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Income Inequality and the Development of Environmental Technologies

Francesco Vona[*] Fabrizio Patriarca[†]

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Abstract

Within rich countries, a large dispersion in the capacity of generating environmental innovations appears correlated to the level of inequality. Previous works analyse the relationship between inequality and environmental quality in a static setting. This paper builds a dynamic model more suitable to analyze technological externalities driven by the emergence of a new demand for green products. Under fairly general assumptions on technology and preferences, we show that: 1. the relationship between inequality and environmental innovation is highly non-linear and crucially depends on per-capita income; 2. an excessive inequality harms the development of environmental technologies especially in rich countries. Key to our results is the fact that externalities generated by pioneer consumers of green products benefit the entire population only for relatively low income distances. The empirical analysis robustly confirms our theoretical results, that is: whereas for rich countries inequality negatively affects the diffusion of innovations, per-capita income is paramount in poorer ones.

Keywords: Inequality, Demand, Environmental Innovations, Pioneer Consumer.

JEL codes: Q55, O14, O15

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1 Introduction[1]

The development of technologies aimed at preserving the environment represents an increasingly urgent priority in the political agenda. Among rich countries, a large cross-country variation in environmental regulation and in the capacity of generating environmental-friendly innovations casts doubt on the relevance of the so-called environmental Kuznets curve hypothesis (Grossman and Krueger 1995), according to which, above certain income levels, economic growth enables a progressive reductions of emissions per capita[2]. Recent works use a political-economy argument to claim that the mechanical process of growth is not sufficient to generate pro-environmental policies, and hence to invert the vicious circle between growth and environmental degradation (Torras and Boyce 1998, Magnani 2000). On the other hand, if the consumption of eco-friendly products increases with income, a standard "aggregation argument" would lead to the opposite conclusion, namely that higher income inequality fosters eco-friendly consumption patterns (Heerink et al. 2001). Accordingly, income inequality has a contrasting effect on the two forces that are recognized to drive environmental innovations (see Beise and Rennings 2005): regulation and the demand for green products. From the empirical side, since the two effects tend to offset each other, no particular correlation should be observed between environmental innovation and inequality.

The purpose of this paper is to extend the analysis of the relationship between income inequality and the diffusion of green products to a dynamic framework where the development of environmental innovations is demand driven. Our prior claim is that many environmental-friendly goods and services are produced and consumed locally (i.e. eco-building, renewable energy, recycling, bio-food, etc.), hence making internal markets particularly important to develop the technological know-how required to a large scale diffusion of these goods. In particular, the emergence of a sizable demand for green products allows to gradually generates profit opportunities in key

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[2]As a matter of fact, a recent comprehensive empirical analysis (Harbaugh et al. 2002) seems to discard the environmental Kuznets curve hypothesis, whereas other analyses emphasize how the reduction of emissions might be merely due to delocalization of pollution in less-developed countries (Suri and Chapman 1998, Roca 2003).

sectors such as transport, agriculture, construction and energy. The scaling-up of clean production methods in these sectors is associated to relevant non-linearities in so far as the development of the appropriate infrastructures favours the replacements of polluting consumption patterns with green ones.

As well-documented in the literature on demand-driven innovations (e.g. von Hippel 1988, Bertola et al. 2006), pioneer consumers have a higher capacity to buy initially more expensive green products, hence they trigger innovations that, throughout price reductions, might enable low-budget consumers to adopt these products (pioneer consumer effect, PC). On the other hand, however, an "excessive income distance" between the two types of consumers does not allow the entire society to benefit from the externalities generated by rich consumers (consumption polarization effect, CP[3]).

In order to fix these ideas in a stylized way, we develop a simple theoretical model that establishes a weak asymmetry between green and non-green wants, being only the latter essential in an Inada sense. It will be shown that, under general assumptions on preferences and technological change, the effect of inequality on the diffusion of the new good is highly non-linear with the PC effect prevailing on the CP one for low levels of per-capita income, whereas the reverse occurs for high levels of per-capita income. Indeed, inequality harms the full development of environmental innovations, especially in those countries closer to the technological frontier and hence more likely to perform innovations (Aghion and Howitt 2004). Due to a high income inequality, the positive externality brought about by the consumption of the rich might not be enough to enable the poor to buy eco-friendly goods, thereby the political-economy and the aggregation argument might go in the same direction. Moreover, high inequality not only pins down the emergence of appropriate environmental regulations, but also hampers the development of knowledge complementary to environmental-friendly behaviour. Finally, an empirical validation of our model robustly confirms that inequality is strongly negatively related to various proxies of environmental innovation, even when country fixed effects are taken into account. This effect is particularly strong for richer countries whereas for poorer countries per-capita income is paramount.

The rest of the paper is organized as follows. Section 2 connects the literature on demand and innovation to the one on inequality and environmental regulation. Section 3 presents the model, the main theoretical results and

[3]Gordon and Dew-Becker (2007) show that the sharp increase in US earning inequality from the late 70s has been associated to a substantial dispersion in consumption habits (Wall-Mart effect) and in expected lifetimes.

possible extensions. Section 4 is devoted to an empirical validation of the model whereas section 5 concludes.

2 Related Literature

The theoretical debate on the relationship between environmental quality and inequality has been largely centred on the shape of the individual preferences for environmental quality and on their aggregation through the political process. In its seminal analysis, Boyce (1994) argued that, even in democratic societies, the decision power is not uniform across individuals, but depends on income levels through lobbying or policy capture. If benefits from environmental degradation and power are positively correlated, more equal societies characterized by more distributed power set expenditures for environmental protection at a higher level. According to Scrugg (1998) and Heerink et al. (2001), Boyce's argument holds only if one assumes implicitly that the rich prefer more pollution than the poor. The comprehensive evidence collected in a recent Oecd study (2008) and in several other studies[4] shows that this is not the case. In particular, while rich and more educated households consume more and hence can have a worse impact on the environment, they also tend to buy environmentally-friendly innovative products. The study concludes that—except in the case of cars—green innovative products are mainly bought by rich, whether for a preference or an income motif.

This critique leads to shift the interest towards a deeper investigation of the political-economy mechanisms able to generate a negative relationship between inequality and environmental quality. Magnani (2000) claims that inequality and expenditures for environmental R&D can be negatively correlated also if richer households prefer more environmental quality than poorer ones. Whereas the empirical analysis provides convincing support to her thesis, the theoretical result is derived under the very peculiar condition that preferences for public goods are increasing in the household relative income. A more parsimonious way to account for non-linear preferences for environmental quality has been offered by Pfaaf et al. (2004) that assume an asymmetric endowment of environmental amenities (positive) and consumption (zero) at zero income. A negative inequality-environment relationship can then be easily obtained by the fact that, if the median voter

[4]See for example Kahn (1998), Gilg at al. (2005), Diaz-Rainey and Ashton (2009). Somehow related is the fact that the quality of consumption is found to be strongly correlated with per-capita income (e.g. Hallak 2006).

is below a certain income threshold, public expenditures for environmental protection are set to zero. Among the channels that support a negative relationship between inequality and the environment, recent works (Rothman 1998, Roca 2003, Boyce 2003) focus on the capacity of rich people to divert the monetary benefits out-of-pollution from the cost of it. In a model of spatial sorting of agents by skills, Gawande et al. (2001) show that hazardous waste sites tend to be located in neighbourhoods with a higher fraction of poorer, less educated workers. An unfair distribution of polluting-intensive activities does not only concern the unequal allocation of resources between North and South, but it is also documented in highly segregated economies such as the US one (see Boyce 2003).

All these models derive their results in static settings and tend to neglect the role of environmental innovations. An exception is the paper of Kempf and Rossignol (2007) where a dynamic trade-off between growth and environment is assumed. Here, the median voter jointly decides the taxes devoted to finance two public goods: environment and infrastructures, which are conductive to growth. They conclude that–if the weight assigned to the "environment" in the utility function is low enough with respect to the one assigned to "consumption"–the more unequal the society, the more likely the political decision would privilege production rather than the environment.

Again, however, assuming a trade-off between growth and environmental quality excludes solutions based on the development of environmental technologies[5]. The growing literature on the determinants of environmental innovations (e.g. Jaffe et al. 2003) focuses on the capacity of appropriate policies to foster technological solutions that can conciliate, at least partially, economic development with ecological considerations. Even if the evidence is somehow mixed (e.g. Jaffe and Palmer 1997), empirical investigations generally find a positive and self-reinforcing relationship between policy stringency and environmental innovations (Lanjouw and Mody 1996, Brunnermeier and Cohen 2003, Popp 2006, Popp et al. 2009 for a review), especially when regulation is well designed (see Johnstone and Haščič 2009, Johnstone et al. 2010). Besides, there are several reasons to believe that a large scale diffusion of environmental technologies depends even more on the emergence of a sizeable internal demand for these products. First, as claimed by Murphy et al. (1989), the size of demand favours the adoption

[5]Environmental innovations are distinguished between end-of-pipe and cleaner production (or integrated technologies). "Cleaner production reduces resource use and/or pollution at the source by using cleaner products and production methods, whereas end-of-pipe technologies curb pollution emissions by implementing add-on measures" Frondel et al. (2004), pp.1.

of increasing returns technologies, or infrastructures, characterized by high fixed costs. In our specific case, most of the solutions that enable a substantial improvement in environmental quality involves the building of in loco infrastructures (recycling network, smart grids, electric-recharging or hydrogen-refueling stations) or presents high initial costs and uncertain investment profiles (renewable energies). Second, radical innovations such as hybrid vehicles are developed by processes of learning-by-using that make them more reliable and cheaper (Rosenberg 1982, von Hippel 1988). This is also the case of all these products, such as eco-building and biological food, whose consumption could be extended to a larger fraction of the population if learning-by-doing were enough strong to trigger the required price reductions.

Innovation scholars have recently developed new dynamic models to sketch out the relationship between consumers heterogeneity, technological change and the development of environmental-friendly technologies (Cantono and Silverberg 2008, Ciarli et al. 2009a, 2009b). These models rest on the key assumption that the positive impact of lead users on the remaining population depends on the distribution of certain characteristics across the population (e.g. distribution of reservation prices) and on the behaviour of agents in the same neighbourhood. As usual in agent-based simulation analyses, the focus is on the identification of diffusion patterns of environmental friendly habits for different shapes of the agents' distribution and initial conditions (Cantono and Silverberg 2008). While the role of lead-users and of consumers' heterogeneity is also essential in our model, we prefer to maintain analytical tractability and, as it will be clear soon, to derive our results in a simpler setting. Moreover, differently from these models, here consumers' heterogeneity is associated with incomes rather than preferences. In the next section of the paper, we develop the dynamic model of environmental innovation driven by demand.

3 The Model

In this section, we develop a simple model to analyze the role of the income distribution in the process of diffusion of a new good differing from the old one as it allows to satisfy a new want[6]. In particular, the new good enables agents to enjoy the same direct utility of the old one plus an addi-

[6]This model represents an extension of two more general models of technological diffusion, structural change and income inequality (Patriarca and Vona 2009, Patriarca and Vona 2010).

tional utility linked to an "eco-friendly" motif. This is a convenient way to model preferences for the environment as it encompasses both the case in which "eco-friendly" goods are of better quality, and the one where they are consumed for "altruistic" reasons or moral obligations (see Eriksson 2004, Conrad 2005, Oecd 2008). As in Pfaff et al. (2004), we further assume that, unlike the basic want, the ecological want is not necessary since environmental amenities are freely available even when the consumption of the new good is zero[7]. This break of the wants' symmetry is enough to derive the particular shape of the Engel's curve required to prove our main results.

3.1 Consumption Choices and Engel's Curves

Let us define a utility function w in the two wants. As usual, we consider a representation of the utility functions in the broader class of the C^2 real functions with non-increasing first derivatives. The two goods x_1 and x_2 are such that x_1 satisfies only the old want whereas x_2 satifies both. Four assumptions are enough to derive our main results:

1. The two goods are perfect substitutes in the satisfaction of the old want, i.e. the utility derived from the old want is a function of $x_1 + x_2$ only.

2. The new good satisfies a new want whose utility is separable from the utility of the old want:

$$w(x_1, x_2) = u(x_1 + x_2) + v(x_2).$$

3. The old want is necessary and there is at least asymptotic satiation, so Inada conditions hold:

$$\lim_{x \to 0^+} u'(x) = +\infty \qquad \lim_{x \to +\infty} u'(x) = 0.$$

   In turn, the new want is not necessary:

$$\lim_{x \to 0^+} v'(x) < +\infty$$

[7]This "asymmetric endowment assumption" (i.e. positive environmental quality and zero consumption if income is zero) is similar to the one made in the unified growth literature to distinguish an initial phase of development fueled by the accumulation of physical capital to a successive one fueled by the accumulation of human capital (see Galor 2005).

4. The utility of the new want is proportional to the level of consumption of the second good: $v(x) = vx$.

While the first two hypotheses are general, the third is critical to establish a minimum degree of hierarchy between wants. Conversely, assumption 4 could be easily relaxed and is not essential to derive our main results (see the Appendix). Thus, we do not assume a direct relationship between income and preferences. Instead, we base our model on the asymmetry between the two wants. In this setting, it is straightforward to show that, subject to the budget constraint $m = p_1x_1 + p_2x_2$, the first order condition of the optimal choice problem is:

$$\frac{u'(x_1 + x_2)}{u'(x_1 + x_2) + v'(x_2)} = \frac{p_1}{p_2}. \tag{1}$$

Thus:

$$\frac{v'(x_2)}{u'(x_1 + x_2)} = \delta_P, \tag{2}$$

where, if $p_1 = 1$, δ_P is the relative price gap, i.e. $p_2 - 1$, that proxies the technological expertise in the production of the two goods. Clearly, good 1 is consumed only if $\delta_P > 0$. The LHS (resp. RHS) of eq. 2 expresses the relative marginal benefit (resp. cost) of substituting the old with the new want. The equivalence holds only for internal solutions, that is, in cases where a mixed bundle of goods is consumed. Under previous hypotheses, we are able to prove that internal solutions emerge only in an internal range of incomes.

PROPOSITION 1: For any given value of δ_P, there exist two values $m^- = \phi(\frac{v}{\delta_P})$ and $m^+ = (\delta_P + 1)m^-$ such that:

- for values of m lower (resp. higher) than m^- (resp. m^+) all the income is spent in the old (resp. new) good.
- for values of $m \in (m^-, m^+)$ the income is spent in a mixed bundle:

$$x_1 + x_2 = \tilde{x} = \frac{m^-}{p_1}, \tag{3}$$

$$x_2 = \frac{1}{\delta_P}\left[m - m^-\right], \tag{4}$$

where ϕ is the inverse of u' (proof in the Appendix).

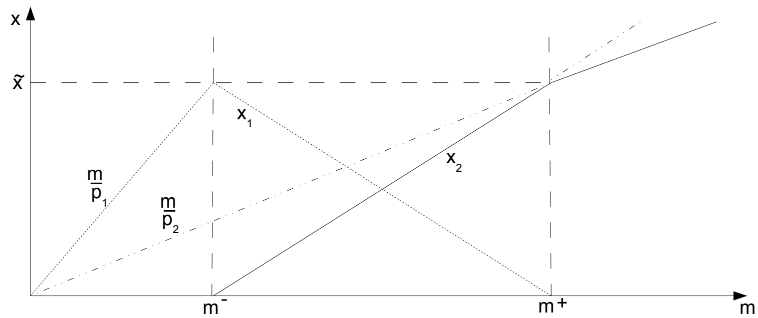

Figure 1: Engel's curves

Figure **??** shows the resulting Engel's curves. Below m^- , income is not enough to buy the quantity $\tilde{x}$, hence agents choose the good satisfing only the want that is strictly necessary. Above m^-, all additional income is entirely spent in substituting the new good with the old one, keeping fixed the overall consumption at $\tilde{x}$. In turn, the level m^+ is the one required to buy exactly the quantity $\tilde{x}$ of the new good. Differentiating x_2 w.r.t. m in the three income regions, one can sort out the shape of the demand curve for the new good x_2. More precisely:

$$\frac{\partial x_2}{\partial m_{m^-<m<m^+}} = \frac{1}{\delta_P} > \frac{\partial x_2}{\partial m_{m>m^+}} = \frac{1}{\delta_P + 1} > \frac{\partial x_2}{\partial m_{_{m<m^-}}} = 0. \tag{5}$$

Inequality 4 maintains that a given income expansion has a higher impact on the consumption of the new good for average income level. In fact, in the region (m^-, m^+), the gradual substitution of the old good with the new one reinforces the positive effect on the consumption of x_2 due to the income expansion itself, while in the third region substitution no longer occurs. As will be clearer, the particular S-shaped relationship of the demand curve of x_2 is essential to derive our results.

The income regions previously identified have a "dual" counterpart in the price domain. The identification of the "price gap" thresholds that corresponds to a shift in consumers' behaviour is particularly important to analyse technological change in so far as, under standard competitive conditions in all markets, prices hinge on costs and then the inverse of the price gap θ can be considered a reliable proxy of the technological level. Corollary 1 reverts the way of reasoning of proposition 1 by fixing the income levels and looking at the thresholds of the technological level θ.

COROLLARY 1: For a given m^*, there exist two values $\theta^-(m^*)$ and $\theta^+(m^*)$ such that:

- for values of θ lower (resp. higher) than θ^-(resp. θ^+) all the income is spent in the old (resp. new) good.
- for values of θ in $\in (\theta^-, \theta^+)$ the income is spent in a mixed bundle (the proof is in the Appendix).

COROLLARY 2: The two thresholds decrease in m and tend respectively to 0 and to ∞ when the income varies respectively from ∞ to 0 (the proof is in the Appendix).

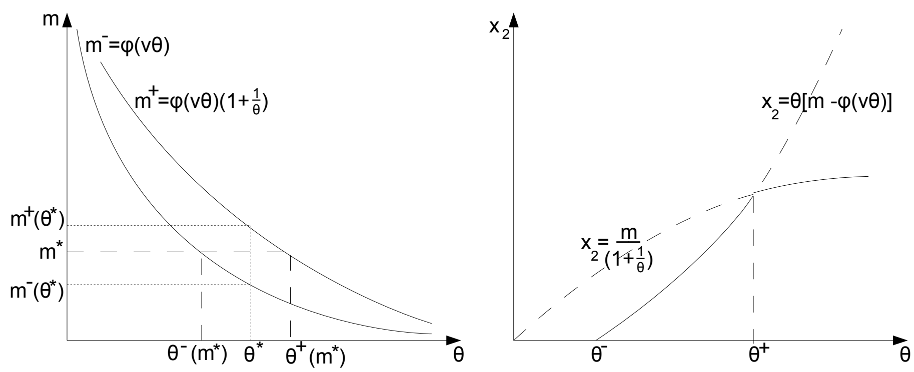

Figure 2: Thresholds determination and new goods demand - technological level curve

The left hand panel of figure **??** depicts the thresholds as a function of both income and technological levels. The right hand panel draws the curve representing the relationship between technological level and the demand for the new good $x_2(\theta)$. It is worth noticing that corollary 2 explicitly connects the direction of the thresholds' movements to the income level. In particular, an increase in income enhances the capacity to buy the new good, hence a positive consumption of the new good might be compatible with relatively less efficient ways of producing it. The opposite occurs in the case of low income levels.

3.2 Income Distribution and Aggregate Demand

In an economy where agents are heterogeneous in their incomes, the previous argument cleraly leads to consider the final composition of aggregate demand, and hence the diffusion of x_2, as strongly dependent on the distribution of income for a given income per capita. Two forces tend to contrast each other. On the one hand, the higher the weight of agents in the top income regions, the higher the share of the new good in the economy. On the other hand, a high income inequality implies that a large fraction of individuals are stucked in the first income region, possibly leading to polarization in consumption habits.

The non-linearities in the Engel's curves emphasized by eq.**??** implies that, in aggregate, the diffusion of the new good jointly depends on the average income and on the level of income inequality. With the purpose of giving a preliminary idea of this process, let us consider numerical examples drawn from a log-normal distribution of income with a concave shaped utility for the old want[8]. In figure **??**, we plot X_2 for mean income varying from m^- up to m^+. When the mean income is relatively high, a more unequal distribution of income mainly translates into an increase in the fraction of agents with income under the threshold m^-, having a negative impact on the diffusion of x_2. Conversely, in relatively poorer economies, the positive effect of an increase in the number of agents with enough income to buy the new good enables a partial diffusion of it.

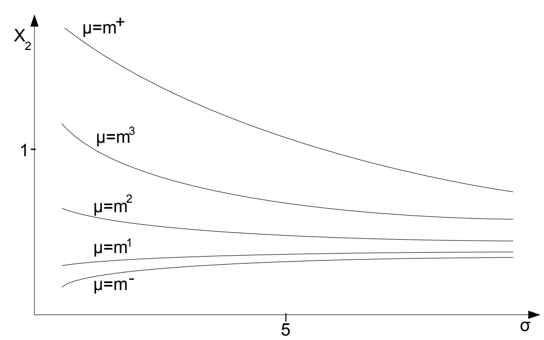

Figure 3: Variance of the income distribution and new good diffusion for different levels of the mean income

This reversal effect of inequality on the diffusion of x_2 is a consequence of the S-shaped feature of the Engel curve of the new good. It is interesting

[8] In particular, we take:

$$q(m) = \frac{1}{m\sigma\sqrt{2\pi}} e^{\frac{(m-\mu)^2}{2\sigma^2}}$$

and $u(z) = \alpha_0 z^{\alpha_1}$ with $\alpha_0 = 1$, $\alpha_1 = 0.5$ and $\delta_P = 2$.

to note that the S-shaped feature of our Engel curve does not allow to sketch a uniform relationship between inequality and the diffusion of x_2 as it would be for concave- or convex-shaped curves considered in the previous literature on the "aggregation argument" (e.g. Heerink et al. 2001, Boyce 2003). We are now able to restate proposition 1 in the case of heterogeneous agents.

PROPOSITION 2: Redistributing income from agents under m^- to agents over m^+ increases the aggregate demand of the new good X_2, while redistributing income from agents in any of the two extreme regions to agents with income in the central region $(m^-,\ m^+)$ increases the level of X_2.

In what follows, instead of using numerical techniques to sketch out this relationship for general distribution function, we prefer to preserve analytical tractability by considering a simplified population where two groups $i = (P, R)$ have incomes m_P, m_R proportional to their human capital endowments (see Bertola et al. 2006). Being m the mean income, m_P and m_R can be expressed as:

$$m_P = m \cdot (1 - \tau) \qquad m_R = m \cdot \left(1 + \tau \frac{n_P}{n_R}\right),$$

where n_P and n_R are the relative weights of the two groups $(n_P + n_R = 1)$. Aggregate demand is then the sum of the demand of each group $x_2(m^i)$, as defined in Proposition 1.

$$X_2 = n_P \cdot x_2(m_P) + n_R \cdot x_2(m_R) \tag{6}$$

Fixed n_P, n_R and m, one can clearly interpret $\tau \in (0, 1)$ as the inequality parameter (see Bertola et al. 2006). In particular, an increase of τ corresponds to a redistribution of income from poor P to rich R agents. In this special case, proposition 2 – together with assumption 1-4 –brings to three important implications:

I1 If agents are in the same income region, the aggregate demand for the new good does not depend on the level of inequality.

I2 If the rich have an income higher than m^+ and the poor are in the mix choice region, a higher inequality brings to a lower aggregate demand for the new good.

I3 If only the rich have income higher than m^-, a higher inequality brings to a higher aggregate demand for the new good.

Taken together implications $I1 - I3$ claim that the effect of an increase in income inequality depends on where are located the two groups relatively to the income thresholds. According to corollary 1, the location of an agent with income m^i on the income regions depends on the position of the effective θ with respect to its specific technological thresholds $\theta^-(m^i)$ and $\theta^+(m^i)$. Both the level of inequality and of average income determines the relative position of the technological thresholds for each group and, at the same time, identifies intervals of the technological level that characterize particular combinations of consumption patterns.

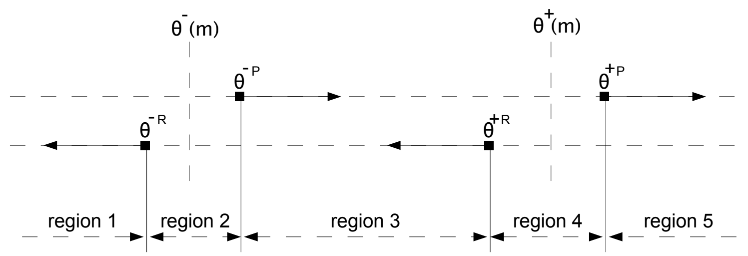

Figure 4: Variation of the technological thresholds for increasing values of τ

Figure **??** displays the relevant case $\theta^{-R} < \theta^{-P} < \theta^{+R} < \theta^{+P}$. In the first interval ($\theta < \theta^{-R}$) the technological level is too low for any agents to demand the new good while in the last one ($\theta > \theta^{+P}$) it is high enough to enable both groups demanding only the new good. In the second interval (over the lowest threshold θ^{-R}) only agents R demand x_2. In the forth interval, the new good is consumed by all agents and is the only one consumed by agents R. The qualitative feature of the third interval changes according to the level of inequality as, for Corollary 2, the thresholds of the two groups move in opposite direction when τ increases. For low τ, the order $\theta^{-P} < \theta^{+R}$ is preserved and both types of agents demand mixed bundles. Conversely, for sufficiently high τ, θ^{-P} jumps above θ^{+R} so that agents P demand only the old good whereas agents R demand only the new one. This implies that there exists a threshold level τ^* such that a technological interval of consumption polarization exists for $\tau > \tau^{*}$[9].

[9] τ^* is the value of income inequality at which $\theta^{-P} = \theta^{+R} = \theta^*$. The two values τ^* and θ^* are the solutions of the non-linear system:

$$\begin{cases} m(1-\tau^*) = \phi(\theta^* v) \\ m(1+\tau^* \frac{n^P}{n^R}) = (1 + \frac{1}{\theta^*}\phi(\theta^* v) \end{cases} .$$

Figure ?? displays the movements of the aggregate demand of X_2^τ for different levels of inequality τ (with $\tau_i < \tau_j$ for $i < j$) keeping the mean income fixed. The five intervals of figure ?? are directly reflected in the demand-technology curve $X_2^\tau(\theta)$ that shifts slopes four times, identifying five parts of the curve. In the first part (lying on the θ axis) and in the last one, both groups of agents are in the same income region and consume exclusively the old or, respectively, the new good depending on the technological level θ. Hence, for $I1$, inequality does not affect the overall demand that coincides with the reference curve $X_2^0(\theta)$ depicted in figure ??.

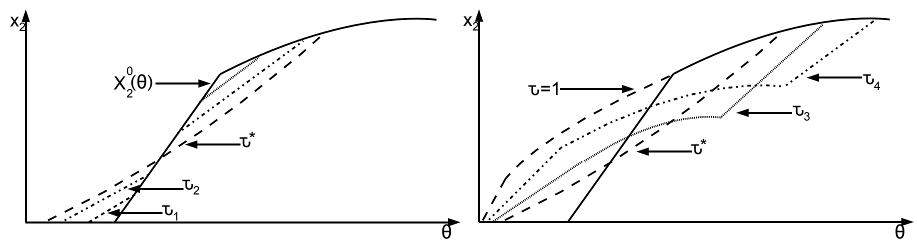

Figure 5: Relationship between aggregate demand and technological level for different values of inequality τ

The feature of the second part of the curve is the base of the pioneer consumption effect. For positive values of inequality, the lower threshold of rich agents θ^{-R} decreases below θ^-, hence a positive demand of the new good emerges also in correspondence to less efficient green technologies. Here, the demand is higher with respect to the case of homogeneous agents X_2^0 and it is increasing with inequality, see $I3$. The opposite occurs in the fourth part, where the demand curve is lower than the reference curve and inequality will reduce the aggregate demand, see $I2$[10]. As we already noticed, the feature of the central part depends on the level of inequality. Up to τ^* both agents are in the mix bundle income region, hence inequality does not affect the overall demand and the actual demand curve coincides with the reference one. Over τ^* (τ_3 and τ_4), polarization brings to the case $I3$: only the agents R consume the new good. As a result, increasing τ increases the overall demand X_2 up to the point where all income is given to rich ($\tau = 1$).

[10]The location of the demand curve in the second and in the fourth part (respectively above and below the reference curve) follows by applying Proposition 2.

3.3 Technological progress and dynamics

Previous results prepared the ground for the analysis of a dynamic context where technological change matters. Let us consider a discrete time context where learning-by-doing (or technological externalities) is captured by a standard positive relationtship f between the actual technological level and the previously realized aggregate demand. The associated dynamical system is defined by the two equations:

$$\theta^t = f(X_2^{t-1}), \tag{7}$$

$$X_2^t = X_2(\theta^t) \tag{8}$$

where $f' > 0$. To define our setting, we consider as benchmark the case of homogeneous agents. In the benchmark case, we make the hypotheses that a process of technical progress is possible, if starting from an adequate initial technological level $\tilde{\theta}$[11]. These hypotheses imply that the two curves in **??** and **??** cross in two points S and E. These points identify a range where the demand corresponding to a given θ generates a higher technological level: $f(x_2(\theta)) > \theta$[12]. A similar dynamic process is shown in figure **??**. Starting from a technological level to the right of S (like point H), the system will converge to the final equilibrium E^* where, according to our hypotheses, agents demand only x_2 and technological progress stops: $f(x_2(\theta)) = \theta$.

In the case of heterogeneous agents, the position of the curve $X_2^\tau(\theta)$ depends on the level of inequality τ. The analysis of the previous section can be straightforwadly extended to a dynamic context: indeed, the final equilibrium is again the interesection of $f(X_2^{t-1})$ and $X_2^\tau(\theta)$. Therefore, provided that the initial technological level is big enough, it is possible to identify a schedule $E(\tau)$ of equilibria characterized by different combinations of inequality and of the final level of the new good. In what follows, the initial technological level θ_0, which implicitly captures the initial state of development of the country, is such that θ_0 is slightly smaller than $\tilde{\theta}$.

As in figure **??**, when agents are quite homogeneous, both agents' thresholds $(\theta^{-i}, \theta^{+i})$ are located in the neighboorhood of the benchmark initial technological levels θ_0, thereby the demand of x_2 is too small to induce technological externalities. A little increase of heterogeneity (τ_1) brings the rich to consume the new good and triggers the dynamic process of change. Since

[11] Moreover, we assume that the technological level can not worsen.

[12] We do not make hypotheses about the exact shape of f between S and E, what we need is only that in such interval it lies below the demand curve. However, looking at the figure **??**, we can notice that this excludes the case of a very convex technical change curve $f(X_2)$.

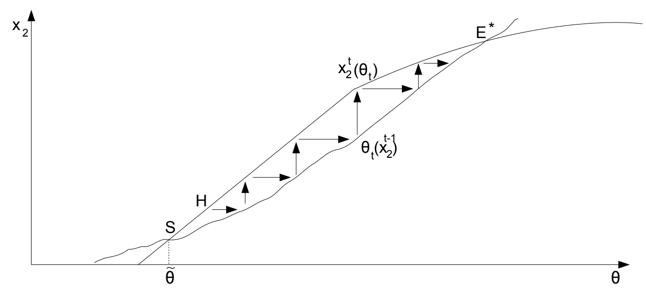

Figure 6: Dynamic interaction of technical progress and new good demand

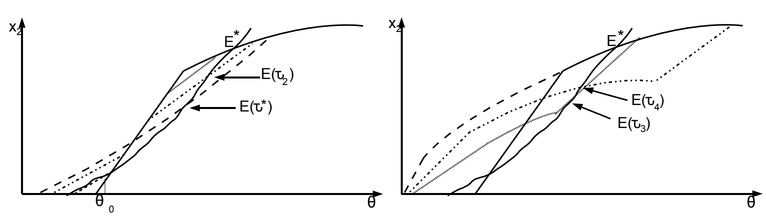

Figure 7: Dynamic interaction of technical progress and new good demand with agents heterogeneity

the two groups are here very close, the demand of rich agents is enough to generate a positive externality on the poor bringing the technological level over their lower threshold θ^{-P}. A second wave of technological improvements, brought about by the consumption of the poor, enables the demand curve to reach the benchmark one X_2^0 before E^*. The final outcome of the process is always a full transition to the new good for any level of inequality compatible with crossing points $E(\tau)$ on the benchmark curve. Note that the level of agent heterogeneity required to bring about those self-reinforcing processes depends on the stage of development of a country: the lower θ_0, the higher should be the level of inequality τ that disguises the PC effect.

For higher values of τ, the PC effect is even higher–i.e. the second part of the demand curve is shifted upwards–but the lower threshold of agents P is also higher. Poor agents start consuming the new good later and, given that f is concave or at least not too convex, their demand have a smaller reinforcing impact on the technological level. As a result, poor do not fully accomplish the transition to the new good and, in this region of medium-high inequality, X_2 uniformily decreases in τ. Also important, the final technological level is lower than in the previous case, notwithstanding the stronger initial effect of agents R which speeds up the first phase of the transition process. The latter result is particular interesting as it states that inequality does not only affect the allocation of expenditures for environmental quality, but might be a source of technological comparative advantage.

For values slightly over τ^*, the system experiences a transitory phase of polarization of consumption: the PC effect is very strong, but agents P are involved in the consumption of the new good only after rich agents have completely shifted their consumption pattern. For levels of inequality well above τ^*, consumption polarization persists: the strong PC effect is not sufficient to reach the technological-level threshold that allows the agents P to consume x_2. This is mainly a consequence of the fact that this threshold is very high because of the very low level of income of agents P. As we already noticed, because of $I3$, consumption polarization is associated to a further reversal in the relationship between inequality and the consumtpion of x_2 that turns out to be positive. However, the outcome is always worse than the one in the initial cases. Only when all income is given to agents R the final outcome is again E^*.

Summing up, even if–especially below certain levels of income per capita–a certain income dispersion is necessary for the technological transiton to start, inequality has generally a negative impact on the final outcome. Once moving to high values of τ, the system ends up in a complete polarization of the consumption patterns. Only in the extreme case, when the new good becomes a niche for rich, inequality turns back to affect positively the final outcome of the process of change.

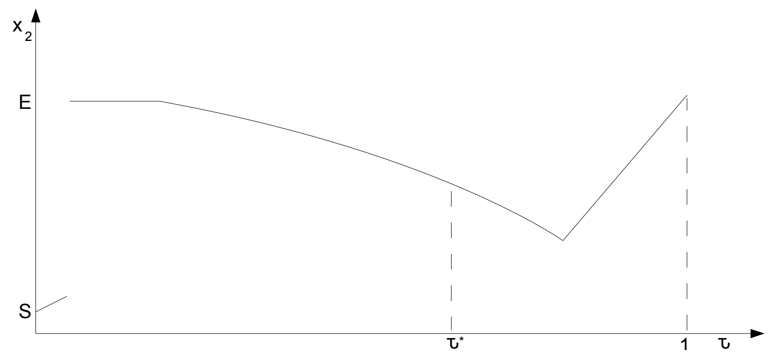

Figure 8: Inequality and final outcome

3.4 Extensions

The model can be easily generalized to include politico-economy considerations and taxation. If distortionary taxes on consumption are voted (e.g. a tax for the polluting good that subsidizes government expenditures in the new one) and assuming a finite decision horizon, the median elector votes for non-negative tax only if she expects to enjoy the consumption of the new good. That is: if the joint externality generated by the consumption of the rich and of the government is large enough to enable a positive consumption also of the poor in the near future. As a result, the effect of inequality on environmental technologies should be magnified by the indirect impact of inequality on regulation. Another interesting extension is to compare the effect on X_2 of a tax on the price of the old good with the one of a progressive tax on income. In our setting, for high levels of inequality the former policy is regressive since poor consume the old good only; the latter, instead, is less effective on X_2 for low level of inequality where PC effects should be disguised.

The reinforcement effect of the "politcal-economy" and the *"dynamic aggregation"* argument should be reflected empirically in a strong negative relationship between inequality, on the one hand, and environmental innovation and regulation, on the other hand.

4 Empirical Validation

In this section, we provide an empirical validation to our theoretical argument that, especially for rich countries, environmental innovations and the diffusion of green products are fostered by a more equal income distribution. A comprehensive analysis of the relationship between inequality and environmental innovations is carried on by considering the size of eco-industries and different indicators of environmental innovations, such as public green R&D and patents in selected fields. Moreover, our analysis covers a long span of time; in particular, the relationship between inequality and environmental innovations is analysed in a panel that goes from the mid 80s till the mid 2000s. For the empirical strategy, we follow Magnani (2000) in using a reduced-form Kuznets curve regressions to analyse the impact of inequality on public green R&D and on the size of eco-industries (see the appendix). Instead, a slightly different specification is applied to estimate the impact of inequality on environmental patents: following Johnstone et al. (2009), we add a proxy of country's technological expertise, i.e. its overall patent activity, to the reduced Kuznets curve specification. Finally, in both cases, the panel dimension is exploited in fixed- and random-effect specifications.

In the analysis, the set of explanatory variables is standard including the Gini index, year dummies, GDP per capita and GDP per capita square (see table 1). Due to lack of yearly data on inequality, we split our time span in five periods (1985-90-95-2000-05). Moreover, the GDP per capita at time t is replaced by its previous five-year average such as to reduce the influence of cyclical fluctuations. The Gini index is based on disposable income in order to account for differences in fiscal policies and welfare regimes. The information on the Ginis are collected from two datasets: 1. the Oecd inequality dataset, as it is the one containing less missing values on net Ginis; 2. the "all Ginis" database built by Branko Milanovic to impute missing data for older observations (see the appendix). Finally, our analysis is limited to Oecd members in so far as environmental innovations tend to be developed by richer countries. The successive exclusion of sub-groups of countries enables us to assess whether inequality have a different impact on environmental innovations depending on the level of per-capita income.

Three proxies of innovation and diffusion of green products are considered as dependent variables, all expressed in per-capita terms: the public R&D devoted to the control and the care of the environment, the per-capita turnover of eco-industries and the quota of priority patent applications in selected environmental domains. The first variable is the one used by Magnani (2000); here, we consider also the ratio between public green R&D

and overall public R&D to capture differences in the direction of innovation policy. The second variable captures the rate of diffusion of green products, hence encompassing both private and public expenditures. The per-capita turnover of the eco-industries (see ECOTEC 1999) is our proxy for the diffusion of green products. Finally, environmental patents are divided in four fields, namely: 1. pollution abatement and waste management, 2. renewable energies, 3. hybrid and electric vehicles, 4. eco-building. In our baseline specification, since the latter three fields include the more innovative technologies, we consider them together. Patents' priority applications are considered under the Patent Cooperation Treaty (PCT) that consents to protect an invention in each of its contracting states[13].

Table 1: Descriptives

Data Description								
	GDP pc (per capita=pc)	**Gini, on disposable income**	**Public green R&D % all pub. R&D**	**R&D green % pc**	**Turnover eco-Industry Pc**	**Overall Patents PCT pc*100**	**Pat. PCT poll. abat. & waste pc*100**	**Patents PCT innovative fields pc*100**
years	85-05	85, 90, 95, 00, 05	85,90,95, 00-05	85,90,95, 00-05	99, 04	85-05	85-05	85-05
mean	21282,6	0,303	2,285	0,342	550,6	4,467	0,114	0,053
-no poor	24545,4	0,292	2,097	0,373	667,1	6,138	0,155	0,072
std. Dev.	8187,1	0,065	1,326	0,222	360,7	6,151	0,147	0,084
-no poor	6583,6	0,045	1,070	0,220	344,5	6,572	0,156	0,092
corr. gini	-0,388	1	-0,162	-0,424	-0,487	-0,251	-0,355	-0,211
obs.	134	140	109	109	36	140	140	140
source	Oecd	Oecd, Milanovic	Oecd	Oecd	DG Env. EU	Oecd	Oecd	Oecd
Note: 'poor' countries are Greece, Portugal, Czech Rep., Slovak Rep., Hungary, Poland, Turkey Missings of GDP are concentrated in 85 and 90 for eastern countries (except Czech Rep. and Poland for 90)								

The first set of regressions shows that both green R&D p.c. and the direction of R&D efforts appear to be strongly negatively related with inequality in the previous period (table **??**). The effect of inequality on green R&D is very large and significant: an increase of one standard deviation in the Gini index reduces the expenditures in green R&D by around 8.3 percentage points, if expressed in p.c. terms, and by around 37 percentage points, if expressed as a fraction of overall R&D. Consistently with the model, the effect of income is significant and very large in the pooled OLS specification, i.e. an increase of one standard deviation in gdp_pc leads to an increase of 38.5% in green R&D_pc. Similarly to findings in Magnani (2000), expertise in doing environmental innovations plays only a secondary role in explaining higher green R&D expenditures. Indeed, whilst fixed-effect estimates lead to a substantial reduction of the inequality coefficient, the Hausman test

[13] Since patent applications are available for all the years considered, we take the five-year sum of patents per hundreds of inhabitants as the exact variable of interest.

accepts a random-effect specification. Even for our homogeneous group of countries, the inequality coefficient increases when Mediterranean, Eastern European and relatively poorer countries are excluded (table **??**). On the other hand, the inequality coefficient remains negative but is not anymore significant below the canonical 10% level when Scandinavian countries are excluded or a full set of area dummies included[14]. This empirical result appears to confirm one of the main theoretical predictions, that is: reinforcement in the inequality-environmental innovation link for richer countries. Coherently with the model, the GDP p.c. displays an opposite behaviour: its effect becomes insignificant (resp. strongly significant) when any group of relatively poorer (resp. relatively richer) countries is dropped. It is worth noticing that the relationship between inequality and environmental innovations appears not driven by the one between inequality and income, i.e. the original Kuznets curve. In fact, descriptive statistics show that the "green direction" of R&D activities tend to increase when poor countries are excluded suggesting that a substantial fraction of the impact of inequality is independent from the one of income (table **??**-**??**).

Table 2: R&D and Eco-industries

Dependent var.:	*Public Green R&D pc*			*Public Green R&D/tot. R&D*			*log(Eco_Ind)*
	pooled ols	rand. eff.	fix. eff.	pooled ols	rand. eff.	fix. eff.	pooled ols (a)
Gini	-1,29***	-1,02**	-0,28	-5,82*	-3,96	-1,38	-5,06**
	[0,44]	[0,44]	[1,15]	[3,12]	[4,84]	[7,12]	[2,47]
gdp_pc	4,71E-005**	5,46E-005***	4,81E-005*	1,65E-004	1,94E-004	2,94E-004*	1,26E-004***
	[2,32E-005]	[1,67E-005]	[2,77E-005]	[1,51E-004]	[1,13E-004]	[1,57E-004]	[2,89E-005]
gdp_pc^2	8,95E-010	-1,07E-009***	-1,02E-009**	-5,61E-009	-5,75E-009***	-6,62E-009***	-1,51E-009***
	[5,74E-010]	[4,17E-010]	[4,43E-010]	[3,41E-009]	[2,21E-009]	[2,41E-009]	[4,28E-010]
year	0,03	0,04**	0,05	0,36**	0,32**	0,17	-0,11
	[0,02]	[0,02]	[0,03]	[0,15]	[0,16]	[0,20]	[0,14]
imputation dummies	yes	yes	yes	yes	yes	yes	yes
constant	0,08	-0,12	-0,26	2,25	1,29	-0,87	5,98***
	[0,32]	[0,25]	[0,50]	[2,31]	[2,71]	[3,48]	[0,57]
R^2	0,37	0,35	0,24	0,21	0,18	0,06	0,59
obs	109	109	109	109	109	109	36
Hausman Test		χ(5)=4,57			χ(4)= 1,00		

Std. Err. adjusted for 25 clusters in Country, boostrapped Std. Err. provide similar results
* significant at 10%; ** significant at 5%; *** significant at 1%
(a) We do not exploit the panel here since observations are available only for 31 countries in 2 periods.

However, using public R&D devoted to the control and care of the environment as a proxy of environmental innovations can be misleading since these expenditures also include end-of-pipe solutions and monitoring efforts. On top of that, this proxy does not account for private sector innovations.

For the European countries plus Canada and the U.S., available data

[14]The exclusion of Scandinavian countries seem to have a particularly strong effect in reducing the size and the significance of the link between inequality and green R&D.

Table 3: Robustness R&D and Eco-industries

Estimated impact of inequality on environ. Technologies			
	Public R&D green pc	Public Green R&D/total R&D	*log (Eco Industr.)*
no poor	-1,83***	-6,16*	-6,88*
no east eu	-1,61***	-5,49*	-6,75*
no scandin.	-0,83*	-5,8	-6,17***
- no Denm.	-1,30**	-5,6	-3,71
no anglo	-1,04**	-4,94	-4,06
- no USA	-1,07***	-4,81	-4,71*
no centr eu	-1,35***	-6,83*	-4,18
- no Germ.	-1,19***	-5,49*	-5,05*
no med	-1,36***	-7,66***	-4,39
- no Port.	-1,39***	-6,41**	-5,19*
no very rich	-1,33***	-6,48**	-5,27**
no Japan	-1,15**	-4,93	-5,06**
dummy area incl.	-0,39	-7,77**	

on eco-industries allows to account for the diffusion of green products. The relationship of this variable with inequality is both very strong and associated with a substantially higher R-square (table **??**). This finding is even starker in so far as European countries share a similar regulatory framework, hence suggesting that level of inequality can account for the dispersion in the environmental performance of countries with a similar regulatory regime. Moreover, the impact of inequality on eco-industries is magnified when any group of poorer countries is excluded[15]. Also in this case, GDP p.c. has a very large and significant effect on the size of eco-industries, whereas the exclusion of one group of rich (resp. poor) strengthens (resp. weakens) this effect (table **??**).

However, data on the size of eco-industries are available for a short period and this does not allow exploiting the panel dimension in the estimates.

Looking at patent applications allows to overcome such difficulties providing a proxy of innovative efforts in fields where the demand-pull effect is expected to be particularly strong such as eco-building, renewable energy and hybrid/electric vehicles. First, we look at the estimated effect of inequality on patents in a relatively mature field such as pollution abatement and waste management[16]. Here, the previously observed negative relationship

[15]In this case, excluding Scandinavian has the effect of increasing the impact of inequality on the size of eco-industries; this effect is largely driven by the Swedish anomaly.

[16]For the patent regressions, the coefficient of gdp_pc tends to be negative and significant. This effect is associated to the strong correlation (0.57) between the overall patent activity and the gdp_pc. However, main results remain robust by excluding gdp_pc in the regressions.

Table 4: Patents Pollution Abatement and Waste Management

Dependent var.	PCT pollution abatement			PCT poll. ab. without East. Eur. Count.	
	pooled ols	*rand. eff.*	*fix. eff.*	*rand. eff.*	*fix. eff.*
Gini	-0,43***	-0,42***	0,07***	-0,60***	-0,1
	[0,15]	[0,11]	[0,27]	[0,17]	[0,30]
gdp_pc	-1,03E-007	4,47E-007	4,42E-006	-3,56E-006	4,75E-006
	[2,04E-006]	[4,93E-006]	[1,12E-005]	[6,35E-06]	[4,75E-06]
gdp_pc^2	2,25E-011	1,49E-011	-2,47E-011	6,52E-011	-2,93E-011
	[2,81E-010]	[1,29E-010]	[1,89E-010]	[1,50E-010]	[1,94E-010]
overall patent pc	0,02***	0,02***	0,01***	0,02***	0,01***
	[2,29E-003]	[2,12E-003]	[2,48E-003]	[2,18E-003]	[2,62E-003]
year	9,77E-004	1,68E-003	7,36E-003	0,01*	0,01
	[3,68E-003]	[3,49E-003]	[0,01]	[0,01]	[0,01]
imputation dumm.	yes	yes	yes	yes	yes
constant	0,15***	0,14**	-0,07	0,24**	-0,09
	[0,06]	[0,07]	[0,17]	[0,11]	[0,18]
R^2	0,78	0,78	0,73	0,77	0,71
obs	134	134	134	120	120
Hausman Test		χ(5)=17,02		χ(5)=7,89	

Std. Err. adjusted for 25 clusters in Country, boostrapped Std. Err. provide similar results
* significant at 10%; ** significant at 5%; *** significant at 1%

emerges in pooled OLS but the fixed-effect model is the favourite specification (table ??). However, when one excludes eastern European countries for which a shorter three-year panel is available, the fixed effect specification is rejected in favour of a random effect one; thereby the relationship between inequality and this class of patents appears not driven by country specificities[17]. Second, also the estimated impact of inequality on patents in innovative fields, i.e. renewables, eco-building and hybrid-electric vehicles, is negative and significant (table ??). Interestingly, the impact remains significant to the inclusion of area dummies and, as usual, increases (resp. decreases) if any group of relatively poorer (resp. relatively richer) is excluded. The picture is more fragmented when each innovative field is considered separately (table ??). As expected, results for the more mature field of renewable energy tend to be more similar with the ones for patents in pollution abatement and waste management–even if the impact of inequality is weakly significant. As for the field of pollution abatement, results seem to be largely driven by Scandinavian countries (table ??). For eco-building, the impact of inequality is much lower, although negative, and it is significant only at a cut-off level near 12%. In the field of hybrid and electric vehicles, inequality has an insignificant effect. This is coherent with the findings of a recent Oecd study (2008) where low-income households appear to be the ones that buy energy efficient cars. More in general, the more the technology

[17]Similar results, available upon request, emerge also if one considers priority patent applications in the European Patent office or, although weaker, for patent applications under the triadic patent family agreement.

is at the beginning of its life-cycle the less important seems to be the effect of inequality, which fits the pioneer consumer hypothesis considered in the model.

Table 5: Patents Innovative Fields

Dependent var.	PCT Innovative(ecob., renew., hyb.&el.vehic.)			PCT Innovative without East. Europ. Count.		
	pooled ols	*rand. eff.*	*fix. eff.*	*pooled ols*	*rand. eff.*	*fix. eff.*
Gini	-0,19*	-0,17**	-0,12	-0,30**	-0,28**	-0,18
	[0,10]	[0,08]	[0,18]	[0,14]	[0,12]	[0,21]
gdp_pc	-1,69E-006	-2,21E-006*	-6,16E-006*	-4,08E-006	-4,86E-006***	-6,55E-006*
	[1,49E-006]	[1,28E-006]	[3,51E-006]	[2,86E-006]	[1,77E-006]	[3,52E-006]
gdp_pc^2	4,68E-011***	5,88E-011**	1,10E-010**	7,63E-006***	8,99E-011***	1,15E-010***
	[1,75E-011]	[2,50E-011]	[4,60E-011]	[2,36E-006]	[1,92E-011]	[4,55E-011]
overall patent pc	0,01***	0,01***	0,01***	0,01***	0,01***	0,01***
	[2,75E-003]	[2,22E-003]	[2,21E-003]	[2,75E-003]	[3,13E-003]	[02,32E-003]
year	4,95E-003*	4,7E-003**	0,01*	0,01**	0,01**	0,01
	[2,76E-003]	[2,43E-011]	[5,06E-003]	[4,45E-003]	[4,37E-003]	[0.01]
imputation dummies	yes	yes	yes	yes	yes	yes
constant	0,06	0,06*	0,09	0,13**	0,13**	0,12
	[0,041795]	[0,0355281]	[0,08]	[0,06]	[0,06[	[0,09]
R^2	0,66	0,66	0,62	6,52	6,5	6,36
obs	134	134	134	120	120	120
Hausman Test		χ(5)=1,71			χ(5)=0,46	
Std. Err. adjusted for 25 clusters in Country, boostrapped Std. Err. provide similar results						
* significant at 10%; ** significant at 5%; *** significant at 1%						

Table 6: Patents Innovative Fields, disaggregated

Dependent var.	elec.&Hybr. veh.	PCT eco-building			PCT renewables		
	pooled ols	*pooled ols*	*rand. eff.*	*fix. eff.*	*pooled ols*	*rand. eff.*	*fix. eff.*
Gini	3,51E-003	-0,04	-0,05*	-0,11	-0,15*	-0,12	0
	[0,01]	[0,02]	[0,03]	[0,11]	[0,06]	[0,07]	[0,1145722]
gdp_pc	-2,57E-007	-5,09E-007	-6,21E-007	-1,80E-006	-9,26E-007	9,76E-007	-1,87E-006
	[2,95E-007]	[7,15E-007]	[8,25E-007]	[2,41E-006]	[8,42E-007]	[8,75E-007]	[1,39E-006]
gdp_pc^2	8,48E-012	1,53E-011	1,62E-011	2,64E-011	2,30E-011	2,93E-011	4,63E-011
	[5,41E-012]	[1,01E-011]	[1,72E-011]	[3,39E-011]	[1,45E-011]	[2,01E-011]	[2,52E-011]
overall patent pc	8,64E-04***	3,80E-004**	4,18E-004***	4,30E-003***	4,51E-03	0	0
	[2,48E-04]	[1,64E-003]	[1,44E-003]	[1,61E,003]	[1,14E-003]	[1,84E-003]	[2,02E-003]
year	8,28E-004*	3,80E-004	4,89E-004	2,24E-003	3,74E-003	3,48E-003	3,78E-003
	[4,14E-004]	[0,0011698]	[1,46E-004]	[3,4E-004]	[1,75E-003]	[1,67E-003]	[2,96E-003]
imputation dumm.	yes	yes	yes	yes	0,05	0,04	0,01
constant	-1,02E-003	0,02	0,02	0,05	yes	yes	yes
	[5,00E-003]	[0,01]	[0,02]	[0,05]	[0,02]	[0,03]	[0,04]
R^2	0,48	0,44	0,44	0,42	0,41	0,41	0,38
obs	134	134	134	134	134	134	134
Hausman Test			χ(5)=1,57			χ(5)=0,70	
Std. Err. adjusted for 25 clusters in Country, boostrapped Std. Err. provide similar results							
* significant at 10%; ** significant at 5%; *** significant at 1%							

In sum, the empirical analysis supports the theoretical prediction that, especially for rich countries, a negative relationship emerges between inequality, on the one hand, and both environmental innovations and the size of eco-industries, on the other. Also consistent with the model, per-capita income turns out to be more important if poor countries are included, whereas

Table 7: Robustness Patents

Estimated impact of inequality on environ. Patents				
	Pollution abatement	*Innovative*	*Renewable*	*Eco building*
no poor	-0,94***	-0,46**	-0,37**	-0,1
no east eu	-0,60***	-0,30**	-0,23*	-0,06
no scandin.	-0,17**	-0,13*	-0,04	-0,08
- no Denm.	-0,37***	-0,10*	-0,06*	-0,04
no anglo	-0,36***	-0,1	-0,11	0,00.
- no USA	-0,36**	-0,13	-0,12	-0,02
no centr eu	-0,42***	-0,26***	-0,23**	-0,05
- no Germ.	-0,42***	-0,19*	-0,15	-0,05
no med	-0,41***	-0,19	-0,15	-0,04
- no Port.	-0,43***	-0,19**	-0,15	-0,04
no very rich	-0,43***	-0,22**	-0,21**	-0,03
no Japan	-0,42***	-0,2*	-0,14	-0,05**
dummy area incl.	-0,16*	-0,11	-0,04**	-0,06**

the opposite occurs for the impact of inequality. When focussing on specific fields, the strength and the meaning of the inequality-(income)-innovation link appears somehow weakened but still emerges, except for innovations at the early stages of their life-cycle where the pioneer consumer effect is probably paramount.

5 Concluding Remarks

The paper presents a demand-driven approach to look at the relationship between inequality and environmental quality. We showed that more equal countries appear also the ones having a comparative advantage in developing clean production methods. Our dynamic model enriches previous anaylises in three directions. First, the externalities generated by pioneer consumers of green products benefit the entire population only for relatively low income distance. As a result, the contrasting effect of inequality on environmental innovations through regulation (+) and demand (-) would no longer occur when moving from a static to a dynamic context. Second, the theoretical results are obtained under very general assumptions on both preferences and the shape of technological change. As in Pfaff et al. (2004), it is enough to assume that environmental quality is less essential than a basic want, whereas the function of technological change should be either concave or at least not too convex. Finally, a more equal distribution of income does not only foster the emergence of appropriate environmental regulations –as in existing literature– but also generate irreversibilities in the development of knowledge complementary to environmental-friendly behaviour.

The empirical analyses robustly confirm our theoretical results as long as country-specific characteristics, i.e. technological expertise, tends to be less important than cross-country variations associated to differences in the Gini index. Moreover, whereas for rich countries inequality negatively affects the diffusion of environmental innovations, the effect of per-capita income tends to be paramount in poorer ones. Specific fields of innovation display a more fragmented pictures especially for those at the real beginning of their technological-cycle, such as eco-building and hybrid cars. This evidence, jointly with the empirical evidence of an early comparative advantage of unequal countries in the more mature sector of renewable energy (i.e. the US, see Lanjouw and Mody 1996), seems to confirm that pioneer consumers, play an important role in explaining early stage of development of new products. Next step will be to build a theoretical model where political economy considerations and taxation are explicitly included in the analysis.

6 Appendix A

6.1 Proof of Proposition 1:

Since $u' : (0,\infty) \to (0,\infty)$ is continuous, monotonic and decreasing, its inverse ϕ has the same properties, hence $m^- = \phi(\frac{v}{\delta_P})$ and consequently $m^+ = (\delta_P + 1)m^-$ always exist and are uniques for any δ_P.

From eq.**??** we have:

$$\frac{v}{\delta_P} = u'(x_1 + x_2), \tag{9}$$

from the definition of ϕ we have eq.**??**. We took $p_1 = 1$ so we can write the budget constraint in the form $x_1 = m - p_2 x_2$. Substituting in eq. **??**: $m - (p_2 - 1)x_2 = m^-$; eq. **??** follows.

6.2 Proof of Corollary 1 and 2

We have to prove that for any level of income m^* there exist exactly two distinct values of the technological level, respectively θ^- and θ^+, at which m^* is respectively the lower and the upper threshold $m^-(\theta^-)$ and $m^+(\theta^+)$. All the points of Corollary 1 trivially follow from this result.
m^* is the lower threshold m^- when:

$$m^* = \phi(\frac{v}{\delta_P}) \tag{10}$$

rearranging and considering the definition of θ and ϕ:

$$\theta^{-} = \frac{u'(m^{*})}{v} \tag{11}$$

The properties of u' we just recall imply the existence and the unicity of θ^{-} and all its further properties in Corollary 2.
m^{*} is the upper threshold m^{+} when:

$$m^{*} = (\frac{1}{\theta} + 1)\phi(v\theta) \tag{12}$$

From same previous arguments about ϕ, the right hand side of eq.**??** ranges monotonically from ∞ to 0 when θ goes from 0 to ∞, hence a θ^{+} that solves eq.**??** always exists and has also the properties in Corollary 2.

6.3 Extensions to non-linear utility of the new wants

We want to show that the hypothesis 4 on preferences, is not necessary. What is essential to all our results is the existence of the two thresholds m^{-} and m^{+}, and the S-shape properties in eq.**??**.

According to eq.**??**, the existence of m^{-} corresponds to the existence of a solution $x^{-} = \frac{m^{-}}{p_1}$ to:

$$u'(x) = \theta v'(0), \tag{13}$$

this is a straight implication of hypothesis 3. The monotonic decreasing shape of u' implies that below m^{-}, the left hand side of eq.**??** will always be greater than the right side and hence agents demand only the old good.

The existence of m^{+} corresponds to the existence of a solution $x^{+} = \frac{m^{+}}{p_2}$ to:

$$u'(x) = \theta v'(x) \tag{14}$$

The Inaada conditions on u imply that the left hand side varies in $(0, \infty)$. If v', that is upper bounded, has also a positive lower bound ($v'(\infty) = k > 0$), the right hand side is also bounded in $(\theta v'(0), \theta k)$, and then a solution to eq. **??** always exists for any θ. Thus, for Proposition 1 to hold, we only need a slacker hypothesis than 4:

4a There is no satiation on the new want.

While the last inequality in eq.**??** is trivial the second is not: along the interval (m^{-}, m^{+}), a substitution effect of x_1 to x_2 will take place; thus the inequality will hold *on average* and at least for most of the interval. The eventual sub-intervals for which it will not be true because the demand of the old good is not increasing, will bring to second order effects on the relationships between demand and both income and technological level. As shown in Patriarca and Vona (2010), both this second order effects than the cases of "reswithcing" with multiple m^+, can be excluded if $\theta v'$ is flatter than u', bringing to a slightly different version of $4a$ corresponding to:

4b There is no satiation on the new want, and substituting the old good with the new one reduces the overall satiation effect.

7 Appendix B

In the reduced-Kuznets curve specification, an index of environmental performance (in our case the quota of public green R&D or the turnover of eco-industries per capita) is regressed on a function of per capita income plus controls and, in our case, the Gini index. More in details:

$$E_{ijt} = \beta \cdot \mathbf{f}(gdp\_pc_{it}) + \gamma \cdot t + \delta \cdot d_{i \in j} + \alpha \cdot ineq + \varepsilon_t,$$

where, for country i belonging to area j (Scandinavia, Anglo-Saxon countries, etc.), t is a year dummy whereas the area dummy $d_{i \in j}$ is equal to 1 if the country i belongs to area j and 0 otherwise. As a specification of the function $f(.)$ of per-capita income, we consider in the analysis a polynomial of degree two, i.e. $\beta_1 \cdot gdp\_pc_{i,t} + \beta_2 \cdot gdp\_pc^2_{i,t}$. However, results available upon request show that nothing changes if we consider a polynomial of degree three.

Imputation of missing values of the Gini is necessary because, otherwise, we would have lost too many data and substantially shortens the panel dimension. Measurement problems raising with imputation are here very relevant since the "all Ginis" dataset and the Oecd one often provide different estimated value for the Gini index. Moreover, the likelihood of errors increases because imputation has been made following rule-of-thumbs rather than standard prediction techniques. In particular, once a value is missing in our main Oecd dataset, we impute the value of the "all Ginis" dataset if available. In order to copy with gaps in the Ginis of the two datasets, we take the average of the two series in order to soften the (within-country) variations. Finally, the average of the two adjacent years is imputed when the internal value is missing. These imputation procedures were carried on extensively for Switzerland and Ireland, whereas for Finland, Japan, Australia, Portugal, Turkey and Mexico small changes were made. Iceland and Korea were dropped as no Gini indexes based on disposable incomes were available.

At the econometric level, we account for measurement errors associated to imputation by adding dummies for imputed values. More precisely, the empirical model becomes:

$$E_{ijt} = \beta \mathbf{f}(gdp\_pc_{it})' + \gamma t + \delta d_{i\in j} + \alpha ineq + d_{imp,t} + \widetilde{\alpha} d_{imp,t} \cdot ineq + \varepsilon_t,$$

where we allow the imputed values to affect both the incercept and the slope of the relationship between inequality and environmental innovations. This is our baseline specification to which we add the overall patent applications per capita when we consider patents as the dependent variable.

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