] + (1-\alpha) \left[\left(\frac{\partial D}{\partial E} + c \right) Z_H^{agg} - \frac{\partial a_H}{\partial e_H} \right] \frac{de_H}{ds}, \quad (15)$$

$$\frac{dW}{de_{min}} = -(2\alpha-1)\left[(1+\tau)c\frac{[1-F(\widetilde{z})]^2+[F(\widetilde{z})]^2}{F'(\widetilde{z})} + (1-s)\frac{\partial a_L}{\partial e_L}\right] + (1-\alpha)\left[\left(\frac{\partial D}{\partial E}+c\right)Z_L^{agg} - \frac{\partial a_L}{\partial e_L}\right], \quad (16)$$

where we made use of the envelope theorem in (14) and (15). The first line of each derivative captures the marginal effect of the policy instrument on aggregate profits, the second line on the traditional welfare component.

Neutral Government ($\alpha = 1/2$) We first consider—as a benchmark—a neutral government ($\alpha = 1/2$) and its optimal policy mix (τ^*, s^*, e^*_{min}). For $\alpha = 1/2$, the first lines of the derivatives (14), (15), and (16) vanish. Then, the optimal tax-subsidy bundle and the optimal minimum energy efficiency standard are determined by the first order conditions $dW/d\tau = dW/ds = 0$ and $dW/de_{min} = 0$, yielding

$$\frac{\partial a_H}{\partial e_H^*} = \left(\frac{\partial D}{\partial E}+c\right)Z_H^{agg} \quad \Leftrightarrow \quad \frac{1+\tau^*}{1-s^*} = \frac{[(\partial D/\partial E)/c+1]\,Z_H^{agg}}{[1-F(\widetilde{z})]^2/F'(\widetilde{z})}, \quad (17)$$

$$\frac{\partial a_L}{\partial e_L^*} = \left(\frac{\partial D}{\partial E}+c\right)Z_L^{agg} \quad \Leftrightarrow \quad \frac{\partial a_L}{\partial e_{min}^*} = \left(\frac{\partial D}{\partial E}+c\right)Z_L^{agg}. \quad (18)$$

where (9) and (10) are used. (The second order conditions are fulfilled, as discussed in Appendix A.)

The conditions (17) and (18) show the simple trade-off that a neutral government faces. On the one hand, more energy-efficient products cut environmental damage and save energy costs, as reflected by the term $[(\partial D/\partial E)+c]\,Z_i^{agg}$. On the other hand, more eco-friendly products increase investment costs, as captured by the term $\partial a_i/\partial e_i$. Balancing these two opposing effects leads to the optimal energy efficiency levels e_H^* and e_L^* (see (17) and (18)).

The government can then choose one out of the infinite number of ee-equivalent tax-subsidy bundles (τ^*, s^*) that induce firm H to invest in the optimal energy efficiency level e_H^* (see (17) in connection with (9)). Since the set of optimal tax-subsidy bundles (τ^*, s^*) contains $(\tau^*, 0)$ and $(0, s^*)$, an energy tax alone or a subsidy alone is sufficient to implement the optimal solution. In addition, the energy efficiency standard e_{min}^*, which forces firm L to raise its product quality to e_L^*, is necessary because the low quality firm does not respond to the other instruments (see (18) in connection with (10)).[12] This justifies to some extent the use of standards, a tra-

[12]We focus on situations in which the optimal standard e_{min}^* lies in the interval $(0, e_{lim})$. Thus, the non-drastic standard restriction $e_{min} < e_{lim}$ prevents the government from implementing an allocation with only one firm in the market, but it does not constrain the second-best solution described by (18). We assume this kind of interior solution in the following analysis.

ditional command-and-control instrument, in addition to taxes and subsidies, two market-based instruments.

Non-Neutral Governments We now turn to the optimal policy mix of a non-neutral government, which is characterised in Proposition 2.

Proposition 2 *Non-Neutral Governments ($\alpha \neq 1/2$).*
(i) In the subgame-perfect equilibrium, the optimal policy mix of a consumer-friendly government ($\alpha < 1/2$) consists of a subsidy s^{**} and a minimum energy efficiency standard e_{min}^{**}. The optimal subsidy rate s^{**} strictly increases with the preference parameter α, while the optimal standard e_{min}^{**} strictly decreases with α. That is, $ds^{**}/d\alpha > 0$ and $de_{min}^{**}/d\alpha < 0$.
(ii) The optimal policy mix of an industry-friendly government ($\alpha > 1/2$) consists of an energy tax τ^{***} and a minimum energy efficiency standard e_{min}^{***}. The optimal tax τ^{***} strictly increases with α, while the optimal standard e_{min}^{***} strictly decreases with α. That is, $dt^{***}/d\alpha > 0$ and $de_{min}^{***}/d\alpha < 0$.
(iii) Measured in terms of achieved energy efficiency, the optimal subsidy s^{**} (tax τ^{***}) is less (more) eco-friendly, and the optimal standard e_{min}^{**} (e_{min}^{***}) is more (less) restrictive, than the corresponding tax-subsidy bundle (τ^{*}, s^{*}) and standard e_{min}^{*} of a neutral government. That is,

$$e_H(s^{**}) < e_H(\tau^{*}, s^{*}) < e_H(\tau^{***}) \quad \text{and} \quad e_{min}^{**} > e_{min}^{*} > e_{min}^{***}. \tag{19}$$

Proof. *See Appendix A.*

As Proposition 2 shows, the type of government does not only drive the choice of policy instruments, but also the extent to which they are used. The distributional implications of the different instruments and their substitutability as a means to combat environmental damage explain the way in which consumer-friendly and industry-friendly governments diverge from the policy of a neutral government.

For reasons already discussed in Section 4.2, a subsidy implies less redistribution from households to firms than an energy tax. However, even a subsidy redistributes at the expense of households, since consumers still have to finance the subsidy payments and additionally suffer from higher product prices. By contrast, the implications of a standard are very different. A higher standard narrows the quality gap, and thus the energy cost differential, between product types. The high quality and low quality products become more similar, leading to intensified price competition. As a consequence, profits of *both* firms decline, while the aggregate residual income of the consumers rises. On redistributional grounds, a consumer-friendly government thus prefers a standard to a subsidy to an energy tax, whereas an industry-friendly government has exactly the reverse preference ordering.

Since the two market-oriented instruments are perfect substitutes as a means of curbing emissions (in the allocative sense discussed in Section 4.2), one of them, the subsidy or the emission tax, is already sufficient on environmental grounds. By contrast, the energy efficiency standard on the one hand and the market-oriented instruments on the other cannot perfectly replace each other, since they affect the energy efficiencies of the two products differently. Consequently, the optimal policy mix of a non-neutral government consists of a standard and only one of the two market-oriented instruments, namely the one which is preferred for distributional reasons. Thus, the consumer-friendly government implements a subsidy along with a standard, whereas an industry-friendly government chooses an emission tax in addition to a standard.

The distributional preferences of a government also determine the extent to which the chosen instruments are used, since market-oriented instruments redistribute from households to firms and standards in the opposite direction. The more a consumer-friendly government prioritises households (i.e., the smaller α), the more it distorts its environmental policy towards the standard and away from the subsidy; that is, the stricter the standard and the lower the subsidy. By contrast, the more an industry-friendly government prioritises firms (i.e., the greater α), the more it distorts its environmental policy towards the energy tax and away from the standard; that is, the higher the tax and the laxer the standard. Formally, the redistributive component is captured by the negative first line of the derivative (15) and the positive first line of the derivative (16), whose absolute values increase as the parameter α decreases.

The focus of a consumer-friendly government on a standard, rather than a subsidy, and of an industry-friendly government on an emission tax, rather than a standard, is also reflected in the resulting energy efficiencies of the products. Compared to a neutral government, a consumer-friendly (an industry-friendly) government enforces a greater energy efficiency of the low (high) quality product, but accepts a lower energy efficiency of the high (low) quality product.

5 Discussion

In this section, we discuss three alternative instruments, a discriminatory investment subsidy, a rebate for the purchase of an energy efficient product, and an *ad valorem* tax or subsidy. We also explore three possible extensions of our model, considering endogenous consumption intensities, more than two firms, and costs of public funds.

5.1 Alternative Policy Instruments

Let us start by analysing alternative policy instruments. First, the government could subsidise only the investment of the firm with the more energy efficient product. Such a discriminatory subsidy could replace the non-discriminatory subsidy applied above. After all, the non-discriminatory investment subsidy does not affect the quality decision of the firm whose product just fulfils the minimum standard; it just generates a windfall profit to the low quality firm. Replacing the non-discriminatory subsidy by a discriminatory one would further limit redistribution in favour of firms, without affecting energy efficiency and pollution.

Such a change of policy, however, would only reinforce our key conclusions. A consumer-friendly government, which already prefers a non-discriminatory subsidy to an energy tax, would endorse even more a discriminatory subsidy. And an industry-friendly government, which prefers an energy tax to a non-discriminatory subsidy, would object even more to a discriminatory subsidy.

Second, the government could grant a rebate to consumers who buy the high quality product. For instance, this rebate could take the form of $\delta_H p_H$, $\delta_H \geq 0$, so that households would effectively pay $(1-\delta_H)\, p_H$ for the high quality product while firm H would still receive p_H. Interestingly, a consumer-friendly government would *not* prefer this instrument to the discriminatory investment subsidy discussed above. To see this, note that a rebate $\delta_H p_H$ to consumers would not affect the firms' market shares, which would still be described by condition (6). Like an investment subsidy, a rebate would provide an incentive for firm H to invest in a more energy efficient product, which would indirectly raise price p_H. But, unlike an investment subsidy, this rebate would also directly increase the price of the eco-friendly product, which would then be

$$p_H = \frac{1+\tau}{1-\delta_H} c\,(e_H - e_L)\,\frac{1-F(\widetilde{z})}{F'(\widetilde{z})}. \tag{20}$$

As (20) and (5) show, the direct effect of the rebate δ_H on price p_H, i.e., $\partial p_H/\partial \delta_H$, resembles the direct effect of the energy tax τ, i.e., $\partial p_H/\partial \tau$. And because of this direct impact, a consumer-friendly government prefers a (discriminatory) investment subsidy not only to an energy tax but also to a rebate to eco-friendly consumers.

Also, an industry-friendly government prefers an energy tax to a consumer rebate. The reason is that the above rebate directly raises only the price of the high quality product.[13] In contrast, an energy tax directly increases the prices of both the high quality and low quality products, as outlined in Sections 3 and 4. All in all, industry-friendly and consumer-friendly governments both regard a consumer rebate as inferior, either to an energy tax or to a (discriminatory) investment subsidy.

[13] The price p_L of the low quality product is still given by the corresponding expression in (5).

Third, we briefly sketch the role of an *ad valorem* tax on the two goods. In contrast to other papers, we have not considered such a tax as a potential instrument. As a negative *ad valorem* tax, i.e., an *ad valorem* subsidy, reduces the consumer price differential between the high quality and the low quality goods, it fosters demand for high quality goods. Consequently, investment in the energy efficiency of a product is more profitable, and pollution can decrease (e.g., Bansal, 2008). However, consumption taxes play a crucial role in generating tax revenues, and their importance for government revenues will probably even grow as a result of increasing capital and labour mobility. Thus, it might be very difficult to replace the existing *ad valorem* taxes by *ad valorem* subsidies (see Lombardini-Riipinen, 2005, for a brief discussion on policy restrictions).

Fortunately, in our context of joint consumption of goods and energy, an energy tax causes ultimately the same qualitative effects as an *ad valorem* subsidy would do, although for different reasons. Thus, an energy tax perfectly replaces the latter instrument. Importantly, the higher an existing *ad valorem* tax is, the higher the optimal energy tax of an industry-friendly government, since it has to overcome the negative impact of a positive *ad valorem* tax on investment incentives and the environment. In this sense, our paper complements previous studies on vertically differentiated markets, which ignore energy consumption. Of course, a consumer-friendly government would stick to its subsidy for investment in more eco-friendly products, but it would adjust the level of the subsidy in the presence of a consumption tax.

5.2 Extensions of Model

To check the robustness of our results, we finally discuss three extensions of our model. In the first extension, we continue to assume that the market is fully covered, but we now determine the consumption intensity endogenously. For instance, each household still purchases one car, but the number of miles driven in the car depends on fuel prices. This extension enables us to analyse how important the energy price elasticity of the consumption intensity is to our conclusions.

To make our point as simple as possible, let us assume that household h's utility is given by $V_h = \eta_h U(z_h) - m_h$, where residual income $m_h = x - p_i - t\,(\overline{e} - e_i)\,z_h + b$ is defined as above and $U'(z_h) > 0$ and $U''(z_h) < 0$ hold. For convenience, the elasticity of sub-utility U with respect to the consumption intensity z_h, i.e., $\varepsilon = U'(z_h)z_h/U(z_h)$, is assumed to be constant. The preference parameter η_h, which characterises the households, is distributed according to a distribution function $F(\eta)$ which has the same properties as $F(z)$ above. All other assumptions of the basic model still apply.

Households choose their utility-maximising consumption intensities after having bought good i. The consumption intensity of a household is then determined by the first order condition

$$\eta U'(z_i) = t(\bar{e} - e_i), \tag{21}$$

where the household index h is omitted and $z_i = z(t; e_i, \eta)$ stands for the optimal consumption intensity of household type η, given that the household has purchased good i with energy efficiency e_i.[14]

The first order condition (21) implies that the short term price elasticity of the consumption intensity, and thus of energy (i.e., the elasticity for given product choice and energy efficiency) is $\sigma := -(\partial z_i/\partial t)(t/z_i) = -U'(z_i)/[U''(z_i)z_i]$. This elasticity, which is constant under our assumptions, proves to be crucial and is used in Proposition 3 below.

The further formal analysis of this extension is relegated to Appendix B to focus now on an intuitive explanation of whether our previous conclusions are still valid in this modified framework. To this end, we state Proposition 3.

Proposition 3 *Endogenous Consumption Intensity*
Consider the extension described above. The profits of both firms increase (decrease) with the energy tax if and only if the short term energy price elasticity of the consumption intensity is smaller (greater) than unity. That is, $d\pi_i/dt \gtreqless 0 \Leftrightarrow \sigma \lesseqgtr 1$. *By contrast, a higher subsidy always increases the profits of both firms, i.e.,* $d\pi_i/ds > 0$.

In contrast to our previous results, a higher tax need not lead to higher profits any more. To understand this result, we explore the new effects which arise when consumption intensities are endogenous. In this case, an increase in the energy price depresses the consumption intensities of the households. The decline in consumption intensities reduces the households' benefits from buying the more energy efficient good H. As a consequence, price competition between the firms is intensified, which in turn negatively affects profits.

This negative 'consumption intensity' effect of a higher tax on profits counteracts the 'old' positive impacts discussed above. The negative effect is stronger the more sensitive the households' intensity choices react to an increase in the energy tax. Thus, the negative effect dominates (is dominated by) the old positive impacts if the consumption intensities of the households respond elastically (inelastically) to changes in energy prices, as expressed in Proposition 3.

[14] A rebound effect emerges now. For given consumer energy prices, a higher energy efficiency induces the consumers to increase their consumption intensities, which partly offsets the positive effect of the enhanced energy efficiency. However, partial equilibrium models that assume a constant net energy price tend to overestimate this rebound effect, as Wei (2010) shows in a general equilibrium model.

This proposition has implications for the conclusions in Sections 3 and 4. Obviously, an industry-friendly government no longer prefers an energy tax to a subsidy once a higher energy tax diminishes profits, since the subsidy always enhances profits. Thus, the previous results break down if the price elasticity of the consumption intensity is sufficiently high. By contrast, the preferences of each government type over policy instruments should remain the same if the choice of the consumption intensity is sufficiently price-inelastic.

There is some empirical evidence that the short-term elasticity is smaller than one, or even close to zero. Take the demand for automobile fuel, for instance. Goodwin et al.'s (2004) review of the empirical literature finds that 46 price elasticities of fuel consumption—calculated by dynamic estimation methods using time-series data—range from 0.01 to 0.57, with a mean of 0.25 (all figures refer to the absolute values of the price elasticities).[15] These estimates are broadly in line with the figures of other reviews (for instance, OECD, 2006) and more recent studies (for instance, Bureau, 2010, and Hughes et al., 2008).

Establishing relationships between energy prices and the consumption intensity of specific household appliances, such as washing machines and TV sets, is certainly a difficult task. While there appears to be a lack of product-specific studies, a number of papers estimate the price elasticity of residential electricity in general. Espey and Espey (2004) analyse 36 papers published between 1971 and 2000. In their dataset, the short-term price elasticity of residential electricity ranges from 0.004 to 2.01, with a mean of 0.35 and a median of 0.28 (see also OECD, 2006/2008). Analysing data from California, Reiss and White (2005) estimate that the corresponding elasticity of households who have neither electrical space heating nor air-conditioning is very close to zero, with 0.08. That is, households who just use energy for washing machines, refrigerators, television sets and the like practically fit our description of households whose consumption intensity is fully price-inelastic.[16]

While there is some variation in the results, most studies find that demand for fuel and residential electricity is fairly price-inelastic. However, the fact that key conclusions in Sections 3 and 4 depend on the elasticity of the consumption intensity certainly qualifies these conclusions. Furthermore, with endogenous consumption intensities, two tax-subsidy bundles can no longer be easily compared with each other. Even if two tax-subsidy bundles are ee-equivalent and thus lead to the same energy efficiency levels, they will imply different consumption intensities, and thus cause different levels of environmental damage; they are no longer completely equivalent

[15] The mean short-term elasticity calculated by static estimation methods and the mean long-term elasticity are 0.43 and 0.64, respectively.

[16] See, e.g., Newell et al. (1999), Austin and Dinan (2005), and Small and van Dender (2007) for further empirical studies on fuel and energy demand and efficiency.

in an allocative sense. Thus, each government type is expected to use a combination of the two market-oriented instruments. Nevertheless, environmental policy will still be distorted towards the instrument favoured on distributional grounds.

A further extension of our model is to allow more than two firms. To get an idea of how a larger number of firms affects the results, we assume exogenous consumption intensities and a fully covered market, as in the basic model, but consider the case of three firms. In equilibrium, we now have a low quality, medium quality and high quality firm. Market shares then depend on the quality levels of the goods. That is, changes in quality levels are no longer only converted into price changes, as in the basic model, but also into changes in the firms' market shares. Nevertheless, our basic conclusions are still valid.

As before, condition (13) continues to characterise ee-equivalent tax-subsidy bundles, which also lead to identical market shares of the three firms and thus to identical environmental damage. Most importantly, a consumer-friendly government continues to prefer a subsidy to a tax, whereas an industry-friendly government still prefers a tax to a subsidy in the way outlined in Proposition 1 and for the same reasons explored in Section 4. In this sense, the previous conclusions are robust. We discuss these issues formally in Appendix B.

Environmental policy becomes more complicated, since it now also influences the products' market shares and because small energy efficiency standards might be not binding. However, as a binding standard continues to make product differentiation more costly, and thus continue to reinforce price competition, a consumer-friendly (industry-friendly) government still faces incentives to implement (oppose) them in order to redistribute between firms and consumers.

This discussion indicates that key results are fairly robust regarding an increase in the *fixed* number of firms. By contrast, with completely free and uninhibited market entry, the analysis would become obsolete in its previous form. Then, new firms would enter the market if the incumbents made profits, thereby completely eroding overall industry profits.[17] Environmental policy could not change this zero-profit outcome as long as the free-entry condition is not violated. In this sense, the conflict between firms and consumers would vanish into thin air, and the existence of some form of market barriers and profits is essential for our analysis.

We could further extend the present model by introducing shadow costs of public funds $\lambda > 0$ (see, e.g., Laffont and Tirole, 1996), thereby taking into account that revenues are usually raised in a distortionary manner. That is, funding the subsidy causes additional costs of $\lambda s\left(a_H + a_L\right)$ to consumers. In contrast, the energy tax

[17] In fact, any integral number of firms might leave each firm with a small profit, but this profit is rather negligible in the presence of free market entry.

revenues generate an additional benefit of $\lambda\tau cE$, as it allows a reduction in the burden of distortionary taxes on households. These shadow costs of public funds make an energy tax more appealing and a subsidy less so. As a consequence, a neutral government would no longer be indifferent between ee-equivalent tax-subsidy bundles, but would always prefer an energy tax (and no subsidy) to an ee-equivalent subsidy or tax-subsidy bundle. Furthermore, an industry-friendly government has even more reason to endorse an energy tax, and to shy away from a subsidy.

The choice of a consumer-friendly government now depends on whether the cost argument in favour of an energy tax overrides the distributional argument in favour of a subsidy. Not surprisingly, this depends on the degree of consumer-friendliness and the magnitude of the costs of public funds. For all levels of the cost parameter $\lambda > 0$, there exists a cutoff value $\widetilde{\alpha} < 1/2$ such that a government whose preference parameter α is below $\widetilde{\alpha}$ will still prefer a subsidy (and no energy tax) to any other ee-equivalent tax-subsidy bundle. However, a government with $\alpha > \widetilde{\alpha}$ will favour an energy tax (and no subsidy) over any other ee-equivalent tax-subsidy bundle, and a government with $\alpha = \widetilde{\alpha}$ will be indifferent between two ee-equivalent tax-subsidy bundles (see Appendix B for details). To put it differently, without shadow costs of public funds, the 'cutoff' government is the neutral one. In contrast, with shadow costs of public funds, the 'cutoff' government is a moderately consumer-friendly one, and the optimal policy bundles change accordingly.[18]

6 Conclusion

In this paper, we have analysed environmental policy in the case of vertically differentiated markets and endogenous energy efficiency levels. In particular, we have explored how distributional goals in addition to environmental goals affect the choice of environmental policy instruments and the extent to which these instruments are employed. Our paper shows that a minimum energy efficiency standard is always part of the optimal policy mix, regardless of the government's distributional preferences. A consumer-friendly government imposes a particularly strict standard and grants a subsidy to firms for investments in more energy efficient products. In contrast, an industry-friendly government introduces only a lax product standard and additionally levies a tax on energy. Finally, we have discussed how various extensions qualify our conclusions.

[18] In a previous version of this paper, we briefly explore further extensions. For instance, we take into account that energy costs also contribute to production costs, and also discuss the case in which more eco-friendly goods raise variable production costs instead of fixed costs. See Haupt and Stadejek (2011).

Appendix A

Proof of Lemma 1 (i) *No 'boundary' equilibrium*: We start by excluding any price competition equilibria with $p_i = 0$. (Negative prices can obviously never emerge in equilibrium.) Note first that the high quality firm H can always set a positive price and generate positive revenues, no matter what non-negative price firm L chooses. By contrast, the low quality firm L is not able to charge a positive price and to gain a positive market share if $p_H \leq (1+\tau)\, c(e_H - e_L)\underline{z} =: \underline{p_H}$ holds, which follows directly from (3). For $p_L \geq 0$, however, $\partial\pi_H/\partial p_H|_{p_H=\underline{p_H}} \geq 1 - \underline{z}F'(\underline{z}) > 0$ (see property (iii) of the distribution function). Thus, $p_H \leq \underline{p_H}$ cannot be an equilibrium. If an equilibrium exists, then $p_H > \underline{p_H}$, implying $p_L > 0$ (since, for $p_H > \underline{p_H}$, there always exists a positive $p_L < p_H$ that generates positive revenues and thus dominates $p_L = 0$; see, again, (3)). This equilibrium is then described by (3) and (5).

Existence of unique 'interior' equilibrium: If condition (6), which follows from (3) and (5), defines a unique threshold $\widetilde{z} \in (\underline{z}, \overline{z})$, and thus unique prices p_H and p_L (see, again, (5)), then an equilibrium exists and is unique. To show that a unique threshold $\widetilde{z} \in (\underline{z}, \overline{z})$ exists, it is sufficient to prove that the right-hand side of condition (6), i.e., $[1-2F(z)]\,/F'(z) =: \Omega(z)$, satisfies the following three properties: 1. $\Omega(\underline{z}) > 0$. 2. $\Omega(z) < 0$ for $z \in (z^{crit}, \overline{z}]$, where z^{crit} is defined as $z^{crit} : F(z^{crit}) = 0.5$. 3. $\partial\Omega(z)/\partial z < 0$ for $z \in [\underline{z}, z^{crit}]$. Then, as the term z is obviously positive and increasing from $\underline{z}$ to $\overline{z}$ in the interval $[\underline{z}, \overline{z}]$, the intermediate value theorem implies that the equilibrium threshold $\widetilde{z}$ is uniquely determined by $\Omega(\widetilde{z}) - \widetilde{z} = 0$ (see (6)), with $\widetilde{z} \in [\underline{z}, z^{crit}]$.

We show that the three properties are fulfilled. 1. $\Omega(\underline{z}) = 1/F'(\underline{z}) > \underline{z} > 0$ follows from property (iii) of the distribution function. 2. $F(z) > 0.5$ for $z \in (z^{crit}, \overline{z}]$ directly implies $\Omega(z) < 0$ for $z \in (z^{crit}, \overline{z}]$. 3. Differentiating $\Omega(z)$ yields

$$\frac{\partial\Omega(z)}{\partial z} < 0 \Leftrightarrow F''(z) > -2\frac{[F'(z)]^2}{1-2F(z)}. \tag{22}$$

for $F(z) \in [0, 0.5] \Leftrightarrow z \in [\underline{z}, z^{crit}]$. Furthermore, inequality $F''(z) > -2\frac{[F'(z)]^2}{1-F(z)}$ holds under property (iv) of the distribution function, and $-2\frac{[F'(z)]^2}{1-F(z)} \geq -2\frac{[F'(z)]^2}{1-2F(z)}$ results for $z \in [\underline{z}, z^{crit}]$. Thus, $\partial\Omega(z)/\partial z < 0$ for $z \in (z^{crit}, \overline{z}]$.

Moreover, $\widetilde{z} \in [\underline{z}, z^{crit}]$ implies that $F(z) < 0.5$. Thus, $p_H > p_L$ follows from (5).

Next, we turn to part (iii) of lemma 1. The equilibrium threshold $\widetilde{z}$ only depends on the properties of the distribution function, as (6) directly shows, and is thus independent of tax τ and energy effectiveness levels e_H and e_L; and so is then $y_H = 1 - F(\widetilde{z})$ and $y_L = F(\widetilde{z})$.

Then, part (ii) of lemma 1 is straightforward. Since $\widetilde{z}$ is independent of τ, e_H and e_L, simple differentiation of (5) yields $\frac{\partial p_H}{\partial e_H} = (1+\tau)\, c\frac{[1-F(\widetilde{z})]}{F'(\widetilde{z})} > 0$, $\frac{\partial p_H}{\partial e_L} =$

$-(1+\tau)\,c\frac{[1-F(\widetilde{z})]}{F'(\widetilde{z})} < 0$, $\frac{\partial p_L}{\partial e_H} = (1+\tau)\,c\frac{F(\widetilde{z})}{F'(\widetilde{z})} > 0$, $\frac{\partial p_L}{\partial e_L} = -(1+\tau)\,c\frac{F(\widetilde{z})}{F'(\widetilde{z})} < 0$, $\frac{\partial p_H}{\partial \tau} = c\,(e_H - e_L)\,\frac{[1-F(\widetilde{z})]}{F'(\widetilde{z})} > 0$, and finally $\frac{\partial p_L}{\partial d\tau} = c\,(e_H - e_L)\,\frac{F(\widetilde{z})}{F'(\widetilde{z})} > 0$.

Proof of Lemma 2 (i) To avoid misunderstandings, let us relabel the two firms as firm 1 and firm 2. Inserting equilibrium values (5) and (6) into (4) yields firm 1's piecewise defined profit function

$$\pi_1(e_1;e_2) = \begin{cases} (1+\tau)\,c\,(e_2-e_1)\,\frac{[F(\widetilde{z})]^2}{F'(\widetilde{z})} - (1-s)\,a\,(e_1) & \text{for} \quad e_1 < e_2 \\ (1+\tau)\,c\,(e_1-e_2)\,\frac{[1-F(\widetilde{z})]^2}{F'(\widetilde{z})} - (1-s)\,a\,(e_1) & \text{for} \quad e_1 \geq e_2 \end{cases}. \tag{23}$$

For all e_2, firm 1's profit function (23) is continuous in e_1, with local maxima at $e_1 = e_{min}$ and $e_1 = e_H$ (where e_H is defined by (9)), as implied by (7) and (8).[19] Comparing the two maxima yields firm 1's piecewise defined reaction function

$$e_1 = \begin{cases} e_H & \text{for} \quad e_2 < \widetilde{e} \\ e_{\min} & \text{for} \quad e_2 \geq \widetilde{e} \end{cases}, \tag{24}$$

where $\widetilde{e}$ is defined by $\widetilde{e} : \pi_1(e_H;\widetilde{e}) = \pi_1(e_{min};\widetilde{e})$, with $\widetilde{e} \in (e_{min}, e_H)$. Note that both e_H and e_{min} are independent of e_2, as (7) and (8) show. Then the property $\widetilde{e} \in (e_{\min}, e_H)$ follows from the inequalities $\pi_1(e_H;e_{min}) > \pi_1(e_{min};e_{min})$ and $\pi_1(e_H;e_2 \geq e_H) < \pi_1(e_{min};e_2 \geq e_H)$ (which in turn follows from (7) and (8)) and the derivatives $\partial\pi_1(e_H;e_2)/\partial e_2 < 0$ for $e_2 \in [e_{min}, e_H]$ and $\partial\pi_1(e_{min};e_2)/\partial e_2 > 0$.

Analogously, we derive firm 2's piecewise defined reaction curve - just substitute index 1 for 2 and vice versa. Therefore, only two equilibria are possible: Either firm 1 chooses e_H and firm 2 chooses e_{min} or vice versa.[20]

(ii) Using $\frac{\partial \pi_H}{\partial e_H} = 0$ (see (7) or (9)), comparative statics yields

$$\frac{de_H}{d\tau} = \frac{\partial a_H/\partial e_H}{(1+\tau)\,\partial^2 a_H/\partial e_H^2} > 0 \quad \text{and} \quad \frac{de_H}{ds} = \frac{\partial a_H/\partial e_H}{(1-s)\,\partial^2 a_H/\partial e_H^2} > 0. \tag{25}$$

Obviously, $\frac{de_H}{de_{min}} = 0$ results.

Proof of the Proposition 1 (i) Consider two ee-equivalent tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2), i.e., (13) holds. Since threshold $\widetilde{z}$ is independent of tax τ and subsidy s (see Lemma 1, part (iii)), and since $e_H(\tau_1, s_1) = e_H(\tau_2, s_2)$ holds, $a_H(\tau_1, s_1) = a_H(\tau_2, s_2)$ and, for given e_{min} (and thus e_L and a_L), $E(\tau_1, s_1, e_{min}) = E(\tau_2, s_2, e_{min})$ result (see (9), (10), and (11)). Thus, the traditional welfare component $x - cE - D(E) - a_H - a_L =: \Phi$ is equal for the two policy bundles (τ_1, s_1)

[19] One of the two local maxima disappears if $e_2 = e_{min}$ or $e_2 \geq e_H$.

[20] These equilibria additionally require that $e_{min} \leq e_{lim}$ is sufficiently small, so that both firms can set sufficiently high prices and realise non-negative profits. Otherwise, one firm would prefer to exit the market.

and (τ_2, s_2) and for given e_{min}, i.e., $\Phi(\tau_1, s_1, e_{min}) = \Phi(\tau_2, s_2, e_{min})$. Therefore, $W(\tau_1, s_1, e_{min})|_{\alpha=1/2} = \Phi(\tau_1, s_1, e_{min}) = \Phi(\tau_2, s_2, e_{min}) = W(\tau_2, s_2, e_{min})|_{\alpha=1/2}$, as argued in part (i) of the proposition.

(ii) and (iii) *Welfare comparison*: Consider again two ee-equivalent tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2). Then,

$$W(\tau_1, s_1, e_{min}) \gtreqless W(\tau_2, s_2, e_{min}) \tag{26}$$

$$\Leftrightarrow (2\alpha - 1)\left[\pi_H(\tau_1, s_1, e_{min}) + \pi_L(\tau_1, s_1, e_{min})\right] \gtreqless (2\alpha - 1)\left[\pi_H(\tau_2, s_2, e_{min}) + \pi_L(\tau_2, s_2, e_{min})\right] \tag{27}$$

$$\Leftrightarrow (2\alpha - 1)\left[(1+\tau_1)\, c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - (1-s_1)\, a_H - (1-s_1)\, a_L\right] \gtreqless (2\alpha - 1)\left[(1+\tau_2)\, c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - (1-s_2)\, a_H - (1-s_2)\, a_L\right] \tag{28}$$

$$\Leftrightarrow (2\alpha - 1)(1-s_1)\left[\frac{(1+\tau_1)}{(1-s_1)} c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - a_H - a_L\right] \gtreqless (2\alpha - 1)(1-s_2)\left[\frac{(1+\tau_2)}{(1-s_2)} c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - a_H - a_L\right] \tag{29}$$

$$\Leftrightarrow (1-2\alpha)(s_1 - s_2)\left[\frac{(1+\tau_1)}{(1-s_1)} c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - a_H - a_L\right] \gtreqless 0 \tag{30}$$

where, for given e_{min} (and thus e_L and a_L), inequality (27) follows from the relation $\Phi(\tau_1, s_1, e_{min}) = \Phi(\tau_2, s_2, e_{min})$; inequalities (28) and (29) follow from (4), (5) and (6); inequality (30) follows from $e_H(\tau_1, s_1) = e_H(\tau_2, s_2)$, $a_H(\tau_1, s_1) = a_H(\tau_2, s_2)$ and the equivalence condition (13). (Here, we wrote, for short, F and F' instead of $F(\widetilde{z})$ and $F'(\widetilde{z})$.)

As discussed above, we focus on policies that allow both firms to realise non-negative profits, i.e., $\pi_H + \pi_L \geq 0$ (and thus to stay in the market). Then, the term in the square bracket of inequality (30) is positive.

Consumer-friendly government: Consider a consumer-friendly government, i.e., $\alpha < 1/2$. In this case, inequality (30) implies $W(0, s_1, e_{min}) > W(\tau_2, s_2, e_{min}) \Leftrightarrow s_1 - s_2 > 0$. Indeed, for $\tau_1 = 0$, equivalence condition (13) leads to $s_1 - s_2 = \frac{\tau_2}{1+\tau_2}(1 - s_2) > 0$ for all $s_2 \in [0, 1)$. This proves part (ii) of proposition 1.

Industry-friendly government: Next, consider an industry-friendly government, i.e., $\alpha > 1/2$. In this case, inequality (30) directly implies that $W(\tau_1, 0, e_{min}) >$

$W(\tau_2, s_2, e_{min}) \Leftrightarrow s_1 - s_2 < 0$. Indeed, since $s_1 = 0$ and $s_2 \neq s_1$ (otherwise, the two bundles $(\tau_1, 0)$ and (τ_2, s_2) were identical), $s_2 > 0$ and $\tau_1 > \tau_2$ hold (otherwise, the two bundles $(\tau_1, 0)$ and (τ_2, s_2) were not ee-equivalent), and thus $s_1 - s_2 = -s_2 < 0$ results. This proves $W(\tau_1, 0, e_{min}) > W(\tau_2, s_2, e_{min})$, as stated in part (iii) of Proposition 1.

Neutral Government - Welfare Maximisation The second order conditions are fulfilled for $\alpha = 1/2$, since

$\frac{d^2W}{d\tau^2}\Big|_{\tau=\tau^*} = -(1-\alpha)\left[\frac{\partial^2 D}{\partial E^2}\left(Z_H^{agg}\right)^2 + \frac{\partial^2 a_H}{\partial e_H^2}\right]\left(\frac{de_H}{d\tau}\right)^2 < 0$

(or, alternatively, $\frac{d^2W}{ds^2}\Big|_{s=s^*} = -(1-\alpha)\left[\frac{\partial^2 D}{\partial E^2}\left(Z_H^{agg}\right)^2 + \frac{\partial^2 a_H}{\partial e_H^2}\right]\left(\frac{de_H}{ds}\right)^2 < 0$),

$\frac{d^2W}{ds^2}\Big|_{s=s^*} = -(1-\alpha)\left[\frac{\partial^2 D}{\partial E^2}\left(Z_H^{agg}\right)^2 + \frac{\partial^2 a_H}{\partial e_H^2}\right]\left(\frac{de_H}{ds}\right)^2 < 0$, and

$\frac{d^2W}{d\tau^2}\frac{d^2W}{de_{min}^2} - \left(\frac{d^2W}{d\tau de_{min}}\right)^2 = (1-\alpha)^2\left[\frac{\partial^2 D}{\partial E^2}\left(Z_H^{agg}\right)^2\frac{\partial^2 a_L}{\partial e_L^2} + \frac{\partial^2 a_H}{\partial e_H^2}\left[\frac{\partial^2 D}{\partial E^2}\left(Z_L^{agg}\right)^2 + \frac{\partial^2 a_L}{\partial e_L^2}\right]\right]\left(\frac{de_H}{d\tau}\right)^2$

> 0 (or, alternatively, $\frac{d^2W}{ds^2}\frac{d^2W}{de_{min}^2} - \left(\frac{d^2W}{dsde_{min}}\right)^2 > 0$).

Proof of Proposition 2 (i) Proposition 1, part (ii), implies that any tax-subsidy bundle (τ_2, s_2) with $\tau_2 > 0$ cannot be optimal, as a consumer-friendly government prefers the ee-equivalent tax-subsidy bundle $(0, s_1)$; that is, $W(0, s_1, e_{min}) > W(\tau_2, s_2, e_{min})$. Thus, the optimal policy mix is described by the first order conditions $dW/ds = 0$ and $dW/de_{min} = 0$ (see (15) and (16)).[21]

Then, using $dW/ds = 0$ and $dW/de_{min} = 0$, comparative statics leads to

$$\text{sg}\frac{ds}{d\alpha} = \text{sg}\left[\frac{d^2W}{de_{min}d\alpha}\frac{d^2W}{dsde_{min}} - \frac{d^2W}{dsd\alpha}\frac{d^2W}{de_{min}^2}\right] \tag{31}$$

where $\frac{d^2W}{dsde_{min}} = (2\alpha-1)\frac{\partial a_L}{\partial e_L} - (1-\alpha)\frac{\partial^2 D}{\partial E^2}Z_L^{agg}Z_H^{agg}\frac{de_H}{ds} < 0$ for $\alpha < 1/2$, $\frac{d^2W}{dsd\alpha} = \frac{1}{1-\alpha}\left[(1+\tau)c\frac{de_H}{ds}\frac{[F(\tilde{z})]^2}{F'(\tilde{z})} + a_H + a_L\right] > 0$, and $\frac{d^2W}{de_{min}d\alpha} = -\frac{1}{1-\alpha}\left[(1+\tau)c\frac{[1-F(\tilde{z})]^2+[F(\tilde{z})]^2}{F'(\tilde{z})} + (1-s)\frac{\partial a_L}{\partial e_L}\right] < 0$. These inequalities, together with $\frac{d^2W}{de_{min}^2} < 0$ (see footnote 21 on second order conditions) imply $ds^{**}/d\alpha > 0$, as stated in part (i) of Proposition 2.

Similarly, comparative statics yields

$$\text{sg}\frac{de_{min}^{**}}{d\alpha} = \text{sg}\left[\frac{d^2W}{dsde_{min}}\frac{d^2W}{dsd\alpha} - \frac{d^2W}{ds^2}\frac{d^2W}{de_{min}d\alpha}\right] \tag{32}$$

where $\frac{d^2W}{dsde_{min}} < 0$ for $\alpha < 1/2$, $\frac{d^2W}{dsd\alpha} > 0$, and $\frac{d^2W}{de_{min}d\alpha} < 0$ (see above), together with $\frac{d^2W}{ds^2} < 0$ (see, again, footnote 21 on second order conditions), imply that $de_{min}^{**}/d\alpha < 0$, as stated in part (i) of Proposition 2.

[21] The second order conditions are fulfilled for $\alpha = 1/2$, as argued above. With 'well-behaved' cost, distribution and damage functions, the derivatives of the welfare function are continuous functions, too. Using continuity arguments, we can then show that the second order conditions are also fulfilled for α sufficiently close to 1/2. We assume that this is the case for $\alpha \in [\underline{\alpha}, \overline{\alpha}]$, where $\underline{\alpha} < 1/2 < \overline{\alpha}$.

(ii) The proof of part (ii) follows along the lines of the proof of part (i). Proposition 1, part (iii) implies that any tax-subsidy bundle (τ_2, s_2) with $s_2 > 0$ cannot be optimal, since an industry-friendly government prefers the ee-equivalent tax-subsidy bundle $(\tau_1, 0)$, i.e., $W(\tau_1, 0, e_{min}) > W(\tau_2, s_2, e_{min})$. Thus, the optimal policy mix is described by the first order conditions $dW/d\tau = 0$ and $dW/de_{min} = 0$ (see (14) and (16)).

Then, using $dW/d\tau = 0$ and $dW/de_{min} = 0$, comparative statics leads to

$$\text{sg}\frac{d\tau}{d\alpha} = \text{sg}\left[\frac{d^2W}{de_{min}d\alpha}\frac{d^2W}{d\tau de_{min}} - \frac{d^2W}{d\tau d\alpha}\frac{d^2W}{de_{min}^2}\right] \tag{33}$$

where $\frac{d^2W}{d\tau de_{min}} = -(2\alpha-1)\,c\frac{[1-F(\tilde{z})]^2+[F(\tilde{z})]^2}{F'(\tilde{z})} - (1-\alpha)\frac{\partial^2 D}{\partial E^2}Z_L^{agg}Z_H^{agg}\frac{de_H}{d\tau} < 0$ for $\alpha > 1/2$, $\frac{d^2W}{d\tau d\alpha} = \frac{1}{1-\alpha}c\left[(e_H - e_L)\frac{[1-F(\tilde{z})]^2+[F(\tilde{z})]^2}{F'(\tilde{z})} + (1+\tau)\frac{de_H}{d\tau}\frac{[F(\tilde{z})]^2}{F'(\tilde{z})}\right] > 0$, and $\frac{d^2W}{de_{min}d\alpha} < 0$ (see proof of Proposition 2, part (i)). These inequalities, together with $\frac{d^2W}{de_{min}^2} < 0$ (see footnote 21 on second order conditions), imply that $d\tau^{***}/d\alpha > 0$, as stated in part (ii) of Proposition 2.

Similarly, comparative statics yields

$$\text{sg}\frac{de_{min}^{***}}{d\alpha} = \text{sg}\left[\frac{d^2W}{d\tau de_{min}}\frac{d^2W}{d\tau d\alpha} - \frac{d^2W}{d\tau^2}\frac{d^2W}{de_{min}d\alpha}\right] \tag{34}$$

where $\frac{d^2W}{d\tau de_{min}} < 0$ for $\alpha > 1/2$, $\frac{d^2W}{d\tau d\alpha} > 0$, and $\frac{d^2W}{de_{min}d\alpha} < 0$ (see above), together with $\frac{d^2W}{d\tau^2} < 0$ (see, again, footnote 21 on second order conditions), imply that $de_{min}^{***}/d\alpha < 0$, as stated in part (ii) of Proposition 2.

(iii) Recall that any welfare-maximising tax-subsidy bundle (τ^*, s^*) can be replaced by an ee-equivalent bundle $(0, s_1^*)$ or $(\tau_1^*, 0)$ that also maximises welfare W for $\alpha = 1/2$ (see Proposition 1). In addition, $ds^{**}/d\alpha$ and $d\tau^{***}/d\alpha$ are continuous functions of α because all terms of these derivatives are continuous in α (continuity theorem). The optimal subsidy s^{**} and the optimal tax τ^{***} are thus continuous functions of α, with $ds^{**}/d\alpha > 0$, $d\tau^{***}/d\alpha > 0$ (see above), $\lim_{\alpha\to 1/2} s^{**} = s_1^*$, and $\lim_{\alpha\to 1/2}\tau^{***} = \tau_1^*$. Consequently, $s^{**}|_{\alpha<1/2} < s_1^*$ and $\tau^{***}|_{\alpha>1/2} > \tau_1^*$. Then, $e_H(0, s^{**}) < e_H(0, s_1^*) = e_H(\tau^*, s^*) = e_H(\tau_1^*, 0) < e_H(\tau^{***}, 0)$, where the inequality signs follow from $de_H/ds > 0$ and $de_H/d\tau > 0$, and the equals signs follow from Definition 1.

Similarly, $de_{min}/d\alpha$ is a continuous function of α, since all terms of this derivative are continuous in α. The optimal standard e_{min}^{**} (e_{min}^{***}) are thus continuous functions of α, with $de_{min}^{**}/d\alpha < 0$ ($de_{min}^{***}/d\alpha < 0$, see above) and $\lim_{\alpha\to 1/2} e_{min}^{**} = e_{min}^*$ ($\lim_{\alpha\to 1/2} e_{min}^{***} = e_{min}^*$). Consequently, $e_{min}^{**}|_{\alpha<1/2} > e_{min}^* > e_{min}^{***}|_{\alpha>1/2}$ holds.

Appendix B

Beta Distribution of Household Characteristic z As the Beta distribution is widely used when the domain is finite, we check whether common forms of this distribution satisfy property (iv) of the distribution of household characteristic z, i.e., $F''(z) \in \left(-2\left(F'(z)\right)^2/\left(1-F(z)\right), 2\left(F'(z)\right)^2/F(z)\right)$. The focus is here on the most common symmetric and asymmetric specifications of the Beta distribution with finite density, for which the distribution function can be calculated in closed form (which is, in general, not the case). These specifications are adapted to the domain $[\underline{z}, \overline{z}]$.

First, consider the symmetric Beta distribution characterised by the density function $F'(z) = \frac{(z-\underline{z})(\overline{z}-z)}{\int_{\underline{z}}^{\overline{z}}(k-\underline{z})(\overline{z}-k)dk}$. Then, $F''(z) = \frac{\overline{z}-2z+\underline{z}}{\int_{\underline{z}}^{\overline{z}}(k-\underline{z})(\overline{z}-k)dk}$, $F(z) = \frac{(z-\underline{z})^2(3\overline{z}-2z-\underline{z})}{6\int_{\underline{z}}^{\overline{z}}(k-\underline{z})(\overline{z}-k)dk}$, and $1-F(z) = \frac{(\overline{z}-z)^2(\overline{z}+2z-3\underline{z})}{6\int_{\underline{z}}^{\overline{z}}(k-\underline{z})(\overline{z}-k)dz}$. Using these terms, we find that $F''(z) > -2\frac{(F'(z))^2}{1-F(z)} \Leftrightarrow 0 < (\overline{z}-2z+\underline{z})(\overline{z}+2z-3\underline{z}) + 12(z-\underline{z})^2 =: \Psi_1(z;\underline{z},\overline{z})$. The last inequality is satisfied for $z \in [\underline{z}, \overline{z}]$ because (i) $\partial\Psi_1(z;\underline{z},\overline{z})/\partial z = 16(z-\underline{z}) \geq 0$ and thus $\Psi_1(z;\underline{z},\overline{z}) \geq \Psi_1(\underline{z};\underline{z},\overline{z})$ for $z \in [\underline{z},\overline{z}]$ and (ii) $\Psi_1(\underline{z};\underline{z},\overline{z}) = (\overline{z}-\underline{z})^2 > 0$. Similarly, $F''(z) < 2\frac{(F'(z))^2}{F(z)} \Leftrightarrow 0 > (\overline{z}-2z+\underline{z})(3\overline{z}-2z-\underline{z}) - 12(\overline{z}-z)^2 =: \Psi_2(z;\underline{z},\overline{z})$ holds for $z \in [\underline{z},\overline{z}]$ because (i) $\partial\Psi_2(z;\underline{z},\overline{z})/\partial z = 16(\overline{z}-z) \geq 0$ and thus $\Psi_1(z;\underline{z},\overline{z}) \leq \Psi_1(\overline{z};\underline{z},\overline{z})$ for $z \in [\underline{z},\overline{z}]$ and (ii) $\Psi_1(\overline{z};\underline{z},\overline{z}) = -(\overline{z}-\underline{z})^2 < 0$. Thus, property (iv) is fulfilled.

Next, consider the asymmetric Beta distribution characterised by the density function $F'(z) = \frac{(\overline{z}-z)^{\beta-1}}{\int_{\underline{z}}^{\overline{z}}(\overline{z}-k)^{\beta-1}dk}$, with $\beta > 1$. Then, $F''(z) = -\frac{\beta-1}{\overline{z}-z}F'(z)$ and $1-F(z) = \frac{\overline{z}-z}{\beta}F'(z)$. Using these terms, we find that $F''(z) > -2\frac{(F'(z))^2}{1-F(z)} \Leftrightarrow \beta > -1$. Also, $F''(z) < 2\frac{(F'(z))^2}{F(z)}$ is satisfied because $F''(z) < 0$ for $\beta > 1$ and $F(z), F'(z) > 0$. Again, property (iv) is fulfilled.

Similarly, this property is satisfied in the case of the asymmetric density function $F'(z) = \frac{(z-\underline{z})^{\beta-1}}{\int_{\underline{z}}^{\overline{z}}(k-\underline{z})^{\beta-1}dk}$, with $\beta > 1$. Moreover, putting $\beta = 1$ gives the uniform distribution as a special case of the Beta distribution. Again, property (iv) is certainly fulfilled because then $F''(z) = 0$.

Proof of Proposition 3 As the elasticity ε, $\varepsilon = U'(z_h)z_h/U(z_h)$, is constant, we have

$$\frac{\partial\varepsilon}{\partial z} = 0 \quad \Leftrightarrow \quad 1-\varepsilon = -\frac{U''(z_i)\,z_i}{U'(z_i)} = \frac{1}{\sigma}, \tag{35}$$

which is frequently used in the following calculations.

A household is indifferent between good H and good L if and only if $\eta U(z_H) - p_H - t(\overline{e}-e_H)z_H = \eta U(z_H) - p_L - t(\overline{e}-e_L)z_L$, where z_H (z_L) denotes the optimal consumption intensity if the household under consideration has purchased good

H (L). Reformulating this indifference condition gives the threshold level $\widetilde{\eta}$ (cf. threshold value (3)):

$$\widetilde{\eta} = \frac{\sigma (p_H - p_L)}{[U(z_H) - U(z_L)]}, \tag{36}$$

where the first order condition (21) and the elasticity condition (35) are used.

Maximising profits (4) in the second stage yields to the equilibrium prices

$$p_H = [U(z_H) - U(z_L)] \frac{1 - F(\widetilde{\eta})}{F'(\widetilde{\eta})} \quad \text{and} \quad p_L = [U(z_H) - U(z_L)] \frac{F(\widetilde{\eta})}{F'(\widetilde{\eta})}, \tag{37}$$

where we have used $d\widetilde{\eta}/dp_H = 1/[U(z_H) - U(z_L)] = -d\widetilde{\eta}/dp_L$, which follows from (36). (Note that first order condition (21) implies $\partial z_H/\partial p_i = \partial z_L/\partial p_i = 0$). Inserting (37) into (36), we can implicitly determine the equilibrium threshold level

$$\widetilde{\eta} = \sigma \frac{1 - 2F(\widetilde{\eta})}{F'(\widetilde{\eta})}. \tag{38}$$

The equilibrium threshold is independent of the political decisions, as its counterpart (6) is in the basic model.

Equilibrium prices (37) and threshold (38) imply that, for given efficiency levels e_H and e_L,

$$\frac{\partial p_H}{\partial \tau} = \frac{1-\sigma}{1+\tau} [U(z_H) - U(z_L)] \frac{1 - F(\widetilde{\eta})}{F'(\widetilde{\eta})} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr 1, \tag{39}$$

$$\frac{\partial p_L}{\partial \tau} = \frac{1-\sigma}{1+\tau} [U(z_H) - U(z_L)] \frac{F(\widetilde{\eta})}{F'(\widetilde{\eta})} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr 1, \tag{40}$$

where again (35) is used. The inequality signs follow from $U(z_H) > U(z_L)$ (because $z_H > z_L$, which in turn follows from the first order condition (21)) and $0 < 1 - F(\widetilde{\eta}) < 1$ (recall that $1 - 2F(\widetilde{\eta}) > 0$—otherwise $p_L > p_H$ would hold, which cannot be an equilibrium). In addition, condition (37) implies

$$\frac{\partial p_H}{\partial e_H} = U'(z_H) \frac{\partial z_H}{\partial e_H} \frac{1 - F(\widetilde{\eta})}{F'(\widetilde{\eta})} > 0, \tag{41}$$

$$\frac{\partial p_L}{\partial e_H} = U'(z_H) \frac{\partial z_H}{\partial e_H} \frac{F(\widetilde{\eta})}{F'(\widetilde{\eta})} > 0, \tag{42}$$

where $\partial z_H/\partial e_H > 0$ directly follows from (21).

The energy efficiency of good L is again identical to the environmental standard (i.e., $e_L = e_{min}$), and the energy efficiency of good H is characterised by the first order condition

$$\frac{\partial \pi_H}{\partial e_H} = 0 \quad \Leftrightarrow \quad \frac{\partial a_H}{\partial e_H} = c z_H \frac{(1+\tau)}{(1-s)} \frac{[1 - F(\widetilde{\eta})]^2}{[1 - 2F(\widetilde{\eta})]}, \tag{43}$$

where we have used (41), $\partial z_H/\partial e_H = -t/\left[\widetilde{\eta}U''(z_H)\right]$ (which follows from (21)), and (38). Then, comparative statics shows that

$$\frac{\partial e_H}{\partial \tau} \gtreqless 0 \quad \Leftrightarrow \quad \frac{\partial^2 \pi_H}{\partial e_H \partial \tau} = (1-\sigma)\, c z_H \frac{\left[1-F(\widetilde{\eta})\right]^2}{\left[1-2F(\widetilde{\eta})\right]} \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr 1 \tag{44}$$

The effects of a higher energy tax on profits are given by

$$\frac{d\pi_H}{d\tau} = \frac{\partial p_H}{\partial \tau}\left[1-F(\widetilde{\eta})\right] \gtreqless 0 \quad \Leftrightarrow \quad \sigma \lesseqgtr 1 \tag{45}$$

$$\frac{d\pi_L}{d\tau} = \frac{\partial p_L}{\partial \tau} F(\widetilde{\eta}) + \frac{\partial p_L}{\partial e_H}\frac{\partial e_H}{\partial \tau} F(\widetilde{\eta}) \quad \Leftrightarrow \quad \sigma \lesseqgtr 1, \tag{46}$$

where the inequality signs follow from (39), (40), (42), (43), and (44). These inequality signs prove the relationship between profits and the energy tax. Not surprisingly, a higher subsidy increases profits:

$$\frac{d\pi_H}{ds} = a_H > 0 \quad \text{and} \quad \frac{d\pi_L}{ds} = \frac{\partial p_L}{\partial e_H}\frac{\partial e_H}{\partial s} F(\widetilde{\eta}) + a_L > 0, \tag{47}$$

where we make use of (42), (43), and $\partial e_H/\partial s > 0$, which follows from (43).

Three Firms All assumptions outlined in Section 2 still apply, but there are now three firms, H, M and L. Without loss of generality, we assume $e_H > e_M > e_L$. Denote by $\widetilde{z}_1$ ($\widetilde{z}_2$) the consumption intensity that characterises the household who is indifferent between good L and M (M and H).

In this extended model, the equilibrium prices are given by

$$p_H = (1+\tau)\, c\,(e_H - e_M)\frac{1-F(\widetilde{z}_2)}{F'(\widetilde{z}_2)}, \quad p_L = (1+\tau)\, c\,(e_M - e_L)\frac{F(\widetilde{z}_1)}{F'(\widetilde{z}_1)}, \tag{48}$$

$$p_M = (1+\tau)\, c\frac{(e_H - e_M)(e_M - e_L)\left[F(\widetilde{z}_2) - F(\widetilde{z}_1)\right]}{F'(\widetilde{z}_2)(e_M - e_L) + F'(\widetilde{z}_1)(e_H - e_M)}. \tag{49}$$

The threshold levels are implicitly determined by

$$\widetilde{z}_1 = \frac{(e_H - e_M)\left[F(\widetilde{z}_2) - F(\widetilde{z}_1)\right]}{(e_H - e_M) F'(\widetilde{z}_1) + (e_M - e_L) F'(\widetilde{z}_2)} - \frac{F(\widetilde{z}_1)}{F'(\widetilde{z}_1)} \tag{50}$$

$$\widetilde{z}_2 = \frac{1-F(\widetilde{z}_2)}{F'(\widetilde{z}_2)} - \frac{(e_M - e_L)\left[F(\widetilde{z}_2) - F(\widetilde{z}_1)\right]}{(e_H - e_M) F'(\widetilde{z}_1) + (e_M - e_L) F'(\widetilde{z}_2)} \tag{51}$$

Finally, the profit-maximising energy efficiency levels are given by the first order conditions

$$\frac{\partial a_i}{\partial e_i} = \frac{(1+\tau)}{(1-s)} c\Gamma_i(e_L, e_M, e_H), \tag{52}$$

where Γ_i is a function of the energy efficiency levels e_H, e_M and e_L, but this function does not directly depend on the policy variables τ and s. Thus, these first order conditions imply that there are sets of ee-equivalent tax-subsidy bundles (i.e., these bundles satisfy condition (13)), which induce the same energy efficiency levels e_H, e_M and e_L. Such ee-equivalent policy bundles also lead to the same threshold levels $\widetilde{z}_1$ and $\widetilde{z}_2$ as well as the same environmental damage level. Therefore, the proof of Proposition 1 can be replicated without complications for the case of three firms. (Note that in the case of a binding standard $e_{min} = e_L$, the first order condition (52) is obviously not relevant for firm L. However, this does not affect the further line of reasoning.)

Shadow Costs of Public Funds Let us take the shadow costs λ of public funds into account. Then, welfare (1) is given by

$$W = (2\alpha - 1)(\pi_H + \pi_L) + (1 - \alpha)\left[x - (1 - \lambda\tau) cE - D(E) - (1 + \lambda s)(a_H + a_L)\right]. \tag{53}$$

We consider two ee-equivalent tax-subsidy bundles (τ_1, s_1) and (τ_2, s_2) and follow along the lines of the proof of Proposition 1 (see above), yielding

$$W(\tau_1, s_1, e_{min}) \gtreqless W(\tau_2, s_2, e_{min}) \tag{54}$$

$$\Leftrightarrow (s_1 - s_2)\left\{(1 - 2\alpha)\underbrace{\left[\frac{1+\tau_1}{1-s_1}c(e_H - e_L)\frac{(1-F)^2 + F^2}{F'} - a_H - a_L\right]}_{\Upsilon :=} - \lambda(1-\alpha)\underbrace{\left(\frac{1+\tau_1}{1-s_1}cE + a_H + a_L\right)}_{\Theta :=}\right\} \gtreqless 0 \tag{55}$$

$$\Leftrightarrow s_1 - s_2 \begin{cases} \gtreqless 0 & \text{for} \quad \alpha < \frac{\lambda\Theta - \Upsilon}{\lambda\Theta - 2\Upsilon} =: \widetilde{\alpha} \\ \lesseqgtr 0 & \text{for} \quad \alpha > \frac{\lambda\Theta - \Upsilon}{\lambda\Theta - 2\Upsilon} =: \widetilde{\alpha} \end{cases}, \tag{56}$$

where Υ and Θ are independent of α and λ, as α and λ do not affect the sets of ee-equivalent tax-subsidy bundles. To derive inequality (56), we use the facts that $\Xi := (1 - 2\alpha)\Upsilon - \lambda(1 - \alpha)\Theta = 0$ for $\alpha = \widetilde{\alpha}$ and $\partial\Xi/\partial\alpha|_{\alpha=\widetilde{\alpha}} = -\Upsilon/(1 - \widetilde{\alpha}) < 0$, implying $\Xi \gtreqless 0 \Leftrightarrow \alpha \lesseqgtr \widetilde{\alpha}$. Inequality (56) implies that for $\alpha < \widetilde{\alpha}$, $W(0, s_1, e_{min}) > W(\tau_2, s_2, e_{min}) \Leftrightarrow s_1 - s_2 > 0$; thus, the government prefers a subsidy (and no tax), i.e., the bundle $(\tau_1, s_1) = (0, s_1)$, to every ee-equivalent tax-subsidy bundle (τ_2, s_2). Conversely, for $\alpha > \widetilde{\alpha}$, $W(\tau_1, 0, e_{min}) > W(\tau_2, s_2, e_{min}) \Leftrightarrow s_1 - s_2 < 0$; thus, the government prefers an energy tax (and no subsidy), i.e., the bundle $(\tau_1, s_1) = (\tau_1, 0)$, to every ee-equivalent tax-subsidy bundle (τ_2, s_2). Furthermore, $\widetilde{\alpha} = 1/2$ for $\lambda = 0$ and $\partial\widetilde{\alpha}/\partial\lambda < 0$ establish that the cutoff value $\widetilde{\alpha}$ is smaller than 1/2 (the parameter value of a neutral government) if the shadow cost parameter λ is positive.

References

Arora, S., and Gangopadhyay, S. (1995), Toward a Theoretical Model of Voluntary Overcompliance, *Journal of Economic Behavior and Organization* 28, 289-309.

Austin, D., and Dinan, T. (2005), Clearing the Air: The Costs and Consequences of Higher CAFE Standards and Increased Gasoline Taxes, *Journal of Environmental Economics and Management* 50, 562-582.

Bansal, S. (2008), Choice and Design of Regulatory Instruments in the Presence of Green Consumers, *Resource and Energy Economics* 30, 345-368.

Bansal, S., and Gangopadhyay, S. (2003), Tax/Subsidy Policies in the Presence of Environmentally Aware Consumers, *Journal of Environmental Economics and Management* 45, 333-355.

Bureau, B. (2011), Distributional Effects of a Carbon Tax on Car Fuels in France, *Energy Economics* 33, 121-130.

Crampes, C., and Hollander, A. (1995), Duopoly and Quality Standards, *European Economic Review* 39, 71-82.

Cremer, H., and Thisse, J.-F. (1994), Commodity Taxation in a Differentiated Oligopoly, *International Economic Review* 35, 613-633.

Cremer, H., and Thisse, J.-F. (1999), On the Taxation of Polluting Products in a Differentiated Industry, *European Economic Review* 43, 575-594.

Eriksson, C. (2004), Can Green Consumerism Replace Environmental Regulation? A Differentiated-Products Example, *Resource and Energy Economics* 26, 281-293.

Espey, J. A., and Espey, M. (2004), Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities, *Journal of Agricultural and Applied Economics* 36, 65-81.

EU (2005), Directive 2005/32/EC of the European Parliament and of the Council, *Official Journal of the European Union* L 191, 29-58.

Faberi, S., Esposito, R., Mebane, W., Scialdino, R., Stamminger, R. (2007), Preparartory Studies for Eco-Design Requirements of EuPs. Lot 14: Domestic Washing Machines and Dishwashers. Task 1 and 2, ISIS, ENEA, and University of Bonn.

Fraunhofer IZM (2007), Preparatory Studies for Eco-Design Requirements of EuPs. Lot 5: Televisions, Task 7, Fraunhofer Institute for Reliability and Microintegration, IZM, Berlin.

Gabszewicz, J. J., and Thisse, J.-F. (1979), Price Competition, Quality and Income Disparities, *Journal of Economic Theory* 20, 340-359.

Gillingham, K., Newell, R.G., Palmer, K. (2009), Energy Efficiency Economics and Policy, *Annual Review of Resource Economics* 1, 597-620.

Goodwin, P., Dargay, J., and Hanly, M. (2004), Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review, *Transport Reviews* 24, 275-292.

Haupt, A., and Stadejek, M. (2011), The Choice of Environmental Policy Instruments and Energy Efficiency: Consumers versus Firms, Working Paper, University of Plymouth.

Hughes, J. E., Knittel, C. R., and Sperling, D. (2008), Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand, *Energy Journal* 29, 113-134.

IEA (2003), Cool Appliances. Policy Strategies for Energy Efficient Homes, Paris.

Laffont, J.-J., and Tirole, J. (1996), Pollution Permits and Environmental Innovation, *Journal of Public Economics* 62, 127-140.

Lombardini-Riipinen, C. (2005), Optimal Tax Policy and Environmental Quality Competition, *Environmental and Resource Economics* 32, 317-336.

METI (2010), Top Runner Program. Developing the World's best Energy-Efficient Appliances, Ministry of Economy, Trade and Industry, Tokyo.

Moraga-González, J. L., and Padrón-Fumero, N. (2002), Environmental Policy in a Green Market, *Environmental and Resource Economics* 22, 419-447.

Newell, R. G., Jaffe, A. B., and Stavins. R. N. (1999), The Induced Innovation Hypothesis and Energy-Saving Technological Change, *Quarterly Journal of Economics* 114, 941-975.

OECD (2006), The Political Economy of Environmentally Related Taxes, Paris.

OECD (2008), Household Behaviour and the Environment. Reviewing the Evidence, OECD, Paris.

Peltzman, S. (1976), Towards a More General Theory of Regulation, *Journal of Law and Economics* 19, 211-240.

Rauscher, M. (1997), International Trade, Factor Movements, and the Environment, Oxford: Oxford University Press.

Reiss, P. C., and White, M. W. (2005), Household Electricity Demand, Revisited, *Review of Economic Studies* 72, 853-883.

Rodriguez-Ibeas, R. (2007), Environmental Product Differentiation and Environmental Awareness, *Environmental and Resource Economics* 36, 237-254.

Ronnen, U. (1991), Minimum Quality Standard, Fixed Costs, and Competition, *Rand Journal of Economics* 22, 490-504.

Rosenfeld, A., McAuliffe, P., and Wilson, J. (2004), Energy Efficiency and Climate Change, in: C.J. Cutler et al. (eds.), Encyclopedia of Energy, Vol. 2, 373-382.

Shaked, A., and Sutton, J. (1982), Relaxing Price Competition Through Product Differentiation, *Review of Economic Studies* 49, 3-13.

Small, K. A., Van Dender, K. (2007), Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect, *Energy Journal* 28, 25-51.

Wei, T. (2010), A General Equilibrium View of Global Rebound Effects, *Energy Economics* 32, 661-672.