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Green Consumers, Emission Taxes, and Firm Relocation

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Abstract

This paper studies the interaction of environmental policy and green preferences under potential firm relocation. A green firm and a brown firm choose the environmental quality of their products. Both an emission tax and consumers' willingness to pay for green products encourage investment in environmental quality. Firms may relocate to avoid taxation or abstain from investment in environmental quality to produce at lower cost.

If the green firm does not relocate, both the green firm and the brown firm provide higher quality levels. Compared to first-best taxation, the equilibrium emission tax is lower (higher) if only the brown (green) firm relocates.

JEL Classification: H23, F18, L13, Q58

Keywords: environmental policy, emission tax, green consumers, relocation

1 Introduction

Production typically generates emissions that are harmful for the environment such as local pollutants or greenhouse gases. Emission levels per unit are not exogenously given but firms may decide to produce in greener or browner ways, i.e. reduce emission levels by increasing environmental quality of products. For instance, firms can use end-of pipe technologies to reduce production emissions or increase energy efficiency by changing the production process to decrease energy-related emissions.

Firms face two sources of incentives to invest in green or environmentally friendly products. A private incentive arises from consumers' willingness to pay for greener

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products. For instance, in the European Union, 94% of citizens believe that protecting the environment is important (European Commission, 2017)¹ and 87% agree that their behavior is important in doing so (European Commission, 2017)². This provides an incentive for firms to offer products with green characteristics, e.g., products that have been made from recycled material or by using renewable energy etc. A public incentive arises from governments' environmental policy such as emission taxes, cap and trade systems, emission standards etc. For instance, an emission tax is typically not only meant to reduce quantities on markets, but also to encourage innovation to increase the environmental quality of production and/or products.

Firms do not necessarily decide to follow these incentives and produce greener products. They may either decide to skim-off the higher willingness to pay of consumers and produce greener products or they may decide to produce at lower cost using less environmental friendly technologies. Especially in a duopoly, firms have an incentive to differentiate products to weaken competition (e.g. Shaked & Sutton, 1982). This is, if one firm provides green products, it may pay-off for the other firm to provide brown goods. Also an emission tax does not necessarily result in greener products if firms have the possibility to relocate to another country to avoid emission taxes. Globalization has made it easier for firms to move production sites to countries with less stringent environmental policy. This has resulted in an intensified competition between governments for mobile firms which may result in a race to the bottom and less stringent environmental policy. This is known as the pollution haven hypothesis (e.g. Sturm, 2003; Rauscher, 2005 for surveys).

Against this background, the paper studies the interaction of environmental policy and green preferences under potential firm relocation. A green firm and a brown firm choose the environmental quality of their products. Both an emission tax and consumers' willingness to pay for green products encourage investment in environmental quality. Firms may relocate to avoid taxation or abstain from investment in environmental quality to produce at lower cost.

Although private and public incentives point in the same direction, the interaction of both kinds of incentives may be not obvious and the combined effect on environmental quality is worth a closer look. In this setting, the interaction of environmental policy, green preferences, choice of product quality, and location decision may be complex.

The effect of environmental policy on environmental outcomes depends on the strin-

¹56% of respondents state that protecting the environment is very important, 38% answer that it is fairly important.

²45% of respondents totally agree that they can play a role in protecting the environment, 42% state that they tend to agree..

gency of environmental policy and on who is actually subject to environmental regulation. So far, the literature has focussed on the effect of environmental regulation on environmental quality if firms have the possibility to avoid being regulated by relocating. In our analysis, we add an additional dimension to this by studying the impact of relocation on environmental quality choices of firms. The limits of environmental regulation therefore do not only depend on firms avoiding being regulated by relocation, but also on the resulting quality decisions by firms. Relocation incentives differ between green firms and brown firms. While green firms try to skim-off the higher willingness to pay for green products, brown firms focus on producing at lower cost. Therefore, brown firms may have a stronger incentive to relocate. At the same time, competition between firms depends on product differentiation which is affected by location choices. Via this channel, environmental policy affects the degree of competition between firms.

We show that relocation decisions resulting from the emission tax have an impact on quality levels of both firms. If the green firm does not relocate, both the green firm and the brown firm provide products with higher environmental quality levels. At the same time, if the green firm does not relocate but the brown firm does, the quality difference is highest, implying that competition between firms is weakest. Welfare-maximizing environmental policy changes with firm relocation: Compared to first-best taxation, the equilibrium emission tax is lower (higher) if only the brown (green) firm relocates.

Our paper is closely related to two strands of literature. The first strand studies the effect of environmental policy in the presence of green consumers. The effect of environmental policy in the presence of green consumers in a vertical duopoly has been studied by Moraga-González & Padrón-Fumero (2002). They demonstrate that the success of a unit emission standard to increase the per unit environmental quality of products may be overcompensated by the reduced quality differentiation between products that results in fiercer price competition and higher quantities. Also Lombardini-Riipinen (2005) analyzes optimal environmental taxation in a vertically differentiated duopoly in the presence of green consumers. Bansal (2008) studies the effect of optimal environmental policy instruments in a duopoly model with vertical quality differentiation in the presence of green consumers. She finds that an ad valorem subsidy may reduce pollution. Brécard (2013) analyzes the effect of a green network effect, which increases utility received by environment-friendly products if the number of green consumers increases. In this model, the green network effect may lower the environmental quality of products. The government may improve welfare by introducing environmental taxes and/ or subsidies. Chandra & Muthukrishnan (2015) study the effect of collective action organized by green consumers. They show that collective action by green consumers may be a

substitute for pollution taxes or subsidies for pollution reductions. Ambec & De Donder (2019) analyze the combined impact of environmental policy and green preferences of consumers. They show that green preferences may weaken environmental protection and that in the presence of green consumers, command-and-control instruments achieve better results than market-based instruments.

What all these papers do abstract from is the possibility of firms to sidestep government interventions by relocating to another country. Relocation decisions are analyzed in a second strand of the literature. The pollution haven hypothesis states that firms prefer to produce in countries with less stringent environmental standards because this allows them to produce at lower cost.

Motta & Thisse (1994) show that strict environmental policy might result in a relocation of domestic firms. Rauscher (1995), however, shows that international tax competition for environmental taxes can result in tax rates that are either too low or too high from a welfare perspective. Markusen et al. (1996) show in a model with two regions and two firms that optimal environmental policy in an open economy where firms decide on their location differs from the closed economy setting. In their setting, small changes in environmental policy may result in firm relocation and large changes in welfare. Greaker (2003) shows that the possibility of firms to relocate might result in stricter environmental regulation. Petrakis & Xepapadeas (2003) study the relocation decisions of a monopolist when the government taxes its emissions. They show that location equilibria differ in the case when the government is pre-committed to its policy and when the government follows a time-consistent path. Pre-committment is not always welfare-improving. Ikefuji et al. (2016) analyze the effect of an emission tax in a duopoly with endogenous location choice when firms provide a homogeneous good. They show that in a Cournot duopoly under an optimal pre-committed environmental tax, relocation decisions of firms depend on tax rates in a non-monotonic way. Their results may explain why the pollution haven hypothesis is not unambiguously supported by empirical studies. Birg & Voßwinkel (2018) extend the analysis of an environmental tax in a duopoly with endogenous location choice by considering (exogenous) vertical quality differences.

The rest of the paper is organized as follows: The next section presents the set-up of the model. Section 3 analyzes price competition and the choice of quality levels. Section 4 studies the location decision of firms. Section 5 analyzes environmental policy. Section 6 concludes.

2 The Model

Consider two countries, $j = H, F$, Home and Foreign. In country H , two firms $i = g, b$, "green" and "brown", sell a product at endogenously chosen quality levels s_g, s_b , with $s_g > s_b$. No output market exists in country F .

Consumers are heterogeneous with respect to their quality preference θ , which is uniformly distributed on the interval $[a, b]$, with $b = a + 1$. Utility from no purchase is zero, utility from a purchase is $U = \theta s_i - p_i$, $i = g, b$. We assume a covered market. The marginal consumer, who is indifferent between buying one of the two products is characterized by the preference parameter $\hat{\theta} = \frac{p_g - p_b}{s_g - s_b}$. Demand for each firms is therefore given by $q_g = b - \hat{\theta}$, $q_b = \hat{\theta} - a$.

Production of both firms generates ex-ante identical per-unit emissions E . Both firms may invest in environmental quality to reduce per-unit emissions to $E - s_i$ ³. These quality improvements increase variable cost of production according to $C(s_i, q_i) = \frac{1}{2}s_i^2 q_i$.

In country H , the government may impose an emission tax rate t per unit of emissions. Each firm can relocate to country F where no tax is imposed. Relocation comes at a fixed cost ϕ .

The timing of the game is as follows: In the first stage, the government in H commits to an emission tax. In the second stage, firms decide simultaneously whether to relocate to F or not. In the third stage, firms choose quality levels. In the fourth stage, firms compete in prices. We solve the game by backward induction.

3 Price Competition and Quality Choice

Four location equilibria are possible and analyzed in this and the following sections:

- HH : Both firms stay in H .
Firms' profits are $\pi_g = (p_g - \frac{1}{2}s_g^2 - t(E - s_g)) q_g$ and $\pi_b = (p_b - \frac{1}{2}s_b^2 - t(E - s_b)) q_b$.
- HF : The green firm remains in H , the brown firm relocates to F .
Firms' profits are $\pi_g = (p_g - \frac{1}{2}s_g^2 - t(E - s_g)) q_g$ and $\pi_b = (p_b - \frac{1}{2}s_b^2) q_b - \phi$.
- FH : The green firm relocates to F , the brown firm stays in H .
Firms' profits are $\pi_g = (p_g - \frac{1}{2}s_g^2) q_g - \phi$ and $\pi_b = (p_b - \frac{1}{2}s_b^2 - t(E - s_b)) q_b$.

³ Assume that emissions are sufficiently high in all location equilibria so that ex-ante emissions exceed the quality level of the green firm ($E > \bar{E}$ i.e. $E > s_g$, see Appendix). This is, in equilibrium, investment in environmental quality does not eliminate all emissions associated with the product.

- FF : Both firms relocate to F .

Firms' profits are $\pi_g = (p_g - \frac{1}{2}s_g^2) q_g - \phi$ and $\pi_b = (p_b - \frac{1}{2}s_b^2) q_b - \phi$.

In the following sections, all four possible location equilibria are analyzed.

In the last stage, firms compete in prices, given the emission tax set by the government in H , the relocation decisions of both firms and the chosen quality levels of both firms (equilibrium prices can be found in Appendix A1).

In the third stage, firms choose quality levels. The environmental tax set in the first stage affects quality choice in two ways. The tax directly affects the quality choice, because a higher quality reduces the tax burden. But the environmental tax also affects the location of both firms, which in turn affects quality choices. If both firms are located in the same country, they are affected symmetrically by the emission tax (or the absence of an emission tax). If only one firm relocates, it has a cost advantage over the other firm. In addition, it has no direct incentive to increase the environmental quality of the good from the emission tax. Given that firms have an incentive to differentiate quality levels, quality level of both firms are affected also if only one firm relocates.

The green firm chooses different quality levels in equilibrium depending on the four different location equilibria. The ranking of quality levels is as follows: $s_g^{FH} < s_g^{FF} < s_g^{HH} < s_g^{HF}$ (see Appendix). The green firm chooses the highest quality levels, if it does not relocate to F . If the green firm stays in country H , it has two incentives to increase the quality level. First, by increasing the quality, it reduces pollution and thereby the emission tax. Second, because production in H is more costly than production in F , it has a higher incentive to offer a higher product quality and increase market power from quality differentiation. This incentive is strongest, if the brown firm produces in F without having to pay the tax. The incentive to provide higher quality is the weakest if the green firm has not to pay emission taxes in F , while the brown firm produces in H under the emission tax.

The quality ranking of the brown firm is also dependent on location equilibria, but, in addition, it also depends also on critical ex ante emission levels and tax rates. Irrespective of these critical values, the brown firm always offers higher quality levels, if the green firm does not relocate. Here, the effect of optimal quality differentiation dominates all other effects. If the green firm stays in H , it chooses the highest quality level. Optimal quality differentiation then results also in a high quality level of the brown firm.

Apart from this effect, the precise quality ranking of the brown firm depends on critical cut-off values for ex ante emissions and the tax rate. If ex ante emissions are sufficiently low and the emission tax rate is also sufficiently low ($\tilde{E} < E < E_{s_b}^{FH,FF} \wedge t <$

$\frac{1}{4}$), the quality ranking of the brown firm is $s_b^{FF} < s_b^{FH} < s_b^{HF} < s_b^{HH}$ (cut-off values can be found in the Appendix).

If ex ante emissions are sufficiently high but below a critical level and the tax rate is sufficiently low ($\widetilde{E_{s_b^{FH,FF}}} < E < \widetilde{E_{s_b^{HH,HF}}} \wedge t < \frac{1}{4}$) or if emissions are sufficiently low and the tax rate is within a critical interval ($\widetilde{E} < E < \widetilde{E_{s_b^{HH,HF}}} \wedge \frac{1}{4} < t < \frac{3}{4}\sqrt{2} - \frac{3}{4}$) or if emissions are within (another) critical interval and the tax rate is sufficiently high ($\widetilde{E} < E < \overline{E_{FH,b}} \wedge t > \frac{3}{4}\sqrt{2} - \frac{3}{4}$), the quality ranking of the brown firm is $s_b^{FH} < s_b^{FF} < s_b^{HF} < s_b^{HH}$. If the emissions are sufficiently high but below a critical threshold and if the tax rate is sufficiently low ($\widetilde{E_{s_b^{HH,HF}}} < E < \overline{E_{FH,b}} \wedge t < \frac{1}{4}$) or if emissions are sufficiently low and the tax rate is sufficiently high ($\widetilde{E} < E < \overline{E_{FH,b}} \wedge t > \frac{3}{4}\sqrt{2} - \frac{3}{4}$) the ranking of quality levels is $s_b^{FH} < s_b^{FF} < s_b^{HH} < s_b^{HF}$.

Depending on the location equilibria, firms choose quality levels to provide sufficiently differentiated quality levels in order to lessen the intensity of price competition. Quality differences are identical in the symmetric cases, i.e. if both firms are located in the same country ($\Delta s^{HH} = s_g^{HH} - s_b^{HH} = \Delta s^{FF} = s_g^{FF} - s_b^{FF} = \frac{3}{2}$). If the green firm stays in H and the brown firm relocates to F , the equilibrium quality difference is $\Delta s^{HF} = \frac{3}{2} + t$. The brown firm does not have to pay the emission tax while the green firm has to, therefore the brown firm has a lower incentive to increase its quality level. If the green firm relocates to F and the brown firm stays in H , the quality difference declines, as the brown firm has to pay the emission tax and has an additional incentive to reduce emissions (increase quality) in order to keep the profit-maximizing quality difference, while the green firm does not have to pay the emission tax ($\Delta s^{FH} = \frac{3}{2} - t$).

4 Location Decision

Consider that emissions are sufficiently high in all location equilibria so that ex ante emissions exceed the quality level of the green firm ($E > \widetilde{E}$ i.e. $E > s_g$, see Appendix). By this assumption, we avoid restrictions in quality choice for the green firm.

Location decisions depend on relocation cost ϕ and the environmental tax rate t . Different combinations of relocation cost and the tax rate result in one of the four possible location equilibria: HH, HF, FH, and FF.

For low or intermediate tax rates and low or intermediate levels of ex ante emissions ($t < \underline{t} \wedge \widetilde{E} < E < \overline{E_{FH}}$ or $\underline{t} < t < \widetilde{t_{HH}} \wedge \widetilde{E} < E < \overline{E_{HH}}$) the following location equilibria hold (cut-off values can be found in the Appendix). If relocation cost are sufficiently low ($\phi < \phi_{FF}$), both firms relocate to F (FF). If relocation cost exceed a critical threshold,

the green firm stays in H , but the brown firm relocates to F . The brown firm has a higher incentive to relocate to F , because given its lower quality level, avoiding the emission tax is more profitable for the brown firm than for the green firm. If the brown firm relocates, it offers a lower quality (because it does not have to pay the emission tax). Thereby product differentiation and market power of the green firm increases. For sufficiently high relocation cost, this benefit outweighs the benefit of lower taxes in F from the perspective of the green firm. Therefore, it stays in H .

If relocation cost is sufficiently high, the tax saving is not sufficiently high to outweigh relocation cost, therefore both firms remain in H ($\phi_{HH,b} < \phi$: HH).

If the tax rate is sufficiently low and below a critical threshold and also ex ante emissions are below a critical threshold ($\underline{t} < t < \widetilde{t}_{HH} \wedge \overline{E}_{HH} < E < \overline{E}_{FH}$), or $\widetilde{t}_{HH} < t < \widetilde{t}_{FH} \wedge \widetilde{E} < E < \overline{E}_{FH}$ both firms relocate to F (FF) if relocation cost is sufficiently low ($\phi < \phi_{FF}$). If relocation cost is higher than the low threshold, where both firms relocate to F , ϕ_{FF} , but between critical threshold levels ($\phi_{FF} = \underline{\phi}_{HF} < \phi < \underline{\phi}_{FH}$), the green firm stays in H and the brown firm relocates to F (HF). If relocation cost is higher than $\overline{\phi}_{HF}$ but lower than the critical threshold $\phi_{HH,b}$, no location equilibrium exists in pure strategies. If relocation cost is sufficiently high ($\phi_{HH,b} < \phi$), both firms remain in H (HH).

If the tax rate is sufficiently low and ex ante emissions are between critical values ($t < \underline{t} \wedge \overline{E}_{HH} < E < \overline{E}_{FH,b}$, $\underline{t} < t < \widetilde{t}_{HH} \wedge \overline{E}_{FH} < E < \overline{E}_{FH,b}$, $\widetilde{t}_{HH} < t < \widetilde{t}_{FH} \wedge E_{FH} < E < \overline{E}_{FH,b}$, $\widetilde{t}_{FH} < t < \frac{3}{8}\sqrt{17} - \frac{9}{8} \wedge \widetilde{E} < E < \overline{E}_{FH,b}$), location equilibria are the following: Both firms relocate (FF) if relocation cost is sufficiently low ($\phi < \phi_{FF}$). If relocation cost is higher than this threshold, but sufficiently low ($\phi_{FF} = \underline{\phi}_{HF} < \phi < \underline{\phi}_{FH}$), the green firm stays in H and the brown firm relocates to F (HF). If relocation cost exceeds a critical threshold but is below another threshold level, where only one firm relocates ($\underline{\phi}_{FH} < \phi < \overline{\phi}_{HF}$), two equilibria exists, HF and FH . If relocation cost exceeds the next threshold but is still sufficiently low ($\overline{\phi}_{HF} < \phi < \overline{\phi}_{FH} = \phi_{HH,g}$), the green firm relocates to F and the brown firm stays in H (FH). If relocation cost is sufficiently high ($\phi_{HH,b} < \phi$), both firms stay in H (HH).

5 Environmental Policy

Consider that the government in H introduces an emission tax to maximize local welfare which is given as consumer surplus plus firms' profit for all firms located in H plus tax revenue minus environmental damage of emissions from all firms located in H . The government commits to the emission tax in the first stage, anticipating firms' reactions

in the following stages. In the following, we present optimal emission tax rates for all four location equilibria. Firms' location decisions affect welfare in three ways: via profits, tax revenue, and environmental damage. Relocation of a firm decreases profits and tax revenue, but at the same time environmental damage.

HH: If both firms stay in the home country, social welfare is given as

$$W_{HH} = CS_g + CS_b + \pi_g + \pi_b + t((E - s_g)q_g + (E - s_b)q_b) - \delta((E - s_g)q_g + (E - s_b)q_b).$$

If both firms remain in H (equilibrium HH), both firms have to pay the tax. The optimal tax rate is the first best tax rate equal to marginal damage ($t_{HH} = \delta$).

HF: In equilibrium HF , social welfare is

$$W_{HF} = CS_g + CS_b + \pi_g + t(E - s_g)q_g - \delta(E - s_g)q_g.$$

The optimal tax rate is lower than in the first best case. The intuition is that if the green firm stays in H and brown firm relocates to F , tax revenue and reduction in environmental damage caused by the tax after the brown firm has relocated, is lower compared to the HH -equilibrium ($t_{HF} < t_{HH}$). In addition, the green firm increases its quality level to increase market power. Thereby, it reduces environmental damage.

FH: In equilibrium FH , social welfare is

$$W_{FH} = CS_g + CS_b + \pi_b + t(E - s_b)q_b - \delta(E - s_b)q_b.$$

The optimal tax rate is higher than in the HH -equilibrium ($t_{FH} > t_{HH}$). If the green firm relocates to F and the brown firm stays in H , both firms offer a lower quality than in the HH -equilibrium. Since the brown firm produces in H , per-unit emissions are higher than in the cases HH and HF . Therefore a higher tax rate is needed to internalize environmental damage.

6 Conclusion

This paper has studied the interaction of environmental policy and green preferences under potential firm relocation. A green firm and a brown firm choose the environmental quality of their products while an emission tax and consumers' willingness to pay for green products encourage investment in environmentally friendly products.

Environmental quality of products is determined by two channels, the emission tax and firm relocation. If the green firm does not relocate, both the green firm and the

brown firm provide higher quality levels. If the green firm does not relocate but the brown firm does, the quality difference is highest, implying that competition between firm is weakest. This is, relocation does not only affect environmental quality by (brown) firms avoiding environmental regulation but also through another channel, by affecting investment in green products.

Compared to first-best taxation, the equilibrium emission tax is lower (higher) if only the brown (green) firm relocates. This is, optimal environmental taxation, and, more generally, the leeway of environmental policy does not only depend on the (possibility of) firm relocation, but also on additional factors resulting from firm relocation, i.e. quality choice.

In our model, we assume that consumers are able to monitor environmental product characteristics perfectly. The analysis of imperfect informed consumers with green preferences is left for future research.

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Appendix

A.1 Equilibrium Prices, Quantities, Quality Levels, and Profits

Assume $E > \tilde{E} = b + \frac{3}{2}t + \frac{1}{4}$ i.e. $E > s_g$.

In equilibrium HH, prices are $p_g^{HH} = \frac{25+8b+16b^2-16t^2+32tE}{32}$ and $p_b^{HH} = \frac{49-40b+16b^2-16t^2+32tE}{32}$. Quality levels are $s_g^{HH} = \frac{4b+4t+1}{4}$ and $s_b^{HH} = \frac{4b+4t-5}{4}$. The quality difference is $\Delta s^{HH} = \frac{3}{2}$. Quantities are $q_g^{HH} = q_b^{HH} = \frac{1}{2}$. Profits are $\pi_g^{HH} = \pi_b^{HH} = \frac{3}{8}$.

In equilibrium HF, prices are

$$p_g^{HF} = \frac{27(8b+16b^2+25)+144t(9b+4b^2+14)+24t^2(52b+8b^2+71)+64t^3(5b-4)-464t^4+16tE(2t+3)(12b+26t+9)+192t^2E^2}{96(4t+3)^2} \text{ and}$$

$$p_b^{HF} = \frac{27(-40b+16b^2+49)+144t(-17b+4b^2+27)+24t^2(-92b+8b^2+155)-64t^3(11b-13)-208t^4+16tE(2t+3)(12b+10t-3)+192t^2E^2}{96(4t+3)^2}.$$

Quality levels are $s_b^{HF} = \frac{3(4b+1)+4t(2b+5)+12t^2+8tE}{4(3+4t)}$ and $s_g^{HF} = \frac{3(4b-5)+8t(b-2)-4t^2+8tE}{4(3+4t)}$. The quality difference is $\Delta s^{HF} = t + \frac{3}{2}$. Quantities are $q_g^{HF} = \frac{9+8t(b+1)+4t^2-8tE}{24t+18}$ and $q_b^{HF} = \frac{9-8t(b-2)-4t^2+8tE}{24t+18}$. Profits are $\pi_g^{HF} = \frac{(2t+3)(8t-8tE+8bt+4t^2+9)^2}{72(4t+3)^2}$ and $\pi_b^{HF} = \frac{(2t+3)(-16t-8tE+8bt+4t^2-9)^2}{72(4t+3)^2}$.

In equilibrium FH, prices are

$$p_g^{FH} = \frac{27(8b+16b^2+25)-144t(9b+4b^2+14)+24t^2(76b+8b^2+71)-64t^3(11b+2)-208t^4+16tE(2t-3)(12b+10t-9)+192t^2E^2}{96(3-4t)^2} \text{ and}$$

$$p_b^{FH} = \frac{27(-40b+16b^2+49)-144t(-17b+4b^2+27)+24t^2(-68b+8b^2+131)+64t^3(5b-1)-464t^4+16tE(2t-3)(12b+26t-21)+192t^2E^2}{96(3-4t)^2},$$

quality levels are $s_g^{FH} = \frac{3(4b+1)-8t(b+1)+4t^2-8tE}{4(3-4t)}$ and $s_b^{FH} = \frac{3(4b-5)-4t(2b-7)-12t^2-8tE}{4(3-4t)}$. The quality difference is $\Delta s^{FH} = \frac{3}{2} - t$. Quantities are $q_g^{FH} = \frac{9-8t(b+1)-4t^2+8tE}{6(3-4t)}$ and $q_b^{FH} = \frac{9+8t(b-2)+4t^2-8tE}{6(3-4t)}$. Profits are $\pi_g^{FH} = \frac{(3-2t)(8t-8tE+8bt+4t^2-9)^2}{72(4t-3)^2}$ and $\pi_b^{FH} = \frac{(3-2t)(-16t-8tE+8bt+4t^2+9)^2}{72(4t-3)^2}$.

In equilibrium FF, equilibrium prices are $p_g^{FF} = \frac{8b+16b^2+25}{32}$ and $p_b^{FF} = \frac{-40b+16b^2+49}{32}$. Quality levels are $s_g^{FF} = \frac{4b+1}{4}$ and $s_b^{FF} = \frac{4b-5}{4}$. The quality difference is $\Delta s^{FF} = \frac{3}{2}$. Quantities are $q_g^{FF} = q_b^{FF} = \frac{1}{2}$. Profits are $\pi_g^{FF} = \pi_b^{FF} = \frac{3}{8}$.

The quality ranking for green firm is

$$s_g^{FH} < s_g^{FF} < s_g^{HH} < s_g^{HF} \text{ for } \tilde{E} < E < \overline{E}_{FH,b} = \frac{(-16t+8bt+4t^2+9)}{8t} \wedge t < \frac{3}{8}\sqrt{17} - \frac{9}{8} = 0.42116, \text{ with}$$

$$s_g^{HH} - s_g^{HF} = -\frac{t(2E-t-2b+1)}{(3+4t)} < 0 \text{ if } E > \tilde{E} = (b + \frac{3}{2}t + \frac{1}{4})$$

$$s_g^{HH} - s_g^{FH} = \frac{t(2E-5t-2b+4)}{3-4t} > 0 \text{ if } E > \tilde{E} \wedge t < \frac{9}{4}$$

$$s_g^{HH} - s_g^{FF} = t > 0$$

$$s_g^{HF} - s_g^{FH} = \frac{t(-16t^2-6t-12b+12E+15)}{9-16t^2} > 0 \text{ if } E > \tilde{E} = (b + \frac{3}{2}t + \frac{1}{4}) \wedge t < \frac{3}{2}$$

$$s_g^{HF} - s_g^{FF} = \frac{t}{4t+3}(3t-2b+2E+4) > 0 \text{ if } E > \tilde{E}$$

$$s_H^{FH} - s_H^{FF} = -\frac{t}{3-4t}(2E-t-2b+1) < 0$$

The quality ranking for the brown firm is

$$\text{i) } s_b^{FF} < s_b^{FH} < s_b^{HH} < s_b^{HF} \text{ if } \tilde{E} < E < \widetilde{E}_{s_b}^{FH,FF} \wedge t < \frac{1}{4}$$

$$\text{ii) } s_b^{FH} < s_b^{FF} < s_b^{HF} < s_b^{HH} \text{ if } \widetilde{E}_{s_b}^{FH,FF} < E < \widetilde{E}_{s_b}^{HH,HF} \wedge t < \frac{1}{4}, \text{ if } \tilde{E} < E < \widetilde{E}_{s_b}^{HH,HF} \wedge \frac{1}{4} < t < \frac{3}{4}\sqrt{2} - \frac{3}{4},$$

$$\text{and } \tilde{E} < E < \overline{E}_{FH,b} \wedge \frac{3}{4}\sqrt{2} - \frac{3}{4} > t$$

$$\text{iii) } s_b^{FH} < s_b^{FF} < s_b^{HH} < s_b^{HF} \text{ if } \widetilde{E}_{s_b}^{HH,HF} < E < \overline{E}_{FH,b} \wedge t < \frac{1}{4} \text{ and if } \widetilde{E}_{s_b}^{HH,HF} < E < \overline{E}_{FH,b} \wedge \frac{1}{4} < t < \frac{3}{4}\sqrt{2} - \frac{3}{4} \text{ with}$$

$$s_b^{HH} - s_b^{HF} = -\frac{t(2E-5t-2b-2)}{4t+3} < 0 \text{ if } E > \widetilde{E}_{s_b}^{HH,HF} = b + \frac{5}{2}t + 1$$

$$s_b^{HH} - s_b^{FH} = \frac{t(2E-t-2b+1)}{3-4t} > 0$$

$$s_b^{HH} - s_b^{FF} = t > 0$$

$$s_b^{HF} - s_b^{FH} = \frac{t(16t^2-6t-12b+12E-3)}{9-16t^2} > 0$$

$$\begin{aligned}
s_b^{HF} - s_b^{FF} &= \frac{t(2E-t-2b+1)}{4t+3} > 0 \\
s_b^{FH} - s_b^{FF} &= -\frac{t(3t-2b+2E-2)}{3-4t} < 0 \text{ if } E > \widetilde{E_{s_b}^{FH,FF}} = b - \frac{3}{2}t + 1 \\
\widetilde{E_{s_b}^{HH,HF}} - \widetilde{E} &= t + \frac{3}{4} \\
\widetilde{E_{FH,b}} - \widetilde{E_{s_b}^{HH,HF}} &= -\frac{1}{8t} (16t^2 + 24t - 9) > 0 \text{ if } t < \frac{3}{4}\sqrt{2} - \frac{3}{4} = 0.31066 \\
\widetilde{E_{s_b}^{FH,FF}} - \widetilde{E} &= \frac{3}{4} - 3t > 0 \text{ if } t < \frac{1}{4} \\
\widetilde{E_{FH,b}} - \widetilde{E_{s_b}^{FH,FF}} &= \frac{1}{8t} (4t - 3)^2 > 0 \\
\widetilde{E_{s_b}^{HH,HF}} - \widetilde{E_{s_b}^{FH,FF}} &= 4t > 0.
\end{aligned}$$

The ranking of the quality difference is $\Delta s^{FH} = \frac{3}{2} - t < \Delta s^{HH} = \Delta s^{FF} = \frac{3}{2} < \Delta s^{HF} = t + \frac{3}{2}$.

A. 2 Location

The following payoff matrix shows profits under the four possible strategy combinations.

1,2	green firm	brown firm
H	π_g^{HH}, π_b^{HH}	π_g^{HF}, π_b^{HF}
F	π_g^{FH}, π_b^{FH}	π_g^{FF}, π_b^{FF}

For equilibrium HH, the critical threshold of relocation cost is $\phi = \max\{\phi_g^{HH} = \frac{(3-2t)(8t-8tE+8bt+4t^2-9)^2}{72(4t-3)^2} - \frac{3}{8}, \phi_b^{HH} = \frac{(2t+3)(-16t-8tE+8bt+4t^2-9)^2}{72(4t+3)^2} - \frac{3}{8}\}$. The green firm stays in H if $\pi_g^{HH} > \pi_g^{FH}$, i.e. if $\phi > \phi_g^{HH} = \frac{(3-2t)(8t-8tE+8bt+4t^2-9)^2}{72(4t-3)^2} - \frac{3}{8}$. The brown firm stays in H if $\pi_b^{HH} > \pi_b^{HF}$, i.e. if $\phi > \phi_b^{HH} = \frac{(2t+3)(-16t-8tE+8bt+4t^2-9)^2}{72(4t+3)^2} - \frac{3}{8}$.

$$\begin{aligned}
\phi_g^{HH} - \phi_b^{HH} &= t \frac{-729-8t(-252t^2+64t^4+81)(2b-1)-8t^2(16t^2-27)(2t^2+11)-64bt^2(16t^2-27)(b-1)}{18(4t-3)^2(4t+3)^2} \\
&+ \frac{16tE(108t+128bt^3-216bt-252t^2-64t^3+64t^4+81)-64t^2E^2(16t^2-27)}{18(4t-3)^2(4t+3)^2}.
\end{aligned}$$

For equilibrium HF, the threshold of relocation cost is $\underline{\phi}^{HF} = \frac{3}{8} - \frac{(2t+3)(8t-8tE+8bt+4t^2+9)^2}{72(4t+3)^2} < \phi < \overline{\phi}^{HF} = \frac{(2t+3)(-16t-8tE+8bt+4t^2-9)^2}{72(4t+3)^2} - \frac{3}{8}$.

Given that the brown firm relocates to F, the green firm stays in H if $\pi_g^{HF} > \pi_g^{FF}$, i.e. if $\phi > \underline{\phi}^{HF} = \frac{3}{8} - \frac{(2t+3)(8t-8tE+8bt+4t^2+9)^2}{72(4t+3)^2}$.

Given that the green firm stays in H, the brown firm relocates to F if $\pi_b^{HF} > \pi_b^{HH}$, i.e. if $\phi < \overline{\phi}^{HF} = \frac{(2t+3)(-16t-8tE+8bt+4t^2-9)^2}{72(4t+3)^2} - \frac{3}{8}$.

$$\overline{\phi}^{HF} - \underline{\phi}^{HF} = t \frac{(81+48t(-2b+2b^2+5)+16t^2(2b+4b^2+7)+8t^3(8b-1)+16t^4-32tE(2t+3)(2b+t-1)+32tE^2(2t+3))}{18(4t+3)^2}.$$

For equilibrium FH, the threshold of relocation cost is $\underline{\phi}^{FH} = \frac{3}{8} - \frac{(3-2t)(-16t-8tE+8bt+4t^2+9)^2}{72(4t-3)^2} < \phi < \overline{\phi}^{FH} = \frac{(3-2t)(8t-8tE+8bt+4t^2-9)^2}{72(4t-3)^2} - \frac{3}{8}$.

Given that the brown firm stays in H, the green firm relocates to F if $\pi_g^{FH} > \pi_g^{HH}$, i.e. if $\phi < \overline{\phi}^{FH} = \frac{(3-2t)(8t-8tE+8bt+4t^2-9)^2}{72(4t-3)^2} - \frac{3}{8}$.

Given that the green firm relocates to F, the brown firm also relocates if $\pi_b^{FH} > \pi_b^{FF}$, i.e. if $\phi > \underline{\phi}^{FH} = \frac{3}{8} - \frac{(3-2t)(-16t-8tE+8bt+4t^2+9)^2}{72(4t-3)^2}$.

$$\overline{\phi}^{FH} - \underline{\phi}^{FH} = t \frac{(-81+48t(-2b+2b^2+5)-16t^2(-10b+4b^2+13)-8t^3(8b-7)-16t^4+32tE(2t-3)(2b+t-1)-32tE^2(2t-3))}{18(4t-3)^2}.$$

For equilibrium FF, the threshold of relocation cost is $\phi < \phi^{FF} = \min\{\phi_g^{FF} = \frac{3}{8} - \frac{(2t+3)(8t-8tE+8bt+4t^2+9)^2}{72(4t+3)^2},$

$$\phi_b^{FF} = \frac{3}{8} - \frac{(3-2t)(-16t-8tE+8bt+4t^2+9)^2}{72(4t-3)^2}\}.$$

Given that the brown firm relocates to F , the green firm also relocates if $\pi_g^{FF} > \pi_g^{HF}$, i.e. if $\phi < \phi_g^{FF} = \frac{3}{8} - \frac{(2t+3)(8t-8tE+8bt+4t^2+9)^2}{72(4t+3)^2}.$

Given that the green firm relocates to F , the brown firm also relocates if $\pi_b^{FF} > \pi_b^{FH}$, i.e. if $\phi < \phi_b^{FF} = \frac{3}{8} - \frac{(3-2t)(-16t-8tE+8bt+4t^2+9)^2}{72(4t-3)^2}$

$$\phi_g^{FF} - \phi_b^{FF} = \frac{-729-8t(36t^2+64t^4-81)(2b-1)-64bt^2(16t^2-27)(b-1)-8t^2(410t^2+32t^4-459)+16tE(108t+128bt^3-216bt+36t^2-64t^3+64t^4-81)-64t^2E^2(16t^2-27)}{18(4t-3)^2(4t+3)^2}.$$

$$\begin{aligned} \phi_g^{FF} - \phi_b^{FF} < 0 \text{ if } \underline{E}_{HH} &= \frac{-81+4t(27-16t^2)(2b-1)+4t^2(63-16t^2)-6\sqrt{-4t^2+9}(3-4t)(4t+3)}{8t(27-16t^2)} < E < \bar{E}_{HH} \\ &= \frac{-81+4t(27-16t^2)(2b-1)+4t^2(63-16t^2)+6\sqrt{-4t^2+9}(3-4t)(4t+3)}{8t(27-16t^2)} \end{aligned}$$

and vice versa, $\phi_g^{FF} - \phi_b^{FF} > 0$ if $E < \underline{E}_{HH} = \frac{-81+4t(27-16t^2)(2b-1)+4t^2(63-16t^2)-6\sqrt{-4t^2+9}(3-4t)(4t+3)}{8t(27-16t^2)} \vee$

$$E > \bar{E}_{HH} = \frac{-81+4t(27-16t^2)(2b-1)+4t^2(63-16t^2)+6\sqrt{-4t^2+9}(3-4t)(4t+3)}{8t(27-16t^2)},$$

with $\underline{E}_{HH} < \bar{E}_{HH}$ if $t < \frac{3}{4}$ and $\underline{E}_{HH} > \bar{E}_{HH}$ if $t > \frac{3}{4}$.

$$\bar{\phi}^{HF} - \phi^{HF} > 0$$

$$\begin{aligned} \bar{\phi}^{FH} - \phi^{FH} < 0, \text{ if } \underline{E}_{FH} &= \frac{48t(2b-1)-16t^2(4b-5)-32t^3-12(3-4t)\sqrt{2t(3-2t)}}{32t(3-2t)} < E < \bar{E}_{FH} \\ &= \frac{48t(2b-1)-16t^2(4b-5)-32t^3+12(3-4t)\sqrt{2t(3-2t)}}{32t(3-2t)} \end{aligned}$$

and vice versa, $\bar{\phi}^{FH} - \phi^{FH} > 0$ if $E < \underline{E}_{FH} = \frac{48t(2b-1)-16t^2(4b-5)-32t^3-12(3-4t)\sqrt{2t(3-2t)}}{32t(3-2t)} \vee E > \bar{E}_{FH}$

with $\underline{E}_{FH} < \bar{E}_{FH}$ if $t < \frac{3}{4}$ and $\underline{E}_{FH} > \bar{E}_{FH}$ if $t > \frac{3}{4}$.

$$\begin{aligned} \phi_g^{HH} - \phi_b^{HH} < 0 \text{ if } \underline{E}_{FF} &= \frac{81-4t(16t^2-27)(2b-1)-4t^2(16t^2+9)-6\sqrt{(3-2t)(2t+3)}(3-4t)(4t+3)}{8t(27-16t^2)} < E < \bar{E}_{FF} \\ &= \frac{81-4t(16t^2-27)(2b-1)-4t^2(16t^2+9)+6\sqrt{(3-2t)(2t+3)}(3-4t)(4t+3)}{8t(27-16t^2)}, \end{aligned}$$

and vice versa, $\phi_g^{HH} - \phi_b^{HH} > 0$ if $E < \underline{E}_{FF} = \frac{81-4t(16t^2-27)(2b-1)-4t^2(16t^2+9)-6\sqrt{(3-2t)(2t+3)}(3-4t)(4t+3)}{8t(27-16t^2)} \vee$

$$\begin{aligned} E > \bar{E}_{FF} &= \frac{81-4t(16t^2-27)(2b-1)-4t^2(16t^2+9)+6\sqrt{(3-2t)(2t+3)}(3-4t)(4t+3)}{8t(27-16t^2)}, \\ &= \frac{81-4t(16t^2-27)(2b-1)-4t^2(16t^2+9)+6\sqrt{(3-2t)(2t+3)}(3-4t)(4t+3)}{8t(27-16t^2)}, \end{aligned}$$

with $\underline{E}_{FF} < \bar{E}_{FF}$ if $t < \frac{3}{4}$ and $\underline{E}_{FF} > \bar{E}_{FF}$ if $t > \frac{3}{4}$.

Location equilibria are

A) FF for $\phi < \phi_{FF,g}$, HF for $\phi_{FF,g} = \underline{\phi}_{HF} < \phi < \bar{\phi}_{HF} = \phi_{HH,b}$, HH for $\phi_{HH,b} < \phi$

if i) $t < \underline{t} \wedge \tilde{E} < E < \bar{E}_{FH}$ or ii) $\underline{t} < t < \widetilde{t_{HH}} \wedge \tilde{E} < E < \bar{E}_{HH}$

with \underline{t} is solution to $f(t) = (2\sqrt{-4t^2+9}(4t+3)(3-2t) - (27-16t^2)\sqrt{2t(3-2t)} - 18t + 24t^2 - 27).$

B) FF for $\phi < \phi_{FF,g}$, HF for $\phi_{FF,g} = \underline{\phi}_{HF} < \phi < \underline{\phi}_{FH}$, HF & FH for $\underline{\phi}_{FH} < \phi < \bar{\phi}_{FH}$, HF for $\bar{\phi}_{FH} < \phi < \bar{\phi}_{HF} = \phi_{HH,b}$, HH for $\phi_{HH,b} < \phi$.

if iii) $\underline{t} < t < \widetilde{t_{HH}} \wedge \bar{E}_{HH} < E < \bar{E}_{FH}$.

with $\widetilde{t_{HH}}$ is solution to $f(t) = -18t + 32t^3 - 27 + 6\sqrt{-4t^2+9}(3-4t).$

C) FF for $\phi < \phi_{FF,g}$, HF for $\phi_{FF,g} = \underline{\phi}_{HF} < \phi < \bar{\phi}_{HF}$, no equilibrium for $\bar{\phi}_{HF} < \phi < \bar{\phi}_{FH} = \phi_{HH,g}$, HH for $\phi_{HH,g} < \phi$

if iv) $\underline{t} < t < \widetilde{t_{HH}} \wedge \overline{E_{HH}} < E < \overline{E_{FH}}$ or v) $\widetilde{t_{HH}} < t < \widetilde{t_{FH}} \wedge \widetilde{E} < E < \overline{E_{FH}}$
with $\widetilde{t_{FH}}$ is solution to $f(t) = 16t^3 - 12t^2 - 18t + (9 - 12t)\sqrt{2t(3 - 2t)}$
D) FF for $\phi < \phi_{FF,g}$, HF for $\phi_{FF,g} = \underline{\phi}_{HF} < \phi < \underline{\phi}_{FH}$, HF & FH for $\underline{\phi}_{FH} < \phi < \overline{\phi}_{HF}$, FH for $\overline{\phi}_{HF} < \phi < \overline{\phi}_{FH} = \phi_{HH,g}$, HH for $\phi_{HH,g} < \phi$
if vi) $t < \underline{t} \wedge \overline{E_{HH}} < E < \overline{E_{FH,b}}$, vii) $\underline{t} < t < \widetilde{t_{HH}} \wedge \overline{E_{FH}} < E < \overline{E_{FH,b}}$, viii) $\widetilde{t_{HH}} < t < \widetilde{t_{FH}} \wedge \overline{E_{FH}} < E < \overline{E_{FH,b}}$, or ix) $\widetilde{t_{FH}} < t < \frac{3}{8}\sqrt{17} - \frac{9}{8} \wedge \widetilde{E} < E < \overline{E_{FH,b}}$.

A.3 Environmental Policy

For the equilibrium HH, welfare is given as $W = \int_{\hat{\theta}}^b (\theta s_g - p_g) d\theta + \int_{b-1}^{\hat{\theta}} (\theta s_b - p_b) d\theta + \pi_g + \pi_b + t^{HH} ((E - s_g) q_g + (E - s_b) q_b) - \delta ((E - s_g) q_g + (E - s_b) q_b)$. The welfare-maximizing tax is $t^{HH} = \delta$.

For the equilibrium HF, welfare is given as $W = \int_{\hat{\theta}}^b (\theta s_g - p_g) d\theta + \int_{b-1}^{\hat{\theta}} (\theta s_b - p_b) d\theta + \pi_g + t^{HF} ((E - s_g) q_g) - \delta ((E - s_g) q_g)$.

The first order condition evaluated at $t = \delta$ is < 0 .

For the equilibrium FH, welfare is given as $W = \int_{\hat{\theta}}^b (\theta s_g - p_g) d\theta + \int_{b-1}^{\hat{\theta}} (\theta s_b - p_b) d\theta + \pi_b + t^{FH} ((E - s_b) q_b) - \delta ((E - s_b) q_b)$.

The first order condition evaluated at $t = \delta$ is > 0 .