Environmental Preferences and Technological Choices: Is Market Competition Clean or Dirty?*

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Abstract

In this paper we bring together patent data, survey data on environmental values, and competition data, to analyze the joint effect of consumers' social responsibility and product market competition on firms' decision whether to innovate clean or dirty. We first develop a model which captures the basic intuition that socially responsible consumers induce firms to escape competition by pursuing greener innovations. Our main empirical findings are that pro-environment attitudes and competition have both a significant positive effect on the probability for a firm to patent more in the clean direction and that the interaction term between attitudes and competition is also significantly positive.

1 Introduction

Should private firms get involved in dealing with global warming and other rising environmental problems? A traditional view against such corporate social responsibility by Milton Friedman (1970), is that firms should concentrate on achieving their economic objectives (starting with profit maximization) and let governments, and/or markets, and/or contracts and regulations, deal with the various kinds of externalities. However, we see governments dragging their feet when it comes to implementing policies that effectively deal with global warming and more generally environmental problems. Indeed, as pointed out by Benabou and Tirole (2010), governments are often captured by lobbies.

Other reasons for why corporate social responsibility should play a growing role in fighting global warming, are: (a) environmental issues are global, and cannot be resolved by any single country; (b) carbon taxes are highly unpopular even with electorates that otherwise proclaim their "greenness": a recent illustration of this fact, was the "yellow vest" movement in France which was triggered by a

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government decision to increase fuel and gasoline taxes. This in turn calls for firms and citizens to also take part in the environmental challenge. This is all the more true when consumers, investors, entrepreneurs, are increasingly willing to act on their own, as they feel a responsibility to "do their part": in other words, private agents and firms respond to intrinsic motivation.

Our focus in this paper is on firms' incentives to "innovate clean", and on the extent to which citizen's environmental values can be effective in shaping firms' decisions.[1] More specifically, we argue that product market competition amplifies firms' response to citizens' demand for greater social responsibility and in particular, for better environment: namely, firms will pursue greener innovations when facing consumers with a higher degree of social responsibility particularly if they face a higher degree of product market competition. The basic intuition is that socially responsible consumers induce firms to escape competition by pursuing greener innovations.

There already exists an extensive literature on the effects of product market competition. First, from a static point of view, more competition increases consumer surplus by reducing equilibrium (quality-adjusted) prices, thereby increasing equilibrium consumption (e.g. see Tirole, 1988). Second, from a dynamic point of view, competition can encourage more innovation by firms which try to escape competition (see Aghion et al, 2005). We contribute to this literature by introducing environmental externalities into the analysis of the effects of product market competition. While the static effect of competition on the environment is likely to be unambiguous - more competition induces more mass consumption and therefore more pollution[2]- the dynamic effect of competition on the environment is more ambiguous a priori. Moreover, what matters for the environment is not so much the effect of competition on the level of innovation, but rather the effect of competition on the *direction* of innovation: namely, to which extent and under which circumstances does product market competition induce firms to develop new products that are more or less environmentally friendly.

Thus our main question is how do consumers' environmental values and the degree of market competition interact empirically, to shape: (i) firms' R&D effort of firms, hence the types of goods consumed; (ii) ultimately, the level of pollution/emissions, and social welfare. We show that the answer depends upon consumers' (and investors) willingness to pay more for such "socially responsible" products (e.g., clean cars, as opposed to bigger, faster, fancier ones).

In the first part of the paper we develop a theoretical model. The economy is populated by representative agents with standard CES taste-for-variety preferences, but who are also care about the environmental "footprint" of their own consumption bundle. There is a continuum of differentiated goods, such as cars, appliances, etc., and the production and/or consumption of each good generates a certain amount of pollution, which is negatively correlated with the environmental-friendliness or "ethicality" of the technology embodied in the good by its producer. Producing cleaner goods, or producing more cleanly, requires incurring up-front *fixed* costs, such as *R&D* expenditures to develop the appropriate technologies. We then look at how the equilibrium amount of clean R&D, and then the equilibrium amount of pollution and aggregate welfare, depend upon consumers' degree of environmental concern (or social responsibility), product market competition, and the interaction between the two. While higher market competition reduces post innovation rents, we show that under suitable parameter restrictions the escape competition incentive to innovate green dominates, and that there is a positive interaction

[1]Citizens could also directly impact on the environment by contributing to environmental NGO's, but it may be more efficient to "delegate" some of their socially responsible preferences to firms, who have knowledge to directly affect outcomes. Moreover, enhancing ones social image may be more effectively achieved through the choice of consumption items (e.g by purchasing greener cars) than through writing checks to charitable causes: the latter tends to be less visible except for the very rich, who write huge and well-publicized checks.

[2]The examples of China or India today, or of the US since the 1980s, are particularly illustrative in that respect.

between consumers' degree of social responsibility and product market competition on the equilibrium amount of green R&D and innovation.

In the second part of the paper, we bring together patent data, survey data on environmental values, and competition data to test empirically the model's key comparative statics. We relate the extent to which firms innovate in a clean direction to firm specific measures of exposure to pro-environmental attitudes and to competition. A firm's exposure to attitudes and competition is defined as a weighted average of country level measures of attitudes and competition, where the weights proxy for the importance of the various countries for the firm. For competition, we also show results using firm-level Lerner index type of competition measures but we can only do this for a sub-sample of firms. We follow Aghion et al. (2016) in two respects: first, we focus primarily on the automobile sector, where the distinction between clean and dirty patents is easy to make and relevant;second, the weights above mentioned are computed using the firm's patenting activity between 1950 and 1995, i.e. before our period of analysis. This is based on the assumption that firms only take out patent protection in a particular market if this market is important to them. We also check robustness to alternative weights definition and to specification at the firm-country level where no weights are needed. Our main findings are that pro-environment attitudes and competition have both a significant positive effect on the probability for a firm to patent more in the clean direction and that the interaction term between attitudes and competition is also significantly positive.

Our research relates to several strands of literature. First, our paper relates to the environment and growth literature pioneered by Nordhaus (1994).[3] However innovation, competition and corporate social responsibility considerations are absent from this literature which revolves around the introduction of environmental costs in an otherwise classical Ramsey growth model. Second, there is the recent literature on corporate social responsibility. Here we refer the readers particularly to Benabou-Tirole (2010) and to Hart-Zingales (2019) and to the references mentioned in these two papers. We contribute to this literature by introducing product market competition as a channel whereby consumers' social preferences can influence firms' decisions.

Our paper also relates to the literature on competition and innovation, see e.g. Vives (2008) and Aghion et al. (2005). We contribute to this literature by introducing environmental and corporate social responsibility considerations into the analysis.

More closely related to our analysis in this paper are recent papers on innovation and the environment, in particular by Acemoglu et al. (2012), Acemoglu et. al (2016) and Aghion et al. (2016). However, none of these papers looks at the joint effect of product market competition and consumers' social responsibility on the greenness of innovation.

The remaining part of the paper is organized as follows. Section 2 develops the theoretical analysis. Section 3 discusses the empirical strategy and data sources. Section 4 presents the empirical results. And Section 5 concludes.

[3] See also Nordhaus (2002), Stern (2007) and Weitzman (2007, 2009),

2 Theoretical analysis

2.1 Basic Model

2.1.1 Consumers

There is a continuum of differentiated good, such as cars, appliances, etc., indexed by $i \in [0,1]$. The production or consumption of each unit of good i generates $\tau_i \in [0,1]$ units of pollution or similar negative externality. Conversely, $e_i \equiv 1-\tau_i$ measures the environmental-friendliness or "ethicality" of the technology embodied in the good by its producer.

The economy is populated by representative agents with standard taste-for-variety preferences, but who are also care about the environmental "footprint" of their own consumption bundle. Formally, preferences are given by:

$$U = \left[\int \left[C_i (1-\tau_i)^{\delta} \right]^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where $\delta > 0$ parameterizes the extent to which consumers feel a *social responsibility* for the externalities they generate, or avoid. The elasticity of substitution (or inverse product differentiation) $\sigma > 1$, will, as usual, be a key measure of the degree of market competition.

Given goods' prices p_i and "greenness" levels e_i, consumers's problem is standard. Normalizing income to $Y \equiv 1$, the optimality conditions take the form

$$C_i^{-\frac{1}{\sigma}} e_i^{\delta\left(\frac{\sigma-1}{\sigma}\right)} = \lambda p_i, \tag{2}$$

$$\lambda = \lambda \int p_i C_i di = \int C_i^{\frac{\sigma-1}{\sigma}} e_i^{\delta\left(\frac{\sigma-1}{\sigma}\right)} di. \tag{3}$$

Hence

$$p_i = \frac{C_i^{\frac{-1}{\sigma}} e_i^{\delta\left(\frac{\sigma-1}{\sigma}\right)}}{\int C_j^{\frac{\sigma-1}{\sigma}} e_j^{\delta\left(\frac{\sigma-1}{\sigma}\right)} dj}, \tag{4}$$

which clearly shows he "ethical premium" that socially responsible consumers are willing to pay for cleaner goods.

2.1.2 Firms

Producing cleaner goods, or producing more cleanly, requires incurring up-front *fixed* costs, such as *R&D* expenditures to develop the appropriate technologies. Monopolistic competitive firms thus choose prices and investments to maximize:[4]

$$\max_{p_i, e_i} \Pi_i = (p_i - c) X_i - \frac{\kappa}{2} e_i^2, \text{ subject to} \tag{5}$$

$$X_i = C_i = (\lambda p_i)^{-\sigma} e_i^{\delta(\sigma-1)},$$

[4] One could also incorporate a variable cost of the form $c\,(e_i)^{\omega} X_i$, but this would just rescale δ.

leading to the optimality conditions:

$$p_i = c\left(\frac{\sigma}{\sigma-1}\right), \tag{6}$$

$$\kappa e_i = \delta\left(\sigma-1\right)\left(p_i-c\right)(\lambda p_i)^{-\sigma}\frac{e_i^{\delta(\sigma-1)}}{e_i}. \tag{7}$$

The first one is familiar and implies that all firms charge the same price p; by (6) they then also choose the same technology e, and by (4) all goods' consumption levels are also equal. The equilibrium is therefore necessarily symmetric, with e given as a function of λ by substituting p into (7):

$$\delta\left(\sigma-1\right)\left(\frac{c}{\sigma-1}\right)(\lambda)^{-\sigma}\left(c\left(\frac{\sigma}{\sigma-1}\right)\right)^{-\sigma}e_i^{\delta(\sigma-1)} = \kappa e_i^2,$$

which simplifies to

$$\delta c^{1-\sigma}\lambda^{-\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma} = \kappa e^{2-\delta(\sigma-1)}. \tag{8}$$

2.2 Equilibrium and main result

Conversely, we now solve for the marginal utility of income λ as a function of technology e, using (6)-(4) and symmetry: $p_i = 1/C$:

$$\begin{aligned}\lambda &= \frac{C^{-\frac{1}{\sigma}}}{p}e^{\delta\left(\frac{\sigma-1}{\sigma}\right)} = e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}(p)^{\frac{1-\sigma}{\sigma}} \\ &= e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}c^{\frac{1-\sigma}{\sigma}}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma-1}{\sigma}} = e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}c^{\frac{1-\sigma}{\sigma}}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma-1}{\sigma}}.\end{aligned} \tag{9}$$

Substituting into (8) and simplifying leads to the following results.

Proposition 1 (technological choices). *Technology's level of environmental-friendliness e is given by:*

$$e^2 = \frac{\delta}{\kappa}\left(\frac{\sigma-1}{\sigma}\right), \tag{10}$$

with $e = 1-\tau < 1$ (interior solution) as long as cleanliness is not too "cheap" to achieve relative to consumers' desire for it ($\delta < \kappa$ is a sufficient condition for all values of σ). Moreover:

$$\frac{\partial e^*}{\partial(\delta/\kappa)} > 0, \quad \frac{\partial e^*}{\partial\sigma} > 0, \quad \frac{\partial^2 e^*}{\partial\sigma\partial(\delta/\kappa)} > 0. \tag{11}$$

These are the *three main predictions* that will be tested in our empirical analysis: the intensity of "green" innovation by firms, measured through their patent mix, should rise with the strength of consumers' *social responsibility* concerns and the degree of *market competition*, and rise more which each of these factors, the higher is the other, thus displaying *complementarity.*

A final remark to conclude this section: in the above analysis we have restricted attention to parameter values for which an interior solution $e > 0$ exists; however, when product market competition as measured by σ increases, the set of parameter values for which profits are no longer sufficient to cover the fixed R&D cost and consequently $e^* = 0$, expands. In other words, there is a counteracting *Schumpeterian* effect to the escape competition effect driving the above proposition: namely, higher competition reduces ex post rents to (clean) innovation. This counteracting *Schumpeterian effect* appears even more clearly in Appendix B where we endogeneize σ by making it depend on the number of firms (the number of firms is in turn is determined by a free entry condition, thus in equilibrium it depends upon an entry cost parameter).

2.3 Competition, pollution and welfare

One is ultimately interested in clean innovation not *per se,* but really because pollution is a public bad, and conversely reducing it a public good. We therefore now ask how the equilibrium *level of pollution* (and, later on, welfare) varies with competition, citizens' social responsibility, and their interaction. Of course, whereas firms' patenting mix is observable at the country and even firm level, there is no data on the resulting changes in local or global pollution that would allow an empirical implementation of this part of the model. The theoretical analysis is nonetheless important to understand the key forces determining whether competition is ultimately "green or brown," and how this relates to the presence and strength of the innovation-directing effects that we do empirically document.

Let us start by noting that *direct* effect of competition on pollution is *always* an adverse one: by driving prices down, it increases demand and production (C) and therefore, for any fixed technology, results in higher emissions

$$Z \equiv C\tau = (1 - e). \tag{12}$$

One can see this effect operating dramatically in China, India, and other developing countries, where allowing producer competition (including via imports, foreign subsidiaries and joint ventures) has massively increased the number of vehicles, and correspondingly the level of pollution. (As well as congestion, which is a very similar externality). One can also see it in the US, both: (i) in historical terms of mass access to cars; (ii) in the trend toward bigger and more powerful cars (an increase in per-driver C or X) : gas-guzzlers in the 60' and 70's, and then SUV's since the 90's, with regular sedans now increasingly rare. There are of course other intervening factors, like fluctuations in oil prices t (which the previous section incorporates) and safety concerns, the latter also involving an arms-race-type externality.[5]

This makes even more interesting and critical the extent of green R&D and innovation, by raising the questions following questions:

1. Can the green-innovation effect of competition, analyzed above and empirically documented in Section..., *prevail* over the "mass consumption" effect, resulting in a *decrease* of total emissions? (For instance, for more cars but mostly hybrid or electric). And if so, what is the role of consumer's social-responsibility motivation in making this happen?

2. More generally, given that both consumption-utility

$$U = Ce^{\delta} \tag{13}$$

[5]This "mass consumption" or direct "quantity" effect *obviates the need* to also consider investments in dirtier but cheaper technologies: competition already has offsetting good and bad effects on emissions, the latter occurring because goods become cheaper (in sales prices rather than production costs). Investments in cost-cutting technologies that simply reduce the marginal cost c without changing τ, or that make cars more attractive at a given price (e.g., more fun or comfortable) would, similarly, also be intrinsically "dirty," as again they would lead to more consumption C and pollution τC.

and pollution damages $Z = (1-e)C$ matter for *welfare,* how does the latter ultimately vary with competition, preferences, and their interaction?

In what follows we answer these questions using the basic model without carbon taxes (they could be added back in, but the additional complexity might require the model to be solved numerically), and focusing again on the elasticity of substitution as the key measure of competition.

2.3.1 Pollution

From (2), (6) and (9), we have:

$$\alpha C^{-\frac{1}{\sigma}} e^{\delta\alpha} = \lambda p = e^{\delta\alpha} c^{1-\alpha} \alpha^{\alpha} \left(\frac{c}{\alpha}\right) \iff C = \frac{\alpha}{c} = \frac{1}{c}\left(\frac{\sigma-1}{\sigma}\right). \tag{14}$$

Using (10), total pollution therefore equals

$$Z = \frac{\alpha}{c}(1-e) = \frac{\alpha}{c}\left(1 - \sqrt{\alpha}\sqrt{\frac{\delta}{\kappa}}\right), \tag{15}$$

which naturally decreases with environmental concerns δ and production costs c, while increasing with green-$R\&D$ costs κ. As to competition, we clearly see its *two opposing effects:* a higher α increases consumption and production C (by driving down prices p closer to marginal cost), but it also induces firms to adopt cleaner technologies. What is the net impact?

Proposition 2 (pollution and competition). *Total pollution is given by (15). When environmental preferences are low relative to the costs of green R&D, $\delta/\kappa < 2/3$, it always rises as competition intensifies. When $\delta/\kappa \geq 2/3$, pollution is hump-shaped in competition, peaking at*

$$\alpha^* = \frac{\sigma^* - 1}{\sigma^*} \equiv \left(\frac{2\kappa}{3\delta}\right)^2, \tag{16}$$

then declining. The benefit of competition appears earlier, and reduces pollution faster, the higher is δ/κ. In both cases, $\partial^2 Z/\partial\alpha\partial\left(\delta/\kappa\right) < 0$.

Naturally, pollution's global minimum is always at zero consumption and production, which corresponds to minimal competition, $\alpha = 0$ (infinite prices, zero demand). But of course that primitive, "horse-and-carriage" state of technology is far from optimal from any reasonable welfare perspective.

2.3.2 Consumption utility

The first component of individuals' welfare is their utility from consumption, which here includes their displeasure or guilt from the externalities their own behavior creates:

$$U = Ce^{\delta} = \frac{\alpha^{1+\delta/2}}{c}\left(\frac{\delta}{\kappa}\right)^{\frac{\delta}{2}}. \tag{17}$$

For any given level of competition σ, it is naturally decreasing in costs c and κ. To examine how U varies with prosocial concerns, note that:

$$\frac{\partial U}{\partial \delta} = \left(\frac{1}{2} - \ln \delta\right) U.$$

Therefore U increases with δ up to $\delta^* \equiv \exp(1/2) = 1.65$, then declines. On one hand, a higher δ means that consumers experience more disutility –e.g., guilt– from each unit of pollution embodied in their consumption. On the other hand, a more environmentally concerned population pushes firms to produce cleaner goods (albeit more expensive ones). Turning now to the effects of competition, we have:

Proposition 3. *Competition results in higher consumption utility, $\partial U/\partial \alpha > 0$, by both pushing goods' prices down and their environmental quality up. This effect of competition increases with consumers' degree of social responsibility, $\partial^2 U/\partial \delta \partial \alpha > 0$, if and only if either of these two factors is high enough, namely,*

$$\alpha > \hat{\alpha} \equiv \frac{1}{\delta} \exp\left(\frac{2+\delta}{4+\delta}\right), \tag{18}$$

where the right-hand side threshold is decreasing in δ.

The first result is immediate from (19), the second one is shown in the appendix.

2.3.3 Welfare

Consumer welfare The second major component of people's welfare are the damages inflicted on then by total emissions. Their net utility is thus

$$V = U - \psi(Z) = Ce^{\delta} - \Psi(C(1-e)),$$

where ψ is some increasing and convex function. Clearly, welfare's variations with respect to α, and thus also the optimal level of competition from consumers' point of view, will depend on the level and sensitivity of $\psi(\cdot)$. We analyze them here using a convenient functional form, but also show more general results in the appendix (Proposition 6).[6]

Specifying $\Psi(Z) = \psi Z^{1+\zeta}$ and using (14)-(15), we have

$$V = \frac{\alpha}{c}\left[\frac{\delta\alpha}{\kappa}\right]^{\frac{\delta}{2}} - \psi\left[\frac{\alpha}{c}\left(1 - \sqrt{\alpha}\sqrt{\frac{\delta}{\kappa}}\right)\right]^{1+\zeta}. \tag{19}$$

Differentiating (19) with respect to α and using the fact that $e^2 = \delta\alpha/\kappa$ then leads to:

$$c.\frac{\partial V}{\partial \alpha} = \left(1 + \frac{\delta}{2}\right)e^{\delta} - \psi\left(1 - \frac{3}{2}e\right)(1+\zeta)\left(\frac{\kappa}{\delta c}\right)^{\zeta} e^{2\xi}(1-e)^{\xi}. \tag{20}$$

Clearly, V is always increasing for α large enough that $e > 2/3$, as in this range consumer utility rises and pollution declines. Its maximum is therefore reached either on $[0, \kappa/\delta)\sqrt{2/3}]$ or at 1, and in the appendix we show:

Proposition 4 (consumer welfare)**.** *Let utility losses from pollution level Z be $\psi Z^{1+\zeta}$, $\zeta \geq 0$.*

[6] One could also try to relate consumers' intrinsic dislike for the (infinitesimal) externalities they create on others to the marginal reduction in the aggregate welfare loss $\Psi(Z)$ that would result from a coordinated reduction in C. While such exactly "Kantian" preferences, linking the marginal utility of individual consumption to $\Psi'(Z)$, are not analytically compatible, with the current setup, imposing a positive relationship between δ and ζ would capture some of that intuition.

1. *For $\zeta \le \delta/2$, consumer welfare $V(\alpha)$ is maximized at $\alpha = 1$ (perfect competition) if and only if*

$$\frac{c^{\zeta}\left(\frac{\delta}{\kappa}\right)^{\frac{\delta}{2}}}{\left(1-\sqrt{\frac{\delta}{\kappa}}\right)^{1+\zeta}} > \psi, \tag{21}$$

and at $\alpha = 0$ (no competition) otherwise. The first case is more likely, the higher are δ/κ and c.

2. *For $\zeta > \delta/2$, (21) is a sufficient condition for $V(\alpha)$ to have an interior maximum, which is then such $0 < \alpha_V^* < (\kappa/\delta)\sqrt{2/3}$. Furthermore, $\partial\alpha_V^*/\partial\psi < 0 < \partial\alpha_V^*/\partial\delta$.*

Profits The last component of total social welfare is firms' profits, which (absent entry, and normalizing $N = 1$) equal:

$$\Pi = 1 - (1 + \frac{\delta}{2})\alpha. \tag{22}$$

Naturally, they fall with α, as competition forces firms to *both* reduce their markup and make costly investments in green *R&D*; they also decline with δ. It clearly follows that increases in competition α and/or in consumer's social responsibility δ will have less favorable effects on both *total economic surplus* $\tilde{U} \equiv U + \Pi$ and *total social welfare* $\tilde{V} \equiv V + \Pi$ than those analyzed above for U and V. As a result, the corresponding optimal degree of competition α will be lower.

The case of $\tilde{U}$ is relatively simple. From (17) and (A.19), consumption utility and firm profits sum to:

$$U + \Pi = \frac{\alpha^{1+\delta/2}}{c}\left(\frac{\delta}{\kappa}\right)^{\frac{\delta}{2}} + 1 - \left(1 + \frac{\delta}{2}\right)\alpha. \tag{23}$$

Differentiating yields:

Proposition 5. *Total economic surplus (gross of pollution damages) is U-shaped in the degree of competition: starting from $\alpha = 0$ it declines, then starts rising once $(e^*)^{\delta} = (\alpha\delta/\kappa)^{\delta} > c$.*

Note that since we have been assuming $\alpha\delta/\kappa$ to ensure an interior solution ($\tau^* > 0$), the above condition for there to be a rising part requires that $c < 1$.Similarly,

$$\lim_{\alpha\to 1}(U + \Pi) = \frac{1}{c}\left(\frac{\delta}{\kappa}\right)^{\frac{\delta}{2}} - \frac{\delta}{2}$$

is positive (alternatively, greater than $\lim_{\alpha\to 0}(U + \Pi) = 1$) if an only if c is small enough. This may seem odd but is not specifically linked to endogenous technological choice, however. Indeed, as $\delta \to 0$ we get back the standard Dixit-Stiglitz model, in which

$$U + \Pi \to \frac{\alpha}{c} + 1 - \alpha = 1 + \alpha\left(\frac{1}{c} - 1\right).$$

The U-shape and the possibility that $\alpha = 0$ could be the optimum are thus general features of CES preferences and fixed consumer income (normalized to 1). For "full" general equilibrium, one would want to rebate firms profits (positive or negative) to consumers, or allow for endogenous entry so that rents will be dissipated on entry costs, with now an endogenous mass $[0, N]$ of firms/goods as opposed to the current $[0, 1]$.

3 Empirical Strategy

We now turn to testing empirically the model's key comparative statics. In particular we relate the extent to which firms innovate in a clean direction to firm specific measures of exposure to pro-environment values and to competition. Our main analysis is at the firm-level. We run regressions of the following form, where γ is the main coefficient of interest

$$Innovation_{j,t} = \alpha Values_{j,t} + \beta Competition_{j,t} + \gamma Values_{j,t} \times Competition_{j,t} \\ + \delta X_{j,t} + J_j + T_t +_{j,t} \quad (24)$$

$Innovation_{j,t}$ is the number of either clean or dirty patents that firm j made in period t throughout the world (or the difference between the number of clean and the number of dirty ones). We use both Poisson specification or linear regressions of log(1+number of clean patents) or log(1+number of clean patents) -log(1+number of dirty patents). J_j are firms fixed effects, T_t period fixed effects (t= 2000 or 2010). Standard errors are clustered at the firm level. $values_{j,t}$ is a firm specific measure of exposure to pro-environment values. It is defined as a weighted average of country level attitude measures. Thus the attitude variable for firm j in period t is given by:

$$Values_{j,t} = \sum_{c=1}^{31} \omega_{j,c} \times values_{c,t} \quad (25)$$

Where $values_{c,t}$ is the attitude level in country c period t and $\omega_{j,c}$ is our measure of the importance of country c for firm j. We compute it using patenting activity from PATSTAT data in a pre-period of analysis. More precisely, we define $\omega_{j,c}$ as the share of patents made in country c by firm j between 1950 and 1995. We restrict attention to the 31 countries for which we have data on social values. For countries who did not patent in the pre-period, or at least did not patent in the relevant set of countries in the pre-period, we assign uniform weights.
Our first competition measure for firm j in period t is defined similarly as a weighted average of country level measures of competition. For a subset of firms, we are able to check robustness to firm level measures of competition, defined as lerner index. $X_{j,t}$ are controls, including GDP, population and oil prices. They are also defined for each firm as a weighted average of country level variables, with weights defined as above.

In order to check the robustness of our results to our weights definition, we also use two alternative weights definition. The first one takes into account countries' GDP in the pre-period: $Values_{j,t} = \frac{\sum_{c=1}^{31} \omega_{j,c} \times GDP_{c,pre-period} \times values_{c,t}}{\sum_{c=1}^{31} \omega_{j,c} \times GDP_{c,pre-period}}$ (results to be included later). The second variant has to do with the way we treat firms who did not patent in the pre-period of analysis. Instead of assigning them uniform weights for each country, we weight each country based the average weights that firms who did patent get for this country (results to be included later). Moreover, we also run the analysis at the firm-country level, where no weights are needed. The specification is as follows

$$Innovation_{j,c,t} = \alpha Values_{c,t} + \beta Competition_{c,t} + \gamma Values_{c,t} \times Competition_{c,t} + \delta X_{c,t} + J_j \times C_c + T_t +_{j,c,t} \quad (26)$$

The dependent variable is based on the number of patents of firm j at time t, *in country* c, which we can directly relate to country level measures of values and competition. We show results with either firm, country and time fixed effects, all separate, or with firm times country fixed effects and time fixed effects.

3.1 Data Sources and summary statistics

3.1.1 Clean Innovation Data

We look at the number of clean innovations, the number of dirty ones, and most importantly the difference between the two. Our main variable of interest is thus Log(1+ number of clean patents) minus Log(1+ number of dirty patents). We focus on innovations in the car industry following Aghion et al. (2016) which we derive from patent data. Any given innovation is typically patented in a variety of countries. However, the PATSTAT patent database maintained by the European patent office allows to track all individual patents belonging to the same patent family. We use this to count families rather than patents and refer to a family as an innovation. Using the patent classification system (IPC[7]) we identify clean innovations as all innovations related to non fossil fuel based methods of propulsion such as electric and hydrogen cars and related technologies (e.g. batteries). Similarly, we identify dirty innovation as those related to the internal combustion engine. In robustness tests we also explore the impact on grey technologies; i.e. technologies that improve the efficiency of the internal combustion engine. For that we rely on the recently introduced Y02 classification system.[8] This was introduced by the European patent office with the help of patent examiners to identify innovations that are relevant to mitigate climate impact and was also applied retrospectively; i.e. for innovations from before the introduction of the classification system.

3.1.2 Social values Data

The data on social values come from the International Social Survey Program (ISSP) and from the World Value Survey (WVS). Several questions could capture the pro-environment values we are interested in. We focus on the one that is common to both surveys and allows to maximise coverage both in terms of countries and time periods. This question is stated as follows in the ISSP: "How willing would you be to pay much higher taxes in order to protect the environment?" Answers vary from 1."very willing" to 5. "very unwilling" and we reverse code it such that a higher value means a more pro-environmental attitude. In the WVS, the corresponding question is the following: "I am now going to read out two statements about the environment. For each of them, can you tell me whether you strongly agree, agree, disagree or strongly disagree?
First statement: I would agree to an increase in taxes if the extra money were used to prevent environmental pollution". Answers are 1. strongly agree, 2. agree, 4. disagree and 5 strongly disagree. We

[7] https://www.wipo.int/classifications/ipc/en/
[8] https://www.epo.org/news-issues/issues/classification/classification.html

code as 3 the "dont know" answers and then reverse code the other answers as we did for ISSP such that a higher value means a more pro-environmental attitude. Using these two question from ISSP and WVS, we cover 31 countries for 2 periods: 2000 and 2010.
We also use one additional variable from each survey to create an index. For ISSP, the question is: "How willing would you be to pay much higher prices in order to protect the environment?". For the WVS, the question is about the respondent agrees with the following statement: "I would give part of my income if I were certain that the money would be used to prevent environmental pollution". Answers to these two additional variables are reverse coded exactly similarly as what is done for the main variables. We then collapse all variables at the country-period level, transform in z-scores and then average over which ever is available for the country-period observation.

3.1.3 Competition Data

To measure competition, we use two approaches. The first one relies on country-level competition measures, using two different indicators coming from different sources: the OECD Product Market Regulation (PMR) indicator and the World Bank openness measure. The second approach relies on firm-level measure of competition.

The PMR indicator from the OECD (Koske and Barbiero, 2015) is comprehensive variable which aggregates responses to three main areas: state control, barriers to entrepreneurship, and barriers to trade and investment. It captures the degree to which policies promote or inhibit competition in areas of the product market where competition is viable. It covers all OECD members as well as 21 non-OECD members, and is computed every five years since 1998, but the complete data is not available for all years and countries. This indicator is built using a questionnaire of 700 questions which are then numerically coded and normalized over a zero to six scale. A greater numerical value indicates more (less) product market regulation (competition). These normalized answers are then aggregated into 18 low-level weighted average, which are then grouped into seven mid-level indicators used to compute the value of state control, barriers to entrepreneurship, and barriers to trade and investment. The final PMR value is just a simple average of these three areas. For robustness we also use as a an alternative measure of competition the openness measure of the World Bank.

To compute firm level measures of competition we rely on a Lerner Index style approach which we derive from a structural production function regression. Compared to a standard Lerner Index this allows for non-constant returns to scale as well quasi fixed production factors. A detailed description of the approach is in the Appendix.

3.1.4 Country-level controls

GDP data and population come from the IMF World Economic Outlook database. It covers IMF members since 1980 using data from national statistics offices and international financial institutions. We get data on country level end user automotive fuel prices from the International Energy Agency (IEA).

3.2 Summary statistics

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4 Main results

Table 1 reports results from our firm-level analysis. Panel A through C vary in the definition of the competition variable they use: panel A and B use weighted averages of country-level measures of competition from either the OECD (panel A) or the World Bank (panel B), while panel C uses a firm level measure of competition. The main column of interest is column 5 which gives the difference in growth rates between the number of clean patents and dirty patents. We see that environmental values and competition both have a significant positive effect on clean innovation and that their interaction term also has a significantly positive coefficient. All variables are converted into z-scores.
Thus the magnitudes of our effect are as follows (Table 1, column 5, panel A): a one standard deviation increase in exposure to pro-environmental values is associated with a growth rate of clean patents 20% superior to that of dirty patents, at the mean level of competition. This effect increases to a 33% difference for levels of competition one standard deviation higher than the mean. In terms of the main effect of competition, a one standard deviation increase in exposure to competition is associated with a growth rate of clean patents 14% superior to that of dirty patents, at the mean level of social. As expected an increase in fuel prices is also associated with a higher growth rate of clean patents relative to dirty ones. These results are robust to using alternative variables to measure competition (panels B and C) or values (results to be updated later).
Tables 2 and 3 report results from an analysis at another level, the firm-country level where we no longer need to use weights to construct our variables of exposure to values and competition. The two tables differ in the set of fixed effects they introduce: table 2 has firm, country and time fixed effects, all separate, while table 3 interacts the firm and country fixed effects. We see that the main parameter of interest, the interaction term between values and competition is consistently significantly positive across panels and tables.

The Appendix reports results from additional tests of the model, in particular how the main effect of values and competition varies with fuel prices. So far our results are mostly insignificant.

5 Conclusion

In this paper we brought together patent data, survey data on environmental values, and competition data, to analyze the joint effect of consumers' social responsibility and product market competition on firms' decision whether to innovate clean or dirty. We found supporting evidence to the effect that pro-environment attitudes and competition both have a significantly positive effect on the probability for a firm to aim at cleaner patents. Moreover, the interaction term between consumers' attitudes and product market competition is itself positive and significant. Our results are robust to a broad set of indicators for environmental values and product market competition.

Although our analysis remains more positive than normative, our empirical findings suggest that educational policies aimed at increasing consumers awareness on environmental issues, should be implemented together with a more active competition policy.

This paper should be seen as a very first step in a broader research agenda. In particular, we need to better understand how product market competition interacts with carbon prices. A first step is taken up in Appendix B. Also, we should extend our empirical analysis beyond the car manufacturing industry. These and other extensions of the analysis in this paper are left for future research.

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A Further proofs and propositions

Proof of Proposition 1. Substituting (9) into type (8) yields

$$\delta c^{1-\sigma}\left[e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}c^{\frac{1-\sigma}{\sigma}}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma-1}{\sigma}}\right]^{-\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}=\kappa e^{2-\delta(\sigma-1)} \iff$$

$$\delta c^{1-\sigma}\left[c^{\frac{1-\sigma}{\sigma}}\left(\frac{\sigma-1}{\sigma}\right)^{\frac{\sigma-1}{\sigma}}\right]^{-\sigma}\left(\frac{\sigma-1}{\sigma}\right)^{\sigma}=\kappa e^{2}. \blacksquare \tag{A.1}$$

Proof of Proposition 8. Consider first the comparative statics of N. From (A.21) it is clear that $\partial N \partial \eta < 0$, while $\partial N \partial \eta < 0$ if and only if

$$\frac{1}{\gamma} > \frac{\frac{\delta}{2\gamma^2}+2\frac{\eta}{\gamma}}{\sqrt{(\frac{\delta}{2\gamma})^2+4(1+\frac{\delta}{2})\frac{\eta}{\gamma}}} \iff \frac{\delta^2}{4\gamma^2}+4\frac{\eta}{\gamma}+2\frac{\delta\eta}{\gamma} > \frac{\delta^2}{4\gamma^2}+4\eta^2+2\frac{\delta\eta}{\gamma},$$

which simplifies to $\eta\gamma < 1$. Note also that, in this case, $N > N(+\infty) = \gamma$ for all δ, which is the first requirement in (A.18). As to the second, it holds for all δ if and only if $N(0) = \sqrt{\gamma/\eta} < 2\gamma$, or equivalently $4\gamma\eta > 1$. Both conditions thus hold, for all δ, if and only if

$$\frac{1}{4} < \eta\gamma < 1. \tag{A.2}$$

Since (A.18) was shown to be necessary and sufficient for (A.16), it follows that when $\eta\gamma$ is in the above range, we have:

$$\frac{\partial e}{\partial \eta} < 0 < \frac{\partial e}{\partial \delta}. \tag{A.3}$$

Finally, we turn to the cross-derivative $\partial^2 e^*/\partial\eta\partial\delta$. Since

$$\frac{\partial e^{*2}}{\partial \eta} = \frac{\delta}{\kappa}\left[\frac{\alpha'(N)N-\alpha(N)}{N^2}\right]\frac{\partial N}{\partial \eta} \quad \text{and} \quad \frac{\partial N}{\partial \delta} = -\frac{\alpha(N)/2}{(1+\frac{\delta}{2})\alpha'(N)+\eta},$$

it follows that

$$\frac{\partial^2 e^{*2}}{\partial\eta\partial\delta} = -\frac{1}{\kappa}\left[\frac{\alpha'(N)-\frac{\alpha(N)}{N}}{(1+\frac{\delta}{2})\alpha'(N)+\eta}\right]-\frac{\delta}{\kappa}\frac{\partial}{\partial\delta}\left[\frac{\alpha'(N)-\frac{\alpha(N)}{N}}{(1+\frac{\delta}{2})\alpha'(N)+\eta}\right].$$

For δ small the second term is negligible compared to the first, which is negative given that (A.2) ensures that $N < 2\gamma$, itself equivalent to $d\ln\alpha(N)/d\ln N > 1$. Finally, letting $u^* = e^{*2}$, we have

$$\frac{\partial e^*}{\partial \eta} = \frac{1}{2}\frac{\frac{\partial u^*}{\partial \eta}}{u^*}.$$

Having shown that $\frac{\partial^2 u^*}{\partial\eta\partial\delta} < 0$ for δ small enough, it it will follow that $\frac{\partial^2 e^*}{\partial\eta\partial\delta} < 0$ provided that $\frac{\partial u^*}{\partial\delta} > 0$ for small δ. Indeed, substituting for $\sigma(N) = N/\gamma$ in (A.14) and using the fact that N tends to $N(0) = \gamma/\eta$

as δ tends to zero, we have:

$$u^* = \frac{\delta}{N\kappa}\left(1 - \frac{\gamma}{N}\right) = \frac{\delta}{\kappa}\sqrt{\frac{\eta}{\gamma}}\left(1 - \sqrt{\frac{\gamma}{\eta}}\right) + o(\delta),$$

which establishes the result. ■

Proof of Proposition 7. Taking logarithms in (A.11), the equilibrium e is uniquely given by $\varphi(\sigma, t, e, \kappa/\delta) = 0$, where we define the function:

$$\varphi(\sigma, t, e, \kappa/\delta) \equiv \ln\left(\frac{\sigma - 1}{\sigma}\right) + (\sigma - 1)\ln\left[1 + t\left(\frac{1-e}{c}\right)\left(\frac{\sigma - 1}{\sigma}\right)\right] - 2\ln e - \ln\left(\frac{\kappa}{\delta}\right). \tag{A.4}$$

Since φ is increasing in σ and t, and decreasing e, c and κ/δ, properties (A.12) are immediate. Turning now to cross-derivatives, we have:

$$\begin{aligned}
\frac{\partial\varphi}{\partial t} &= (\sigma - 1)\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1 + t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)},\\
\frac{\partial\varphi}{\partial e} &= (\sigma - 1)\left(\frac{-t}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1 + t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)} - \frac{2}{e} \Longrightarrow\\
\left(\frac{\partial e}{\partial t}\right)^{-1} &= \frac{(\sigma - 1)\left(\frac{t}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1+t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)} - \frac{2}{e}}{(\sigma - 1)\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1+t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)}}\\
&= \frac{t}{1-e} - \frac{2}{e\left[(\sigma - 1)\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1+t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)}\right]}.
\end{aligned}$$

which varies with σ in the same way as:

$$\begin{aligned}
\psi(\sigma) &\equiv \frac{(\sigma-1)^2}{\sigma + t\left(\frac{1-e}{c}\right)(\sigma - 1)}. \qquad \text{(A.5)}\\
\frac{\psi'(\sigma)}{\psi(\sigma)} &= \frac{2}{\sigma - 1} - \frac{1 + t\left(\frac{1-e}{c}\right)}{\sigma + t\left(\frac{1-e}{c}\right)(\sigma - 1)}\\
&\propto 2\left[\sigma + t\left(\frac{1-e}{c}\right)(\sigma - 1)\right] - (\sigma - 1)\left[1 + t\left(\frac{1-e}{c}\right)\right]\\
&= \sigma + 1 + t\left(\frac{1-e}{c}\right)(\sigma - 1).
\end{aligned}$$

Therefore: ψ is increasing in σ, implying that $\partial e/\partial t$ is decreasing in σ, or $\partial^2 e/\partial t\partial\sigma < 0$. Next: $\partial\varphi/\partial(\delta/\kappa) = \kappa/\delta$, so:

$$\begin{aligned}
\left(\frac{\partial e}{\partial(\delta/\kappa)}\right)^{-1} &= \frac{\delta}{\kappa}\left[(\sigma - 1)\left(\frac{t}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\frac{1}{1 + t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)} + \frac{2}{e}\right]\\
&= \frac{\delta}{\kappa}\left[\left(\frac{t}{c}\right)\frac{(\sigma-1)^2}{\sigma + t\left(\frac{1-e}{c}\right)(\sigma - 1)} + \frac{2}{e}\right]\\
&= \frac{\delta}{\kappa}\left[\left(\frac{t}{c}\right)\psi(\sigma) + \frac{2}{e}\right],
\end{aligned}$$

which is decreasing in σ. Therefore, $\partial^2 e/\partial\sigma\partial(\delta/\kappa) > 0$. ■

Proof of Proposition 2 Define $\beta \equiv \delta/\kappa < 1$ and $x \equiv \sqrt{\alpha} \in [0,1]$, so that (15) can be rewritten as:

$$f(x) \equiv x^2(1-\beta x). \tag{A.6}$$

We have $f'(x) < 0 \iff 2(1-\beta x) < \beta x$, i.e. $x > 2/(3\beta)$. Therefore f is increasing in $\alpha = x^2$ on $[0,1] \cap [0, \sqrt{4\kappa/9\beta}]$ and decreasing on $[0,1] \cap [\sqrt{4\kappa/9\beta}, 1]$. In both cases, moreover, we have $\partial^2 f/\partial\beta\partial x < 0$, therefore the rate of pollution increase (respectively, decrease) is slower (respectively, faster), the larger is δ/κ. ∎

Proof of Proposition 3. From (17), $\partial^2 U/\partial\delta\partial\alpha > 0$ if and only if

$$\frac{\partial}{\partial\delta}\left[\left(1+\frac{\delta}{2}\right)(\alpha\delta)^{\frac{\delta}{2}}\right] > 0 \iff \frac{\partial}{\partial\delta}\left[\ln\left(1+\frac{\delta}{2}\right) + \frac{\delta}{2}\ln(\alpha\delta)\right] > 0 \iff$$
$$\frac{1}{2+\delta} + \frac{1}{2}([1+\ln(\alpha\delta)]) > 0 \iff \alpha > \frac{1}{\delta}\exp\left(-\frac{4+\delta}{2+\delta}\right).$$

The last term is the threshold $\hat{\alpha}$, and it derivative with respect to δ has the sign of $2/(2+\delta)^2 - 1/\delta < 0$. ∎

Proof of Proposition 4. (1) From (20), $V'(\alpha) > 0$ if and only if

$$v(e) \equiv \left(\frac{1+\delta/2}{1+\zeta}\right)\left(\frac{\delta c}{\kappa}\right)^{\xi}\frac{e^{\delta-2\zeta}}{(1-e)^{\zeta}} - \psi\left(1-\frac{3}{2}e\right) > 0, \tag{A.7}$$

allowing us to analyze the variations of $V(\alpha)$ as a function of $e = \sqrt{\alpha\delta/\kappa}$. For $\delta \geq 2\xi$, $v(e)$ is strictly increasing, so V is either monotonic on $[0,1]$ (if $v(0) \geq 0$) or first decreasing on some $[0,\tilde{\alpha}]$ and then increasing on $[\tilde{\alpha}, 1]$. (For $\zeta = 0$, in particular, V is convex in α). In either case, its global maximum is reached at 0 or 1,which yields the first part of the proposition.

(2) For $\delta < 2\xi$, on the other hand, $v(0) = +\infty$, so $\alpha = 0$ is never even a local optimum of V. The global optimum is then $\alpha = 1$ or some interior α_V^*, and a sufficient condition for the latter case is that $V(0) > V(1)$, which again is the stated condition.

Turning comparative-statics result, it is clear from (20) that $\partial^2 V/\partial\psi\partial\alpha < 0$, which establishes the first claim since $\partial^2 V/\partial\alpha^2 < 0$ at any interior maximum. Turning to the effects of social values, we have

$$c.\frac{\partial^2 V}{\partial\delta\partial\alpha} = \frac{e^{\delta}}{2} + \psi\left(1-\frac{3}{2}e\right)\left(\frac{(1+\zeta)\zeta}{\delta}\right)\left(\frac{\kappa}{\delta c}\right)^{\zeta} e^{2\xi}(1-e)^{\xi} + \Omega\frac{\partial e}{\partial\delta}, \tag{A.8}$$

where

$$\Omega \equiv \left(1+\frac{\delta}{2}\right)\delta e^{\delta-1} + \frac{3\psi}{2}(1+\zeta)\left(\frac{\kappa}{\delta c}\right)^{\zeta} e^{2\zeta}(1-e)^{\zeta} - \psi\left(1-\frac{3}{2}e\right)(1+\zeta)\left(\frac{\kappa}{\delta c}\right)^{\zeta}\zeta\left(\frac{2}{e} - \frac{1}{1-e}\right)e^{2\zeta}(1-e)^{\zeta}. \tag{A.9}$$

Evaluating (A.9) and (A.8) at the optimum, which satisfies the first-order-condition

$$\psi(1+\zeta)\left(\frac{\kappa}{\delta c}\right)^{\zeta} e^{2\xi}(1-e)^{\xi} = \left(1+\frac{\delta}{2}\right)\frac{e^{\delta}}{1-3e/2}, \tag{A.10}$$

yields:

$$\Omega \equiv \left(1+\frac{\delta}{2}\right)\delta e^{\delta-1} + \psi(1+\zeta)\left(\frac{\kappa}{\delta c}\right)^{\zeta} e^{2\zeta}(1-e)^{\zeta}\left[\frac{3}{2} - \left(1-\frac{3}{2}e\right)\zeta\left(\frac{2}{e} - \frac{1}{1-e}\right)\right],$$

$$\begin{aligned}
c.\frac{\partial^2 V}{\partial\delta\partial\alpha} &= \frac{e^{\delta}}{2} + \left(1+\frac{\delta}{2}\right)\frac{e^{\delta}\zeta}{\delta} \\
&+ \left[\left(1+\frac{\delta}{2}\right)\delta e^{\delta-1} + \left(1+\frac{\delta}{2}\right)\frac{e^{\delta}}{1-3e/2}\left[\frac{3}{2} - \left(1-\frac{3}{2}e\right)^2\frac{2\zeta}{e(1-e)}\right]\right]\frac{e}{2\delta} \\
&= \frac{e^{\delta}}{2} + \left(1+\frac{\delta}{2}\right)\frac{e^{\delta}}{2} + \left(1+\frac{\delta}{2}\right)\frac{e^{\delta}}{\delta}\left[\zeta + \frac{1}{1-3e/2}\left[\frac{3e}{4} - \left(1-\frac{3}{2}e\right)^2\frac{\zeta}{1-e}\right]\right].
\end{aligned}$$

Examining the terms proportional to ζ inside the square brackets, we can observe that:

$$1 > \frac{1}{1-3e/2}\left(1-\frac{3}{2}e\right)^2\frac{1}{1-e} \iff 1-e > 1-3e/2 \iff e/2 > 0,$$

which finishes to establish that $\partial^2 V/\partial\delta\partial\alpha > 0$ at the interior optimum. ■

Generalization of Proposition 4. We combine here Propositions 2 and 3, with $\alpha^*(\delta)$ and $\hat{\alpha}(\delta)$ given by (16) and (18) respectively, and further note that

$$\hat{\alpha}(\delta) < \alpha^*(\delta) \iff \delta \exp\left(\frac{2+\delta}{4+\delta}\right) < \left(\frac{2\kappa}{3}\right)^2,$$

in which the left-hand-side is clearly increasing in δ. This allows to state the following results.

Proposition 6. *There are thresholds $\alpha^*(\delta)$ and $\hat{\alpha}(\delta)$ for the intensity of market competition, both decreasing in consumers' social-responsibility concerns δ, such that:*

1. *For $\alpha > \alpha^*(\delta)$, further increases in competition unambiguously raise consumer welfare V, by simultaneously increasing consumption utility U and reducing total pollution Z.*
2. *For $\alpha > \hat{\alpha}(\delta)$, competition's effect on consumer welfare is more favorable (less negative or more positive), the greater are individuals' ethical concerns: $\partial^2 V/\partial\sigma\partial\delta > 0$.*
3. *There exists a $\tilde{\delta}$ (increasing in κ) such that $\alpha^*(\delta) < \hat{\alpha}(\delta)$ if and only if $\delta < \tilde{\delta}$.*

A.1 Incorporating carbon prices or taxes

In this section we extend the model to allow for carbon or other environmental taxes, or equivalently variations in the price of polluting inputs; in the empirical analysis, the corresponding variable will be the tax-adjusted price of oil.. We show that all the results in Proposition 1 remain unchanged, and derive further predictions about the impact of the tax or oil price and its interactions with both market competition and consumer preferences.

Assume that a tax of t per unit of pollution emitted when consuming/using a good, or in the process of producing it, is now imposed on consumers. Thus, when producer prices are p_i, consumers face prices $q_i \equiv p_i + t\tau_i$. Equivalently, the pollution is created by the use of a complementary good (gas for the car, heavy metals components in electronics, CFC's in air-conditioning units) in fixed proportion τ_i, and the total price (including taxes or subsidies) of that input is t per unit.

Producers' problem is unchanged, and thus still leads to $p_i = p$ and $e_i = e = 1 - \tau$ given, as a function of λ, by (8). On consumers' side, the prices p_i are replaced by $q_i = p + te = q$. The equilibrium is therefore again symmetric, with now: $C = 1/q$ and (3) taking the form

$$\lambda = q^{\frac{1-\sigma}{\sigma}} e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}.$$

Substituting into (8), the new equation defining e is therefore:

$$\delta c^{1-\sigma} \left[q^{\frac{1-\sigma}{\sigma}} e^{\delta\left(\frac{\sigma-1}{\sigma}\right)}\right]^{-\sigma} \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} = \kappa e^{2-\delta(\sigma-1)} \iff \left(\frac{\sigma-1}{\sigma}\right)^{\sigma} \left(\frac{q}{c}\right)^{\sigma-1} = \frac{\kappa}{\delta} e^2.$$

Or, finally:

$$\left(\frac{\sigma-1}{\sigma}\right) \left[1 + t\left(\frac{1-e}{c}\right)\left(\frac{\sigma-1}{\sigma}\right)\right]^{\sigma-1} = \frac{\kappa}{\delta} e^2. \tag{A.11}$$

The left-hand side is decreasing in e and the right-hand side increasing, so again as long as $\delta/\kappa < 1$ (or $< \sigma/(\sigma-1)$ more generally), there is a unique equilibrium and it is interior. We can furthermore show (proof in the appendix).

Proposition 7 (**carbon prices and technological choices**). *Technology's level of environmental friendliness $e = 1 - \tau \in (0,1)$ is uniquely given by (A.11), and has the following comparative-statics properties:*

$$\frac{\partial e^*}{\partial(\delta/\kappa)} > 0, \ \frac{\partial e^*}{\partial \sigma} > 0, \ \frac{\partial^2 e}{\partial \sigma \partial(\delta/\kappa)} > 0. \tag{A.12}$$

$$\frac{\partial e^*}{\partial(t/c)} > 0 \ , \frac{\partial^2 e^*}{\partial \sigma \partial(t/c)} < 0. \tag{A.13}$$

The level effects are the same as before, except that now the marginal cost of production c also matters, reducing clean investments, whereas carbon or oil prices t correspondingly raise them; this is intuitive. Also unchanged is the result that competition and environmental preferences are *complements,* whereas we now see that competition and carbon taxes (or oil prices) are *substitutes.* The underlying intuition is that both t/c and σ push firms to increase e^*, thus moving up the increasing-marginal-cost curve.

A.2 Entry

An alternative measure of competition is the number of firms in the market, which we will denote N, or, in the long run, the size of entry costs determining it. The direct, mechanical effect of a smaller market share $1/N$ for each firm is to make fixed-cost investments less profitable, and this applies in particular to the kind of "green R&D" on which we focus here. At the same time, an essential feature of competition as usually understood is to increase consumers' ability to play one firm against the other, captured for instance by an increase in the elasticity of substitution, as analyzed above. Appealing to a recent literature on entry and endogenous markups, we shall posit in what follows a relationship between N and σ that, while chosen as a convenient reduced form, is very close to the one for which Behrens, and Murata (2007) provide explicit microfoundations.

Exogenous number of firms. In a first step, let us abstract from the-free entry condition, thus treating N as exogenous in the short to medium run. Proposition 1 was derived under the normalization $N \equiv 1$, but this immediately extends to any fixed number of firms, with

$$e^{*2} = \frac{1}{N}\frac{\delta}{\kappa}\frac{\sigma - 1}{\sigma}. \tag{A.14}$$

The direct investment-reducing effect of a smaller market share is immediately apparent. As explained above, however, we also allow a greater density of firms to affect the elasticity of substitution; thus σ,or equivalently the inverse markup

$$\alpha \equiv \left(\frac{\sigma - 1}{\sigma}\right), \tag{A.15}$$

is taken to be an increasing function of N.

Let us now look for conditions under which greater competition, now defined in the sense of a higher N, continues to increase investments in clean technologies, in a manner complementary with consumers' social-responsibility concerns. From (A.14), it is then clear that

$$\frac{\partial e^*}{\partial N} > 0; \quad \frac{\partial^2 e^*}{\partial \delta \partial N} > 0, \tag{A.16}$$

if and only if firms' *markup falls more than one for one* with $N : d\ln\alpha/d\ln N > 1$, or equivalently in terms of σ :

$$N\sigma'(N) + \sigma(N) > (\sigma(N))^2. \tag{A.17}$$

That a higher N should make demand more elastic is intuitive, but note that since $\alpha < 1$ the effect on (A.14) bounded, so that the desired elasticity condition requires that N not be too large. To make things concrete, we shall assume from here on that

$$\sigma(N) = N/\gamma,$$

where N must be such that $N > \gamma$ to ensure that $\sigma(N) > 1$, or equivalently $\alpha(N) = 1 - \gamma/N > 0$.[9]

[9]As a comparison, in Behrens and Murata's (2007) general-equilibrium model of monopolistic competition with CARA preferences, the elasticity of substitution in any symmetric equilibrium is shown to take the form $\sigma = 1 + cN/\gamma$.

Substituting into (A.17), the comparative statics (A.16) thus hold for N in the range:

$$N \in [\gamma, 2\gamma]. \tag{A.18}$$

Free-entry equilibrium. Each firm's profits are $\Pi = (p-c)C - \kappa e^2/2 = (1-c/p)/N - \kappa e^2/2$, which by (A.14) equals

$$\Pi = (1-\alpha) - \frac{\delta}{2}\alpha = 1 - (1+\frac{\delta}{2})\alpha. \tag{A.19}$$

In the long run, N is thus determined by the free-entry condition:

$$\Pi = \frac{1}{N}\left(1 - \alpha(N) - \frac{\delta}{2}\alpha(N)\right) = \eta, \tag{A.20}$$

where $\eta > 0$ is the fixed cost of entering the market. With $\sigma(N) = N/\gamma$, this takes the form $1 + \frac{\delta}{2} - \frac{\delta}{2\gamma}N = \frac{\eta}{\gamma}N^2$, so the equilibrium number of firms is

$$N = \frac{\delta}{4\eta}\left[-1 + \sqrt{1 + \frac{8\gamma\eta}{\delta}\left(1 + \frac{2}{\delta}\right)}\right], \tag{A.21}$$

naturally decreasing in η. In the appendix we show that it is decreasing in δ if and only if $\eta < 1/\gamma$, as evidenced by the fact that $N(\eta, +\infty) = \gamma$ and $N(\eta, 0) = \sqrt{\frac{\gamma}{\eta}}$. These results lead, in turn to a set of sufficient conditions under which comparative statics to similar to (11) for σ and (A.16) for N obtain, but now only involving the exogenous entry cost η as a measure of competition.

Proposition 8 (effects of entry)**.** *For $\eta\gamma \in (1/4, 1)$, we have $\frac{\partial e^*}{\partial \eta} < 0 < \frac{\partial e^*}{\partial \delta}$ If, furthermore, δ is small enough, then $\frac{\partial e^*}{\partial \eta \partial \delta} < 0$.*

Thus, increased competition in the sense of reduced barriers to entry can again increase green investment, and the more ethically concerned consumers are, the more so. It need not have that effect, however, and in particular η cannot be driven too low, or else the number of firms becomes so large that the market-share effect swamps the elasticity effect. Which way the balance of these two forces goes thus is thus ultimately an empirical question, and Section **??** will show (using multiple indicators of firm competition and environmental concerns) that the data largely support the green-R&D promoting of competition, an especially of its interaction with social responsibility

For these reasons, and clearly also for tractability, we chose to work with the basic CES model, in which competition is directly parametrized by σ. This allowed us to both derive further positive predictions that we will examine in the data, and to carry out a welfare analysis, a key part of which involve determining when competition increases or lowers the equilibrium level of emissions.

B Computation of firm level Lerner Index

We estimate firm level measures of competition using a (revenue) production function framework. Note that firm level (log) revenue (R_{it}) growth can be written as

$$\Delta r_{it} \approx \frac{\gamma}{\bar{\mu}_{it}} + \bar{s}_{Mit}\left(\Delta m_{it} - \Delta k_{it}\right) + \bar{s}_{Lit}\left(\Delta l_{it} - \Delta k_{it}\right) + \frac{1}{\bar{\mu}_{it}}\Delta\omega_{it} \tag{A.22}$$

where $\Delta r_{it} = \ln R_{it} - \ln R_{it-1}$ (and equivalently for production factors) and we assume a homothetic translog production function with materials M_{it} and labor L_{it} as flexible factors and capital K_{it} a quasi fixed production factor. γ is a scale paramter. $\bar{s}_{Mit} = \frac{s_{Mit}+s_{Mit-1}}{2}$ is the average share of materials expendisture in revenue between period t and $t-1$ (and equivalently for labor inputs). ω is a composite shock comprising of a Hicks neutral production shifter (TFPQ) and a demand shifter. $\bar{\mu}_{it}$ is the average markup of prices over marginal cost between period t and $t-1$. Hence, $\bar{\mu}_{it}$ -1 is a Lerner index specific to firm i at time t. Short run profit maxmisation implies that

$$s_{Mit} = \frac{\alpha_{Mit}}{\mu_{it}} \tag{A.23}$$

where α_{Mit} is the elasticity of output w.r.t to changes in production factor M (and analougously for labor). Note that in the translog case

$$\alpha_{Mit} = \alpha_M + \alpha_{KM}k_{it} + \alpha_{LM}l_{it} + \alpha_{MM}m_{it} \tag{A.24}$$

Note that the specification is consistent with a wide variaty of market structures. For further discussion see Martin (2012) and Forlani (2016). We can rewrite equation A.22 as

$$LHS_{it}\frac{\bar{\alpha}_{Mit}}{\gamma} - \Delta k_{it} = \frac{1}{\gamma}\Delta\omega_{it} \tag{A.25}$$

where

$$LHS_{it} = \frac{\Delta r_{it} - \frac{\gamma}{\bar{\mu}_{it}} + \bar{s}_{Mit}\left(\Delta m_{it} - \Delta k_{it}\right) + \bar{s}_{Lit}\left(\Delta l_{it} - \Delta k_{it}\right)}{\bar{s}_{Mit}}$$

Subject to assumptions about the evolution of the $\Delta\omega_{it}$ shock, we can fit this to standard firm level data using a GMM approach; e.g. suppose that $\Delta\omega_{it}$ follows an AR(1) process so that

$$\omega_{it} = \rho\omega_{it-1} + \eta_{it}$$

where $\eta_{it} \sim iid$. We can then write

$$\hat{\eta}_{it} = LHS_{it}\frac{\bar{\alpha}_{Mit}}{\gamma} - \Delta k_{it} - \frac{\rho}{\gamma}\left[LHS_{it-1}\frac{\bar{\alpha}_{Mit-1}}{\gamma} - \Delta k_{it-1}\right]$$

and to estimate the parameters

$$\delta = \left[\frac{\rho}{\gamma}, \frac{\alpha_M}{\gamma}, \frac{\alpha_{KM}}{\gamma}, \frac{\alpha_{LM}}{\gamma}, \frac{\alpha_{MM}}{\gamma}\right]$$

we can use the moment conditions

$$E\left\{\hat{\eta}_{it} \times \left[LHS_{it-1}, \frac{1}{\Delta k_{it}}, \frac{\bar{k}_{it}}{\Delta k_{it}}, \frac{\bar{l}_{it}}{\Delta k_{it}}, \frac{\bar{m}_{it}}{\Delta k_{it}}\right]\right\}$$

After identifying δ, we can compute $\widehat{\frac{\alpha_{Mit}}{\gamma}}$ using equation A.24 Using A.23 we can then compute

$$\frac{\widehat{\gamma}}{\mu_{it}} = s_{Mit} \left(\widehat{\frac{\alpha_{Mit}}{\gamma}} \right)^{-1} \tag{A.26}$$

which is an inverse Lerner Index scaled by the returns to scale parameter γ; i.e. it tells us the excess of markups over returns to scale. Hence, while this is different from the markup over marginal costs this is the more relevant in terms of measuring market power as it corresponds to the excess earnings over what would be reasonable to compensate for increasing returns.

We also implement a simpler version assuming a Cobb Douglas production function implying that $\alpha_{Mit} = \alpha_M$. Both approaches lead to similar results.

Table 1: **Main results**

VARIABLES	(1) Poisson # clean	(2) Poisson # dirty	(3) Log (1+ #clean)	(4) Log (1+ #dirty)	(5) Log (1+#clean) - Log (1+#dirty)
			Panel A: OECD measure of competition		
values	0.0508	-0.0965	0.0387	-0.159***	0.198***
	(0.185)	(0.119)	(0.0361)	(0.0346)	(0.0405)
competition	0.0717	-0.350	0.172***	0.0341	0.138**
	(0.440)	(0.279)	(0.0579)	(0.0584)	(0.0639)
valuesXcompetition	0.0138	-0.0273	0.0998***	-0.0291	0.129***
	(0.139)	(0.103)	(0.0277)	(0.0288)	(0.0326)
log fuel price	-0.394	-2.085**	0.478**	-0.155	0.633**
	(1.147)	(0.916)	(0.202)	(0.240)	(0.257)
Observations	7,882	7,428	17,124	17,124	17,124
R-squared			0.183	0.024	0.123
Number of firms	3,941	3,714	8,562	8,562	8,562
			Panel B: World Bank measure of openness		
values	0.0599	-0.441**	0.0544	-0.233***	0.287***
	(0.364)	(0.214)	(0.0423)	(0.0415)	(0.0508)
competition	0.223	0.380	0.470***	0.219**	0.251*
	(1.412)	(0.916)	(0.101)	(0.108)	(0.134)
valuesXcompetition	0.0163	-0.129**	0.0470***	-0.0425***	0.0895***
	(0.104)	(0.0633)	(0.0172)	(0.0158)	(0.0202)
log fuel price	-0.663	-0.451	0.404*	0.128	0.276
	(1.195)	(0.967)	(0.228)	(0.222)	(0.263)
Observations	7,882	7,428	17,124	17,124	17,124
R-squared			0.180	0.026	0.122
Number of firms	3,941	3,714	8,562	8,562	8,562
			Panel C: Firm level competition measure		
values	-1.171	-2.191***	0.410***	-0.247**	0.657***
	(1.099)	(0.421)	(0.106)	(0.101)	(0.137)
competition	-0.0692	-0.0575	0.0283	0.0466*	-0.0183
	(0.223)	(0.182)	(0.0244)	(0.0249)	(0.0304)
valuesXcompetition	0.342**	0.158*	0.0379**	-0.0150	0.0530**
	(0.166)	(0.0915)	(0.0182)	(0.0192)	(0.0242)
log fuel price	4.017	12.21***	0.952	0.349	0.602
	(8.809)	(3.472)	(0.582)	(0.591)	(0.620)
Observations	786	882	2,706	2,706	2,706
R-squared			0.299	0.060	0.206
Number of firms	393	441	1,854	1,854	1,854

Note: We restrict attention to patents in the automobile sector. All regressions include firm and period fixed effects, controls include log of GDP and log of population. The difference between the columns are in terms of dependent variable while the difference between the panels are in terms of the competition measure used. Standard errors in parenthesis are clustered at the firm level. * $p < .1$, ** $p < .05$, *** $p < .01$

Table 2: **Analysis at the firm*country*year level, with firm, country and year fixed effects**

VARIABLES	(1) Poisson # clean	(2) Poisson # dirty	(3) Log (1+ #clean)	(4) Log (1+ #dirty)	(5) Log (1+#clean) - Log (1+#dirty)
			Panel A: OECD measure of competition		
values	0.108	0.0554	-0.00718***	-0.00696**	-0.000215
	(0.0815)	(0.0633)	(0.00252)	(0.00334)	(0.00345)
competition	0.0250	0.204**	-0.00486	0.00214	-0.00700
	(0.114)	(0.0869)	(0.00307)	(0.00440)	(0.00464)
valuesXcompetition	0.0323	-0.117***	0.00302*	-0.00555***	0.00857***
	(0.0618)	(0.0425)	(0.00157)	(0.00210)	(0.00210)
log fuel price	0.907***	0.331*	0.120***	-0.0145	0.135***
	(0.245)	(0.169)	(0.00944)	(0.0125)	(0.0133)
Observations	29,461	34,246	51,569	51,569	51,569
R-squared			0.066	0.059	0.026
Number of firms	2,734	3,346	6,510	6,510	6,510
			Panel B: World Bank measure of openness		
values	0.158**	0.100**	-0.00246	-0.00164	-0.000814
	(0.0742)	(0.0480)	(0.00190)	(0.00244)	(0.00257)
competition	0.166**	-0.186*	0.0178***	-0.00603	0.0238***
	(0.0785)	(0.113)	(0.00360)	(0.00530)	(0.00545)
valuesXcompetition	0.116***	-0.0485*	0.0133***	0.00202	0.0113***
	(0.0318)	(0.0251)	(0.00145)	(0.00167)	(0.00173)
log fuel price	0.552**	0.135	0.0875***	-0.0129	0.100***
	(0.231)	(0.150)	(0.00676)	(0.00875)	(0.00966)
Observations	31,640	37,043	55,231	55,231	55,231
R-squared			0.067	0.060	0.025
Number of firms	2,747	3,362	6,514	6,514	6,514

Note: In this table there is no weights used to construct firm level measures of social or competition because the analysis is at the firm*country*year level instead of the firm*year level in Table 1. * $p < .1$, ** $p < .05$, *** $p < .01$

Table 3: **Analysis at the firm*country*year level, with firm*country and year fixed effects**

VARIABLES	(1) Poisson # clean	(2) Poisson # dirty	(3) Log (1+ #clean)	(4) Log (1+ #dirty)	(5) Log (1+#clean) - Log (1+#dirty)
	Panel A: OECD measure of competition				
values	-0.176	0.0107	-0.0165***	-0.00721	-0.00933*
	(0.118)	(0.0963)	(0.00376)	(0.00493)	(0.00536)
competition	0.0837	0.216	-0.00270	0.00390	-0.00659
	(0.136)	(0.133)	(0.00370)	(0.00552)	(0.00574)
valuesXcompetition	-0.214**	-0.188**	0.00506**	-0.00761***	0.0127***
	(0.0923)	(0.0889)	(0.00197)	(0.00277)	(0.00296)
log fuel price	0.943***	0.361	0.143***	0.0123	0.130***
	(0.291)	(0.286)	(0.0105)	(0.0137)	(0.0151)
Observations	7,504	9,514	51,569	51,569	51,569
R-squared			0.074	0.001	0.035
Number of firm*country	3,752	4,757	37,739	37,739	37,739
	Panel B: World Bank measure of openness				
values	-0.236**	0.111	-0.00878***	-0.000862	-0.00791**
	(0.113)	(0.0986)	(0.00276)	(0.00356)	(0.00400)
competition	0.647***	-0.332	0.0300***	-0.00155	0.0315***
	(0.213)	(0.216)	(0.00515)	(0.00672)	(0.00776)
valuesXcompetition	-0.217**	-0.0810	0.0146***	6.62e-05	0.0146***
	(0.0919)	(0.0852)	(0.00166)	(0.00224)	(0.00257)
log fuel price	1.061***	0.165	0.106***	0.0141	0.0924***
	(0.308)	(0.259)	(0.00985)	(0.0115)	(0.0133)
Observations	7,718	9,824	55,231	55,231	55,231
R-squared			0.073	0.001	0.034
Number of firms * country	3,859	4,912	40,008	40,008	40,008

Note: Same as table 2 but with firm*country and year fixed effects, instead of firm, country and year fixed effects * $p < .1$, ** $p < .05$, *** $p < .01$