Environmental Preferences and Technological Choices: Is Market Competition Clean or Dirty?[†]

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We investigate the effects of consumers' environmental concerns and market competition on firms' decisions to innovate in "clean" technologies. Agents care about their consumption and environmental footprint; firms pursue greener products to soften price competition. Acting as complements, these forces determine R&D, pollution, and welfare. We test the theory using panel data on patents by 7,060 automobile sector firms in 25 countries, environmental willingness to pay, and competition. As predicted, exposure to prosocial attitudes fosters clean innovation, all the more so where competition is strong. Plausible increases in both together can spur it as much as a large fuel price increase. (*JEL* D22, L62, O31, O34, Q52, Q53, Q54)

Should private firms get involved in mitigating climate change? A traditional view against such corporate activism is that firms should concentrate on maximizing profits and let governments deal with externalities. In practice, however, we often see governments being ineffective at addressing environmental problems.[1] It then falls upon intrinsically motivated consumers, investors, and firms to "do their part" through other channels.

This paper shows how citizens' social-responsibility concerns and the degree of competition between firms jointly shape the direction of innovation, acting as *complements*. We first develop a simple model of innovation where agents care about both the level and environmental footprint of their consumption. We analyze how

these "ethical" preferences, together with market structure, affect the equilibrium amount of clean R&D and through it aggregate pollution and welfare.

While competition has a direct, short-run negative impact on the environment—lower prices induce more consumption and therefore more pollution[2]—it can also encourage clean innovation as a means of product differentiation. Intuitively, firms will seek to develop greener products when facing more environmentally motivated customers, and the more so, the harder they must compete for these buyers.

Due to its offsetting quantity and quality effects, the impact of competition on emissions has a concave profile. Furthermore, because social responsibility and competition *leverage each other*, when the former is strong enough, the profile can be hump shaped, or even decreasing, reversing the direct effect. Similarly, more prosocial consumers not only push this profile down but also make increases in competition (desirable for the usual reasons) less environmentally costly or even beneficial.

We then bring together patent data, survey data on environmental values, and competition measures to test the model's key comparative statics. We relate the extent to which firms innovate in a clean direction to their exposure to proenvironmental attitudes and competition. Attitudes vary at the country level, while competition is a Lerner-type index at the country times four-digit sector level. A firm's exposure is defined as a weighted average of the country or country-sector level measures, where the weights proxy for the importance of the different countries to the firm. Our data cover 7,060 firms and 25 countries during 1998–2002 and 2008–2012. We find a significant positive effect of proenvironment attitudes on the probability for a firm to innovate relatively more in the clean direction, and this effect is stronger the higher competition is. Our empirical analysis suggests that the combination of realistic increases in prosocial attitudes and in product market competition can have the same effect on green innovation as a 17 percent increase in fuel prices worldwide.

Our research contributes to several literatures. The first one is that on competition and innovation (Aghion, Harris, and Vickers 1997; Aghion et al. 2001; Aghion et al. 2005; Vives 2008). The second is that on growth and the environment, pioneered by Nordhaus (1994),[3] particularly the work on endogenous directed technical change analyzing how R&D is shaped by public policies such as carbon taxes and/or subsidies to green innovation (Newell, Jaffe, and Stavins 1999; Popp 2002; Acemoglu et al. 2012; Aghion et al. 2016). We connect these two literatures and bring in individuals' willingness to "do their part" through their own consumption choices, which becomes essential when policymaking is deficient. Third is the literature on individual and corporate social responsibility (CSR), both reflecting a mix of intrinsic and reputational motivations (Bénabou and Tirole 2010, 2011; Hart and Zingales 2017); we introduce here product competition as a channel through which consumers' social preferences influence firms' investment decisions. This also relates the paper to experiments such as Falk and Szech (2013) and especially Bartling, Weber, and Yao (2015), where lab subjects compete in the roles of both consumers and producers.

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[2] The examples of China or India today, or the increasing market share of SUVs everywhere since the 1980s, illustrate this. Similarly, increasing worldwide competition in the airline industry results in increasing travel and emissions.

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

On the empirical side, some papers have examined how competition affects CSR performance, finding mixed results.[4] We depart from this literature in several ways. First, we focus on the environmental dimension rather than overall CSR, on the automobile industry, and on firms' innovation decisions rather than their production or emissions (which, the model shows, need not go in the same direction). Most importantly, we emphasize the *interaction* in each firm's set of markets between competition and consumers' environmental concerns. Differences in national preferences and firms' differential exposures to them not only have a significant effect per se but turn out to be what makes competition actually matter for whether R&D is clean or dirty.

I. Model

Time is discrete, with individuals and firms living for one period. At the beginning of each period t, firms choose R&D investments, aiming to maximize expected profits. Once innovations have realized, firms produce with their respective technologies, competing for consumers. Revenues are paid out as wages to production and R&D workers, and net profits are redistributed to consumers, who are also firms' shareholders.

A. *Preferences*

There is a continuum of differentiated goods, $j \in [0, 1]$. Within and/or across these sectors, firms potentially differ both by the price they charge and the environmental (un)friendliness of the goods they produce. The production or consumption of one unit of good with environmental quality q generates $x = 1/q$ units of polluting emissions.

The representative consumer has standard taste-for-variety preferences but is also concerned about his environmental footprint. When buying $y_{j,f}$ units of quality $q_{j,f}$ from each firm f in sector j (denote that set as $\mathcal{F}_j$), he achieves consumption utility

$$(1) \qquad\qquad U_t = \int_0^1 \ln \bar{y}_{j,t} \, dj,$$

where

$$(2) \qquad\qquad \bar{y}_j = \int_{f \in \mathcal{F}_j} y_{j,f} (q_{j,f})^\delta \, df$$

is his emissions-impact-discounted consumption of variety j. The disutility suffered from total emissions will come in subtraction when analyzing welfare but is taken by each individual as given.

These preferences embody a form of ethical motivation. An individual's contribution to aggregate emissions is negligible and for instance does not affect the quality of the air anyone breathes; nonetheless, he intrinsically dislikes contributing to the externality. He feels guilty, or/and socially embarrassed, about the carbon he emits

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[4] See Fisman, Heal, and Nair (2006); Fernández-Kranz and Santaló (2010); Flammer (2015); Hawn and Kang (2013); Duanmu, Bu, and Pittman (2018); and Liu et al. (2021).

when driving or flying and so would pay a premium for cleaner goods. δ captures the strength of these social-responsibility concerns.

While sectors are imperfect substitutes, within each one firms' quality-adjusted offerings are perfect substitutes. Therefore, all demand for variety j will go to the firm(s) in $\mathcal{F}_j$ with the highest quality/price ratio, q^δ/p. Furthermore, with logarithmic preferences the same amount will be spent on each variety; we normalize it to 1, choosing current expenditure as the numeraire.

B. *Technology and Market Structure*

Labor is the only input, with agents offering an infinitely elastic supply at a wage normalized to 1. It takes c units of labor to produce one unit of output (e.g., one car), with the firm's technology determining the associated emissions, $1/q$. That technology, in turn, reflects the cumulative number $k_f \in \mathbb{N}$ of (green) innovations it made in the past or copied from someone who did:

$$q_f = \gamma^{k_f},$$

where $\gamma > 1$ measures the size of a leading-edge environmental innovation. Since consumers value a quantity-quality combination (y, q) as $y q^\delta$, it effectively takes $c \gamma^{-\delta k_f}$ units of labor for a firm at level k_f to produce one unit of quality-adjusted output.

Each sector j consists of a duopoly, $f = A, B$, plus a lagging competitive fringe, as follows. First, in each period t both firms have free access to the frontier technology achieved in period $t - 1$. These strong knowledge spillovers simplify the R&D problem by limiting the investment horizon to a single period.

Second, a firm's R&D effort can result in at most one innovation over the current frontier: for any $z \leq 1$, investing $\kappa z^2/2$ units of labor yields a probability z of inventing a technology that is γ times cleaner and a probability $1 - z$ of zero progress.

Together, these assumptions imply that the gap that can open between firms is at most one innovation, $|k_B - k_A| \in \{0, 1\}$, and it *resets to zero* at the start of every period.

A third simplifying assumption is that at the innovation stage (where $k_A = k_B$), only one (either) of the two firms has an opportunity to invest in R&D. The other lacks, in the current period, a suitable idea or managerial capacity, effectively making its κ prohibitively large.

There can thus, at any point in time, only be two kinds of sectors: *leveled*, where the duopolists' qualities are "neck and neck," and *unleveled*, where a *leader* is one step ahead of its *follower*. At the start of each period t, which corresponds to the *investment* phase, all sectors are neck and neck, while during the subsequent *production* phase of that period, a fraction z are unleveled, corresponding to the R&D intensity chosen by investing firms.

In each sector, there is also a competitive fringe of potential entrants. These firms will neither produce nor do research in equilibrium but act as a threat, disciplining the duopolists. We thus assume that at the start of each period t, the fringe can costlessly imitate the previous-best technology, meaning one that embodies only the

$k' = k - 1$ previous innovations, where $k = k_A = k_B$ is the level from which the duopolists start and may further innovate.

C. *Competition and Profits*

Recall that consumers spend the same amount on each variety, and firms in each sector compete for that fixed revenue, normalized to 1. Consider first an unleveled sector, where an innovation just occurred. The leader has a quality advantage of γ^δ over the follower—its cars pollute γ times less—so it can engage in limit pricing, charging $p_M = \gamma^\delta c$ and capturing all demand. The output and operating profits of such a *de facto* monopolist are

$$(3) \qquad y_M = \frac{1}{p_M} = \frac{1}{\gamma^\delta c}, \ \pi_M = 1 - \frac{1}{\gamma^\delta}.$$

Consider now a leveled sector, where no innovation recently occurred. If the two firms engage in unfettered competition, the equilibrium price falls to c, resulting in zero profits. Conversely, if they collude perfectly to maximize joint profits, they set $p = p_M$ like the leader in an unleveled sector and reap $\pi_M/2$ each. Indeed, $c\gamma^\delta$ is the price that just keeps out the competitive fringe, which produces goods γ times more polluting than those of the duopolists.

Following Aghion et al. (2005), we span the range between these two extremes by representing (inverse) market competition as the extent to which neck-and-neck firms are able to collude at the production-and-sales stage. Thus, we assume that the normalized profit for each firm is:

$$\pi_D(\Delta) \equiv (1 - \Delta) \pi_M,$$

where $\Delta \in [1/2, 1]$ parametrizes the degree of competition.[5] The corresponding price and sectoral output are given by equating total profits to total sales minus costs:

$$(4) \qquad p(\Delta) = \frac{c}{1 - 2(1 - \Delta)\pi_M} = \frac{c}{1 - 2(1 - \Delta)(1 - \gamma^{-\delta})} \in [c, p_M],$$

$$(5) \qquad y(\Delta) = \frac{1}{p(\Delta)} = \frac{1}{c}\left[1 - 2(1 - \Delta)(1 - \gamma^{-\delta})\right] \in \left[y_M, \frac{1}{c}\right].$$

For given technologies, competition has the standard effect of forcing down the equilibrium price, which increases consumer demand and production. More units produced and sold, in turn, result in more emissions—the *mass-consumption effect*. The other consequence of competition is to affect incentives to innovate, which we examine next.

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[5] We assume that collusion occurs only at the (ex post) stage of production and pricing and not at the ex ante stage of R&D, which for instance could be harder to monitor.

D. *Escaping Competition through Clean Innovation*

Recall that each sector starts the current period with both firms neck and neck, then one of the two (at random) is endowed with an opportunity for engaging in R&D. If it invests $z \leq 1$, it succeeds in developing a cleaner technology with probability z, reaping π_M; with probability $1 - z$, it fails and must collude with its equally able competitor, reaping only π_D. A potential innovator thus solves

$$\max_{z \in [0,1]} \left\{ z \pi_M + (1 - z) \pi_D(\Delta) - \kappa z^2/2 \right\},$$

resulting in $z = \min\left\{ (\pi_M - \pi_D(\Delta))/\kappa, 1 \right\}$. We restrict attention to parameters values such that

$$(6) \qquad \kappa > \pi_M = 1 - \frac{1}{\gamma^\delta} \equiv \kappa_1,$$

meaning that innovations are not too easy in terms of their importance or cost. The optimal R&D intensity is then interior:

$$(7) \qquad z(\Delta) = \frac{\Delta \pi_M}{\kappa} = \frac{\Delta}{\kappa}\left(1 - \frac{1}{\gamma^\delta}\right).$$

Averaging across sectors $j \in [0,1]$, the rate of R&D is also the proportion of them where innovation will occur, so the aggregate flow of clean innovations per period is simply $I \equiv z(\Delta)$. Hence:

PROPOSITION 1: *Both market competition and consumers' social-responsibility concerns raise investment in, and the total flow of, clean innovations. Moreover, these two forces act as complements:*

$$(8) \qquad \frac{\partial I}{\partial \Delta} > 0, \frac{\partial I}{\partial \delta} > 0, \frac{\partial^2 I}{\partial \Delta \partial \delta} > 0.$$

In a more general model with clean *and* dirty innovations (e.g., SUVs), greater competition would generally enhance both types, but the proportion of clean ones would still rise with prosocial values and their interaction with market competition.

E. *Pollution and Welfare*

At the production stage of each period, there is a fraction z of sectors in which one firm has become cleaner than the other by a factor γ, and a fraction $1 - z$ where the innovation effort has failed, so that both still use period $t - 1$'s frontier technology. Total emissions (normalized by total expenditure) thus equal

$$(9) \qquad X = [1 - z(\Delta)]y(\Delta) + z(\Delta) y_M/\gamma.$$

This is a concave quadratic polynomial in Δ, reflecting two opposing effects. On the one hand, by increasing output $y(\Delta)$ in neck-and-neck sectors, competition directly increases pollution. On the other hand, the fear of lower profits causes firms to seek

a quality advantage through R&D; as a result, a greater fraction $z(\Delta)$ of sectors develop clean technologies, which tends to reduce emissions.

PROPOSITION 2: *Define $\kappa_2 \equiv 1 - \gamma^{-\delta}(1 + 1/\gamma)/2 > \kappa_1$ and let $\kappa > \kappa_1$. As competition $\Delta \in [1/2, 1]$ increases:*

(i) *For $\kappa < \kappa_2 - \kappa_1/2$, aggregate pollution $X(\Delta)$ decreases monotonically.*

(ii) *For $\kappa > \kappa_2 + \kappa_1/2$, $X(\Delta)$ increases monotonically.*

(iii) *For $\kappa \in (\kappa_2 - \kappa_1/2, \kappa_2 + \kappa_1/2)$, $X(\Delta)$ is hump shaped; moreover, it is minimized at $\Delta = 1$ (versus $\Delta = 1/2$) if and only if $\kappa < \kappa_2$.*

(iv) *For all κ in $[\kappa_1, \kappa_2]$, $X(\Delta)$ is minimized at $\Delta = 1$.*[6]

This proposition and the next are illustrated in Figure 1. All propositions are proved in online Appendix A.

PROPOSITION 3: *Aggregate pollution $X(\Delta)$ decreases with consumers' social-responsibility concerns δ. For all $\kappa > \kappa_1$ (more generally, if R&D effort is interior), it decreases more, the stronger is market competition: $\partial^2 X/\partial\Delta\partial\delta < 0$.*[7]

Let us now evaluate net social welfare. Its first component is utility from consuming the z "greener" and the $1 - z$ "dirtier" varieties:

$$(10) \qquad U = (1 - z(\Delta))\ln y(\Delta) + z(\Delta)\ln[\gamma^\delta y_M].$$

Competition raises U through both a quantity effect (higher $y(\Delta)$) and a quality effect (higher $z(\Delta)$, reallocating consumption toward cleaner varieties). The second component of well-being is environmental quality. Assuming a linear disutility from aggregate pollution, welfare equals[8]

$$(11) \qquad W = U - \psi X, \psi > 0.$$

Proposition 2 showed that when innovation costs κ are relatively high, or competition Δ relatively weak, $\partial X/\partial\Delta > 0$. Whether greater competition improves or damages social welfare then hinges on how large ψ is. When κ is low and Δ sufficiently high, conversely, $\partial X/\partial\Delta < 0$, so $\partial W/\partial\Delta > 0$.

The impact of prosocial concerns similarly depends on how costly R&D is and on the competitive pressure on firms to bear those costs. For fixed z, a higher δ

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[6] Proof outline. The polynomial (9) is maximized at $\hat{\Delta}_X(\kappa, \gamma, \delta) = 1/2 + (2\kappa - 1 + \gamma^{-\delta}/\gamma)/4\pi_M$, which rises with κ from $1/2$ at $\kappa_2 - \kappa_1/2$ to 1 at $\kappa_2 - \kappa_1/2$. Moreover, $X(1) < X(1/2)$ if and only if $\kappa_1 < \kappa_2$.

[7] Proof outline. (a) In (9), as δ rises, both y_M and $y(\Delta)$ decrease (agents reduce their consumption to pollute less), and there is a substitution toward cleaner goods ($z(\Delta)$ rises). (b) The higher is Δ, the less responsive is $y(\Delta)$ to consumer preferences (as profits $\pi(\Delta)$ declines), whereas z responds more.

[8] These are the only two terms since (i) the disutility of labor employed in production and research is exactly compensated by wage payments and (ii) wages plus operating profits are entirely consumed by individuals, so that total income equals total spending.
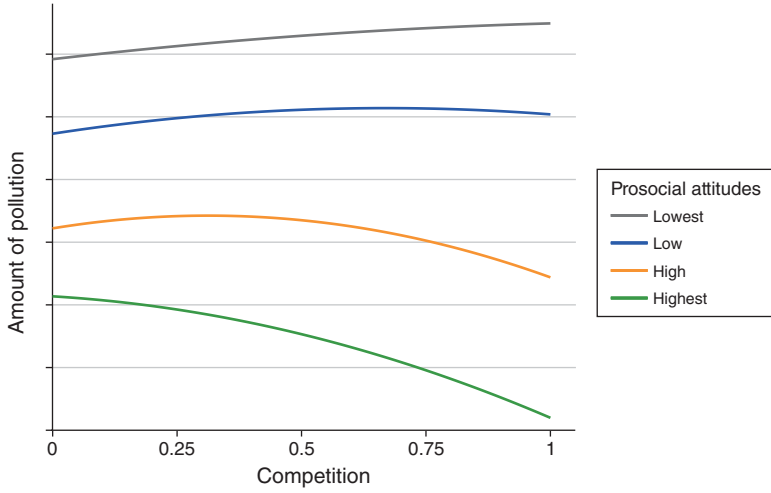
FIGURE 1. EFFECT OF COMPETITION AND SOCIAL VALUES ON POLLUTION

means that consumers experience more "guilt" from each unit of pollution embodied in their consumption, lowering U. A more environmentally responsible population, however, pushes firms to produce cleaner goods: z increases, raising U and lowering X.

PROPOSITION 4: (*i*) *For* $\kappa \in [\kappa_1, \kappa_2 - \kappa_1/2]$, *social welfare W increases monotonically with competition; more generally, there is* $\hat{\kappa} > \kappa_2$ *such that for all* $\kappa \in [\kappa_1, \hat{\kappa}]$, *W is maximized at* $\Delta = 1$. (*ii*) *W increases with consumers' environmental concerns* δ *if and only if competition is strong enough.* (*iii*) *If* ψ *is large enough or if* $\kappa \geq 2\kappa_1$, *preferences and competition are complements,* $\partial^2 W/\partial\Delta\partial\delta > 0$.[9]

II. Empirical Strategy and Identification

We now test the model's key predictions for innovation, stated in Proposition 1. Specifically, we relate the extent to which a firm increases its innovation in the clean direction to changes in its exposure to environmental values and competition, by running regressions of the form:

$$(12) \qquad \Delta Innovation_j = \alpha \Delta Values_j + \beta \Delta Competition_j$$

$$+ \gamma \Delta \big(Values_j \times Competition_j \big) + \delta \Delta X_j + \varepsilon_j.$$

All variables are first differences at the firm level between 2008–2012 and 1998–2002. We restrict the analysis to these two periods because of data constraints

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[9]Proof outline. Given the properties of $X(\Delta)$ in Proposition 2: (a) follows from $\partial U/\partial\Delta > 0$ and (b) from the fact $\partial U/\partial\pi_M > 0$ when Δ is above some threshold $\Delta(\pi_M, \kappa)$ that makes the product mix $z(\Delta) = \Delta\pi_M/\kappa$ sufficiently responsive to $\pi_M = 1 - \gamma^{-\delta}$ to dominate the increased guilt from consumption (discussed above), as δ rises; (c) follows directly from (11) where ψ is concerned; for κ, it follows from (10) and (4).

(see below). In our preferred specification, $Innovation_j = \log(1+\text{number of clean patents}_j) - \log(1+\text{number of dirty patents}_j)$.[10]

$\Delta Values_j$ is a firm-specific weighted average of country-level changes in proenvironmental attitudes:

$$\Delta Values_j = \sum_{c=1}^{25} \omega_{j,c} \times \Delta values_c,$$

where $\omega_{j,c}$ measures the importance of country c for firm j. In theory one would use firms' sales or profits, but such data are not available. Instead, we compute $\omega_{j,c}$ using the share of patents filed in country c by firm j between 1950 and 1995, based on the idea that protecting intellectual property is more worthwhile where one expects its market to be larger. Aghion et al. (2016) show that these weights are very correlated with sales for the firms for which country-level sales data are available. We restrict attention to the 25 countries for which we have data on both environmental values and potential confounders (i.e., fuel price and environmental policies). Our competition measure is also a shift-share variable described below. Finally, the X_j are controls defined below.

The shift-share or Bartik design used for our main variables of interest has recently been discussed by Goldsmith-Pinkham, Sorkin, and Swift (2020); Borusyak, Hull, and Jaravel (2022), and Adão, Kolesár, and Morales (2019). These suggest two paths to identification: exogenous shocks and exogenous weights. A possible threat to identification in our setting is that firms with higher capabilities to innovate in clean technologies might patent more in countries with more proenvironmental consumers. This would introduce endogeneity with respect to both shocks and weights. Additionally, the innovation behaviour of national champions might exert a direct influence on country-level values.

We take several steps to address such concerns. First, our regressions are in first differences between our two periods. Second, the weights are based on presample patenting behaviour. Hence, we only require firms' clean innovation *growth* (rather than *level*) to be unrelated to country-level shocks and/or to market selection in the presample period. Third, we control for the headquarter country, which deals with reverse causality due to support for "national champions."

Fourth, our preferred specification includes extensive conditioning variables: dummies for the country with the maximum weight for each firm; sector dummies to purge any potential endogeneity arising from sector-specific growth shocks; and variables constructed using the same firm-country weights (population, GDP, fuel price, environmental policies index) to control for potential country-level confounders correlated with the dependent variable and the shocks of interest.

Besides identification issues, Adão, Kolesár, and Morales (2019) also note that common country-level shocks across firms with a similar weight structure can affect standard errors. We consequently perform the adjustment proposed by these authors, noting that because our framework includes interactions effects and

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[10] We show robustness to using clean share defined as $\frac{(1 + clean_j)}{(2 + clean_j + dirty_j)}$. The 1 added to both numerator and denominator ensures smoothness for firms that did not patent in one of the periods.

many controls, it lies somewhat outside the set of formal results available in their paper (see online Appendix D for details).

III. Data

A. *Innovation*

Our innovation measures come from patents in the car industry. Compared to R&D investment, patents are available at a more disaggregated level and can thus be classified as clean or dirty. Moreover, the auto sector is innovation intensive, and patents are perceived as an effective means of protection against imitation (Cohen, Nelson, and Walsh 2000). An innovation is typically patented in multiple countries, but the European Patent Office's PATSTAT database (patstat) allows us to track all individual patents belonging to the same family. A patent family identifies an inventive step that is subsequently patented several times with different patent offices. We use this to count families rather than patents and refer to a family as an innovation.

To classify innovations, we use the International Patent Classification (IPC) system and the Y02 classification introduced by the European Patent Office in 2002 to rate the climate impact of innovations (both pre- and post-2002). Clean innovations are those involving non-fossil-fuel-based propulsion, such as electric or hydrogen cars and affiliated technologies (e.g., batteries), while dirty ones are those related to the internal-combustion engine. We leave aside the "grey" and "other" categories, which are neither unambiguously "clean " nor "dirty" (see Table C.1 in the online Appendix).

Figure 2 shows the worldwide evolution of car-related innovations since the 1960s. The annual number has grown from around 3,000 in the 1960s to over 40,000 in 2010. Until 2000, this growth was mostly driven by patents in the "other" category, but since then clean patents also grew rapidly. Our sample consists of all firms in the industry that patented at least once during either 1998–2002 or 2008–2012[11] and for which we have the four-digit sector code, required for our competition measure. This yields 7,060 firms, of which 2,662 patented in both periods. In 1998–2002, conditional on patenting, the average number of innovations per firm is 0.78 clean ones and 4.3 dirty ones; in 2008–2012, these figures are 3.2 for both types.

B. *Environmental Values*

The data on attitudes come from the International Social Survey Program (ISSP[12]) and the World Values Survey (WVS[13]). Several questions could capture the values we are interested in, but they are often asked only in a limited set of countries or during a single survey wave. We thus create a synthetic index based on the only question common to both surveys that asks about willingness to accept higher taxes for the environment, and, since taxes pertain to public policy more directly than to consumer spending, one additional question from each survey. In the ISSP it is about willingness

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[11] Our environmental willingness-to-pay measures are available only during these two periods. We thus take five-year windows centered on 2000 and 2010 and sum a firm's annual innovations over each.

[12] Haller, Ressler, and Hadler (2003); Hadler, Carton, and Jorrat (2019)

[13] Inglehart et al. (2018a, b); Gedeshi, Zulehner, and Rotman (2021)

Panel A. Absolute number of innovations
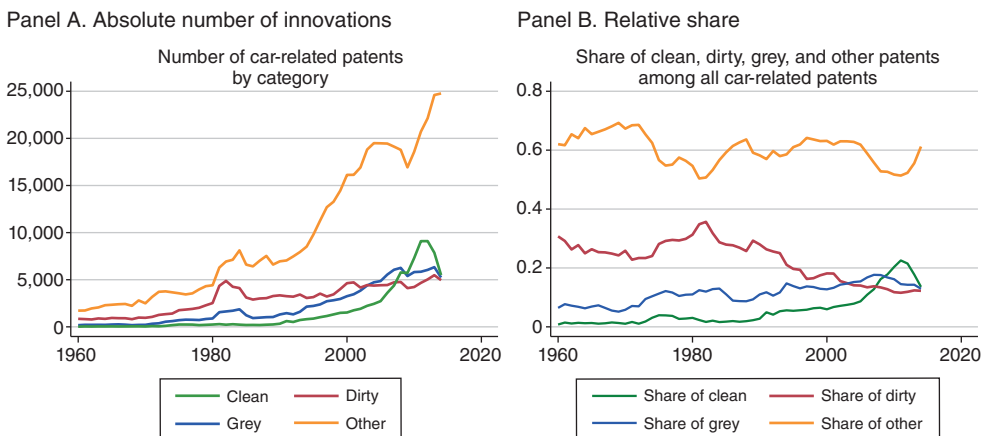
Panel B. Relative share

FIGURE 2. EVOLUTION OVER TIME OF CLEAN, DIRTY, GREY, AND OTHER CAR-RELATED INNOVATIONS

Notes: Patents classified as clean, dirty, grey, or other based on the IPC and Y02 classification systems. See main text and online Appendix C.1 for more details.

Source: PATSTAT

to pay higher prices in order to protect the environment, and in the WVS it is about willingness to give up part of one's income to prevent environmental pollution.

We code all answers so that higher values mean more proenvironmental attitudes (see online Appendix C for details). We then average all variables at the country-period level, transform them into z-scores, and eventually average across all variables available for the country-period observation. We thus have data on environmental willingness to pay for 25 countries for two periods, namely 2000 and 2010.

In most countries, proenvironmental values decreased over this period. This is not a specificity of the datasets we use, nor of the exact point in time when we measure attitudes. Online Appendix B, Figure 3 provides a time series plot of answers to a similar question, asked by the Gallup survey (Saad 2019) to US respondents. The prevailing trend from the early 1990s to the beginning of the 2010s was a sharp *reduction* in environmental concerns. The reasons for this are unclear, and there is even little awareness of this fact in the literature. Figure 3 also shows a sharp reversal after our period of analysis. This is a more general trend: Carlsson et al. (2021) show that between 2010 and 2020, willingness to pay for climate mitigation also increased in China and Sweden. Therefore, in the last section, we will forecast what our estimates imply for green innovation if the decrease in environmental values during the first decade of the 2000s was totally reversed by their more recent upturn.

C. *Competition*

To compute a firm's exposure to competition, we rely on a Lerner-style approach, derived from a structural production-function regression. This requires using additional balance sheet data from ORBIS (Bureau van Dijk 2018). Compared to

a standard Lerner Index, it allows for nonconstant returns to scale and quasi-fixed production factors (see online Appendix C.3). Contrary to other sectors or national trends, most automobile firms experienced a reduction in market power during that time period (see online Appendix Figure A2).

A Lerner-style competition measure, however, raises endogeneity concerns. Patents, by definition, give the holder market power, so if we find a relation between competition and innovation, it could be due to reverse causality. We therefore assume that firm-level competition at time t (inverse markups) is a weighted average of the degree of competition in country c and two-digit sector s, $comp_{c,s(j),t}$, and an idiosyncratic firm-level shock $\nu_{j,t}$:

$$\frac{1}{\mu_{j,t}} = \sum_c comp_{c,s(j),t} \times w_{c,j} + \nu_{j,t}.$$

Rather than use raw inverse markups, one would like to base the analysis on the $comp_{c,s(j),t}$, which are not directly observed. In principle, we could recover the $comp_{c,s(j),t}$ by regressing (inverse) markups on patent weights $w_{c,j}$, but weights might again be endogenous to firm-level shocks. We therefore base our assessment of the market environment for firm j on firms other than j, specifically on firms outside of j's narrow four-digit industrial sector. Indeed, if a close competitor to j succeeds with an innovation, it could reduce j's markup or affect its patent shares (j may try to differentiate itself by focusing on other countries). Our "leave one sector out" instrument assumes that a firm's innovation would only causally affect firms within its narrow sector but not outside.[14]

D. *Country-Level Controls*

We control for end user, tax-inclusive automotive fuel prices from the International Energy Agency (International Energy Agency 2021), real GDP per capita from the World Bank (World Bank 1960–2021), population from the IMF's World Economic Outlook, and the Environmental Policy Stringency (EPS) Index from the OECD, which provides a comprehensive measure of environment-related regulations, taxes, tariffs, and R&D subsidies (Botta and Kozluk 2014). All country-level indicators are transformed into firm-level variables through the same weighting approach as for the main regressors.

E. *Patent Portfolio Weights*

Our benchmark definition of country-firm weights $\omega_{j,c}$ is the share of a firm's patents filed in each country between 1950 and 1990. We include all patents of the firm in the relevant countries, not only automobile-related ones. Germany and the

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[14] We compute our firm-level competition index by first running, for each firm j, a regression $\frac{1}{\mu_{i,t}} = \sum_c comp_{c,s(i),t} \times w_{c,i} + \nu_{i,t}$ on the sample of firms i such that $s(i) = s(j)$ and $s4dig(i) \neq s4dig(j)$, where $s4dig(i)$ is the four-digit sector classification of firm i. This provides us with firm-specific estimates $co\hat{m}p_{c,s(j),t}$ of the competitive environment for every country and time period. Provided the shocks to ϵ_j in (12) only affect firms within a four-digit sector, these estimates will be orthogonal to them. Our index of exogenous changes in firm-level exposure to competition is therefore $\Delta co\hat{m}p_j = \sum_c \left(co\hat{m}p_{c,s(j),t} - co\hat{m}p_{c,s(j),t-1} \right) w_{c,j}$. Online Appendix C.4 provides more details.

United States have the largest weight, with 8 percent on average, followed by the United Kingdom, France, Korea, and Japan, with about 4 percent on average. Other weights definitions yield similar results.[15]

IV. Empirical Results

Table 1 reports our benchmark results, with all magnitudes expressed as z-scores. Panel A displays the main effects of environmental values, competition, and their interaction on the direction of innovation, controlling only for population and GDP per capita. Panel B further controls for fuel price and environmental policies. Panel C adds sector fixed effects and dummies for the headquarter country and that with the highest weight. Column 1 shows the main outcome of interest, namely the change in the growth rate of clean innovations relative to dirty ones; columns 2 and 3 report the effects on both types separately, while column 4 uses the change in the share of clean patents to alleviate potential concerns related to the log transformation.

We see that greener consumer values significantly push innovation in the clean direction and all the more so where competition is high. Competition has a positive effect on clean innovation, but it is not significant once we add all the controls (panel C).[16]

In our preferred specification of panel C, a 1 standard deviation increase in exposure to proenvironmental values is associated with a growth rate of clean patents 16 percent higher than that of dirty ones, at the mean level of competition. This effect increases to 20 percent for levels of competition 1 standard deviation higher than the mean. Predictably, an increase in fuel prices is also associated with a higher growth rate of clean patents relative to dirty ones.

Table 2 examines the results' robustness, using as benchmark the specification of Table 1, panel C. Panel A incorporates preperiod GDP into the weights definition, based on the idea that large countries matter more:[17,18]

$$(13) \qquad \omega_{j,c} = \frac{\omega_{j,c} \times GDP_{c,preperiod}^{0.35}}{\sum_{c=1}^{25} \omega_{j,c} \times GDP_{c,preperiod}^{0.35}}.$$

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[15] In our preferred weight definition, we compute $w_{c,i} = \frac{1 + PAT_{c,i}}{\sum_{\kappa} 1 + PAT_{\kappa,i}}$, where $_{i,c}$ is the number of patents firm i has filed in country c. By adding 1 to every firm-country combination, we ensure a smooth comparison between firms with no versus some presample patenting.

[16] This is consistent with the model, for small δ : $z(\Delta) \approx (\Delta/\kappa)\delta \ln \gamma$, so $\partial z/\partial \Delta \approx 0$, whereas $\partial z/\partial \delta$ and $\partial^2 z/\partial \delta \partial \Delta$ are significantly positive. More generally, the net effect of competition on R&D is known to be ambiguous (see the introduction), and our estimates suggest that environmentally conscious consumers help tilt that balance toward more (clean) innovation.

[17] Following Dechezleprêtre et al. (2020), we use $(GDP)^{0.35}$: Eaton, Kortum, and Kramarz (2011) estimate an elasticity of firms' average exports to GDP of destination country of 0.35.

[18] Further checks are available upon request. In particular, some firms in our sample did not patent in the relevant set of countries during the preperiod. In our baseline specification, we assign them uniform weights by adding one to the number of patents of a firm in each country. This ensures a smooth transition between firms with and without presample patents. Our results are robust to (i) not doing this transformation, (ii) dropping firms that did not patent in the preperiod, and (iii) assigning them, for each country, the average weight among firms that *did* patent in the preperiod.

TABLE 1—THE EFFECTS OF VALUES AND COMPETITION ON THE DIRECTION OF INNOVATION

Dependent variables:	$\Delta(\log(1+\text{clean}) - \log(1+\text{dirty}))$	$\Delta\log(1+\text{clean})$	$\Delta\log(1+\text{dirty})$	Δclean share
	(1)	(2)	(3)	(4)
Panel A. The main variables of interest				
ΔValues	0.1461	0.0684	−0.0777	0.0228
	(0.0219)	(0.0209)	(0.0186)	(0.0039)
ΔCompetition	0.0751	0.0185	−0.0566	0.0126
	(0.0379)	(0.0309)	(0.0294)	(0.0073)
ΔValues $\times$ Competition	0.0286	0.0006	−0.0280	0.0034
	(0.0115)	(0.0100)	(0.0089)	(0.0020)
R^2	0.027	0.034	0.016	0.016
Observations	7,060	7,060	7,060	7,060
Panel B. Robustness to controlling for fuel price and environmental policies				
ΔValues	0.1149	0.0802	−0.0348	0.0181
	(0.0240)	(0.0230)	(0.0198)	(0.0043)
ΔCompetition	0.0614	0.0228	−0.0386	0.0105
	(0.0376)	(0.0307)	(0.0286)	(0.0073)
ΔValues $\times$ Competition	0.0240	0.0024	−0.0216	0.0027
	(0.0116)	(0.0101)	(0.0088)	(0.0020)
Δlog fuel price	0.9607	−0.3084	−1.269	0.1471
	(0.3193)	(0.2913)	(0.2763)	(0.0603)
ΔEPS	0.1141	−0.0620	−0.1761	0.0171
	(0.0999)	(0.0859)	(0.0881)	(0.0194)
R^2	0.029	0.035	0.021	0.017
Observations	7,060	7,060	7,060	7,060
Panel C. Robustness to adding sectoral and other controls				
ΔValues	0.1633	0.0955	−0.0678	0.0266
	(0.0265)	(0.0262)	(0.0246)	(0.0050)
ΔCompetition	0.0109	0.0028	−0.0082	0.0027
	(0.0402)	(0.0327)	(0.0300)	(0.0079)
ΔValues $\times$ Competition	0.0415	0.0143	−0.0272	0.0051
	(0.0155)	(0.0138)	(0.0120)	(0.0026)
Δlog fuel price	0.9505	0.1364	−0.8141	0.1530
	(0.3979)	(0.3707)	(0.3857)	(0.0793)
ΔEPS	0.1712	0.0489	−0.1224	0.0326
	(0.1139)	(0.0944)	(0.0993)	(0.0228)
Fixed effects				
Sector fixed effects (84)	Yes	Yes	Yes	Yes
HQ country (56)	Yes	Yes	Yes	Yes
Highest country share (25)	Yes	Yes	Yes	Yes
R^2	0.078	0.103	0.053	0.068
Observations	7,060	7,060	7,060	7,060

Notes: The difference between the various panels is in terms of controls. Besides the coefficients shown or the fixed effects mentioned, all specifications control for GDP per capita and population. All variables are first differences. Standard errors are robust.

Panel B performs the analysis at the firm-country level, for which no weights are needed. The specification is

$$(14) \qquad \Delta Innovation_{j,c} = \alpha \Delta Values_c + \beta \Delta Competition_c$$

$$+ \gamma \Delta Values_c \times Competition_c + \delta \Delta X_c + \varepsilon_{j,c}.$$

TABLE 2—ROBUSTNESS CHECKS

Dependent variables:	Δ(log (1+clean) $-$ log (1+dirty)) (1)	Δlog (1+clean) (2)	Δlog (1+dirty) (3)	Δclean share (4)
Panel A. Robustness to using other weights				
ΔValues	0.1658	0.0971	−0.0687	0.0270
	(0.0267)	(0.0263)	(0.0245)	(0.0050)
ΔCompetition	0.0186	0.0099	−0.0088	0.0027
	(0.0356)	(0.0267)	(0.0287)	(0.0070)
ΔValues × Competition	0.0329	0.0063	−0.0266	0.0039
	(0.0155)	(0.0137)	(0.0124)	(0.0026)
Δlog fuel price	1.025	0.1754	−0.8493	0.1642
	(0.3969)	(0.3700)	(0.3851)	(0.0790)
ΔEPS	0.1833	0.0615	−0.1218	0.0341
	(0.1137)	(0.0938)	(0.0996)	(0.0227)
Fixed effects				
Sector fixed effects (84)	Yes	Yes	Yes	Yes
HQ country (56)	Yes	Yes	Yes	Yes
Highest country share (25)	Yes	Yes	Yes	Yes
R^2	0.077	0.102	0.053	0.068
Observations	7,060	7,060	7,060	7,060
Panel B. Analysis at the firm-country level				
ΔValues	0.00149	0.00420	0.00272	0.000303
	(0.00129)	(0.000938)	(0.00109)	(0.000259)
ΔCompetition	0.000743	0.00203	0.00129	0.000149
	(0.000704)	(0.000480)	(0.000596)	(0.000145)
ΔValues × Competition	0.00225	0.00268	0.000432	0.000387
	(0.000667)	(0.000469)	(0.000551)	(0.000133)
Δlog fuel price	0.141	0.166	0.0250	0.0290
	(0.0111)	(0.00815)	(0.00928)	(0.00222)
ΔEPS	0.0124	0.0104	−0.00193	0.00269
	(0.00143)	(0.00102)	(0.00122)	(0.000299)
Sector fixed effects (84)	Yes	Yes	Yes	Yes
HQ country (56) FE	Yes	Yes	Yes	Yes
Highest country share (25)	Yes	Yes	Yes	Yes
R^2	0.016	0.022	0.012	0.016
Observations	137,925	137,925	137,925	137,925
Panel C. Computing the standard errors with the methods of Adão, Kolesár, and Morales (2019)				
ΔValues	0.1633	0.0955	−0.0678	0.0266
	(0.0170)	(0.0067)	(0.0161)	(0.0032)
ΔCompetition	0.0109	0.0028	−0.0082	0.0027
	(0.0054)	(0.0015)	(0.0054)	(0.0010)
ΔValues × Competition	0.0415	0.0143	−0.0272	0.0051
	(0.0021)	(0.0006)	(0.0024)	(0.0003)
Δlog fuel price	0.9505	0.1364	−0.8141	0.1530
	(0.1970)	(0.0780)	(0.1880)	(0.0349)
ΔEPS	0.1712	0.0489	−0.1224	0.0326
	(0.1136)	(0.0274)	(0.1061)	(0.0195)
Fixed effects				
Sector fixed effects (84)	Yes	Yes	Yes	Yes
HQ country (56)	Yes	Yes	Yes	Yes
Highest country share (25)	Yes	Yes	Yes	Yes
R^2	0.079	0.103	0.054	0.069
Observations	7,060	7,060	7,060	7,060

Notes: The baseline specification in this table is that of Table 1, panel C. Panel A incorporates GDP in the weight definition. Panel B runs the analysis at the firm-country level. Panel C computes the standard errors with the formula of Adão, Kolesár, and Morales (2019). Besides the coefficients shown or the fixed effects mentioned, all specifications control for GDP per capita and population. All variables are first differences.

In the firm-level analysis, if an innovation is patented in several countries, we count it once and use the date of the first patent. Here, we look at all patents: for a given innovation, there might be different filing dates for different countries.

Panel C reports the standards errors computed using Adão, Kolesár, and Morales's (2019) formula. This adjustment is not straightforward, as our setting features an interaction term between two shift-share variables, as well as many controls. In our case, this leads to lower standard errors. This suggests negative correlation of the residuals within cluster (where "cluster" refers here to the weighted exposure to countries).[19]

To summarize: in line with the model's predictions, proenvironmental values push innovation in the clean direction, all the more so when competition is more vigorous.

V. Accounting and Counterfactual Exercises

We now use our fitted model (Table 1, panel C) to conduct both retrospective and prospective simulations.

Table 3 (panel A, column 1) shows that between 1998–2002 and 2008–2012, the share of clean innovations increased by 35 percentage points. How can this be reconciled with the fact that citizens in our sample countries generally became *less* concerned with environmental priorities between 2000 and 2010?

First, environmental attitudes evolved very differently across countries. If the only change had been a uniform decline (the observed mean), the clean share would have fallen by 4.8 percentage points. Because of correlation between firms' changes in exposure ΔV_j and their level of patenting activity (see online Appendix B for details), the impact of the properly weighted average of ΔV_j's is somewhat different but still adverse: evaluated at the (patent-weighted) average level of competition $\bar{C}$, it equals -1.9 points (column 2). This negative effect is further reversed because values decreased more for firms exposed to lower levels of competition (column 3). Columns 4 and 5 consider the same decomposition for competition. The effect of competition is close to zero (the coefficient for competition in Table 1, panel C is almost zero). The pure interaction effect is small due to values and competition moving in opposite directions on average (column 6). Hence, on net, competition and value changes account for a small negative change in clean shares of -1.1 percentage points (column 7).

Second, over that period there was a doubling of tax-inclusive fuel prices. Column 8 shows that incorporating variations in oil prices explains 20.2 percentage points, almost two-thirds of the observed clean share. The rest is mostly explained by changes in environmental policies (our EPS variable is included in column 9, "Other").

In panel B we turn to a *prospective* scenario, asking what would happen if—starting from the 2008–2012 values—there was an increase in both competition and prosocial attitudes. To simulate realistic magnitudes, we use the average *absolute*

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[19] In specifications without any control, the adjustment increases standard errors relative to the benchmark, but the coefficients of interest remain significant; we do not report it because the point estimates are not well identified without controlling for potential confounders.

TABLE 3—HISTORICAL AND PROSPECTIVE COUNTERFACTUALS

	Actual	◁———			Due to				———▷
	$\bigtriangledown$	$(\alpha + \gamma\bar{C})$ $\times \Delta V$	$\gamma(C - \bar{C})$ $\times \Delta V$	$(\beta + \gamma\bar{V})$ $\times \Delta C$	$\gamma(V - \bar{V})$ $\times \Delta C$	$\gamma\Delta V \times \Delta C$	$\Delta V, \Delta C$	$\Delta V, \Delta C,$ ΔP	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. Historical									
Clean share change	34.6	−1.9	0.3	0.1	0.1	0.4	−1.1	20.2	14.4
Panel B. Prospective									
Clean share change		4.4	0.8	0.0	0.0	0.1	5.4		
Equiv. $\Delta P/P(\%)$		13.75	2.5	0.0	0.0	0.25	17.0		

Notes: Share changes are in percentage points. Column 1 reports historical evolutions; columns 2 and 3, those due solely to changes in (firms' market exposures to) environmental values ΔV_j and their interactions with (exposures to) competition levels C_j, the average of which is $\bar{C}$. Columns 4 and 5 do the same for changes ΔC_j in competition and their interactions with value levels V_j. Column 6 gives the "second-order" effects from interactions between the ΔV_j and ΔC_j. Column 8 computes the total changes attributable to variations in values, competition, and oil prices. Column 9 is the difference between the actual change and the predicted change based on the value, competition, and price effects. In unreported results we find that changes in the environmental policy index account for nearly all of "Other." See online Appendix B for details.

changes seen between periods 1 and 2. For values, there was a decrease of 0.78 standard deviations, and we now simulate a *uniform* increase of the same size; for competition there was an increase of 0.08 standard deviations, and we consider a same-sized uniform increase.

We find that the envisioned increase in prosocial attitudes would raise the share of clean innovations by $4.4 + 0.8 = 5.2$ points, while that in competition would have an effect close to zero. Their combined effect is a 5.4 points increase, which is equivalent to that of a 17 percent worldwide rise in fuel prices. Given that even moderate attempts to increase fuel prices often elicit dramatic public reactions (e.g., the French *gilet jaunes*) or political gridlock (e.g., the US Congress), this suggests that grassroots and public campaigns to promote citizens' environmental responsibility could be a viable alternative policy option, especially where markets can be expected to become more competitive.

VI. Conclusion

Are citizens' often-stated desires to adopt more environmentally responsible behaviors just "cheap talk" or powerful motivations that end up having a major influence on what new products will be developed and sold? And what is the role of market competition in the process? To answer these questions, we proposed a simple model and brought together data on firm-level automotive-sector patents, national environmental attitudes, and competition intensity. We found support for the predictions that proenvironment attitudes and their interaction with competition both have a significantly positive effect on the probability for a firm to aim at cleaner patents.

More generally, the results provide support for models in which intrinsically or reputationally motivated individuals incur costs to act in a "socially responsible" manner in spite of having a negligible impact on the aggregate outcome, such as pollution. Moreover, such prosocial motivations can actually "move markets," even at the upstream stage of product research and development, especially if competition can be expected to intensify.

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