Comments on the paper
"Environmental taxes, inequality, and technical change" by F. Patriarca and F. Vona

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Assessing the effects of environmental policies is a highly valuable enterprise, for a number of reasons. Scientific evidence is piling up about the relationship between global warming and human-induced emissions of greenhouse gases (IPCC 2007). With their countries stuck in the deepest recession since the 1930s, governments can reignite growth by stimulating improvements in energy efficiency. Fighting pollution can save the lives of many, while it can keep public health spending under control.

Patriarca and Vona perform this assessment by means of a theoretical model built around a well-defined causal mechanism: a fall in the relative price of the green good fuels adoption, which in turn feeds back into further price decrease via learning economies, much in the spirit of Cantono and Silverberg (2009) (see also Vona and Patriarca 2011). An environmental tax can act as a trigger for this causal mechanism, as it affects the relative price of green goods. The effects of the tax are mediated by the average income level, income inequality, and the rate of technological learning. Hence, the paper is essentially an investigation on a causation process in which the environmental tax is the cause, and diffusion of the green good is the effect. Income inequality, which plays a prominent role in the paper, can be seen as a moderating factor.

I see a lot of potential in exploring the relationship between income inequality and the environment. One of the main results of the paper is that, in a high income country with sufficiently fast learning, income inequality slows down the diffusion of the green technology, because the distance between pioneer consumers and the remaining population is too high. Far-reaching implications can be drawn from this finding. It has been shown that the increase in income inequality witnessed in recent years is at least partly an outcome of financialisation, which has caused an explosion in executive compensations (Finnov 2012). The inequality-diffusion relationship found by Patriarca and Vona implies that, by achieving a more equal income distribution, financial reforms that overturn the financialisation trend can improve the effectiveness of carbon taxes on green technology diffusion, in a sort of institutional complementarity (Aoki 1992) between financial and environmental regulation. The ensuing improvement in energy efficiency would make firms more competitive, throwing light on an interesting transmission channel between the financial and the real sectors of the economy. Hence, the insights provided by the paper go well beyond the mere assessment of an environmental policy measure. Policy-makers should definitely pay more attention to the inequality-environment nexus. Nevertheless, in what follows I shall discuss a number of issues, in hope that the authors could further improve along their highly promising research path.

Let me tackle the issue of consumer behavior first. The model depicts consumers as endowed with full, substantive rationality, who maximize utility and interact only through the price system. Income is the only source of heterogeneity among consumers. These are highly stylized assumptions that the authors are going to relax in future research, as I understand from their concluding section. In their exhaustive review paper, Gsottbauer and van den Bergh (2011) give important hints on the implications of bounded rationality and social interactions for environmental policy. As a take-home message, it is increasingly recognized that policy design needs to take the behavioral evidence into account. For instance, Janssen and Jager (2002), Schwoon (2006), and Cantono and Silverberg (2009) postulate that consumer choice depends not only on the level of personal need satisfaction, but also on social needs. In other words, individuals are placed on a social network, and their choices are affected by the choices made by their neighbors. Status considerations and the quest for information on new goods justify this. This given, maximizing utility in isolation is considered as just one possible cognitive processing mode. Consumers in Cantono and Silverberg (2009) are pure imitators. In Janssen and Jager (2002), consumers can alternatively engage in repetition, if their satisfaction is maximized; in social comparison if changes in the surrounding environment cause the satisfaction level to drop (i.e. comparison between past choice and the best choice made by the neighbors); in imitative behaviors after increases in the variability of the satisfaction level. Consistently, the pro-environmental impact of price differentials can be overestimated if the consumer is represented as a pure *homo oeconomicus* responding to only monetary incentives, neglecting behavioral biases (see the results in Janssen and Jager 2002, as well as the default option and endowment effects in Pichert and Katsikopoulos 2008, who performed laboratory experiments on the switch to green energy). Another issue of potential interest for environmental policy assessments is that, by neglecting other-regarding preferences, policy analysis could place too much weight on efficiency goals and too little on equity and fairness, that may be highly valued by agents embedded in a network of social relationships.

Concerning the supply side of the economy, in the Patriarca-Vona model exogenous improvements in technology and deliberate firm-level innovative outcomes are collapsed into a single learning parameter. Explicit modeling of firm-level green technology decisions, however, would allow to separate the two learning determinants and analyze how the effects of a carbon tax interact with innovation-related policies. Results from Janssen and Jager (2002) show that the effectiveness of a tax policy depends on the balance between imitators and innovators (the former slowing down diffusion), as well as on whether firms adapt their products at all (e.g. if they perform R&D to either innovate or imitate). One may also suppose that investments by innovation-oriented firms give rise to a positive externality on the willingness to pay (WTP) for green products: R&D investments stimulate the returns to education, and a more educated workforce is more concerned with environmental issues.

Finally, I would suggest that a fully dynamic policy analysis, cast in a coevolutionary framework, would provide further hints as to the long-term effects of environmental taxation. For one, focusing on certain tax rates in simulation scenarios hides the presumption that such measures are politically viable. Whether this is the case, it depends on pressures on policy-makers by interest groups, including those representing firms, that are not modeled in the paper. Studying how policy-making and firms strategies (including lobbying) coevolve could be a fruitful area for future research. As a further issue, the model includes no assumption on how environmental tax revenues are spent. This common modeling choice is safe if the use of tax revenues is neutral, which is hardly the case. Tax revenues can be used to invest in (green) public infrastructures and R&D subsidies, as well as in public education which may determine an increase in the WTP for green products and better preferences against income inequality. Conversely, tax revenues may be wasted by bad politicians, possibly hindering green technical change. It may be interesting to explore to what extent the results of the model hold even after considering such scenarios: agent-based modeling is particularly well suited for dynamic policy exercises.

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Reply to Comments

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We wish to thank Alessandro Sapio for the very useful and stimulating comments. Two interesting points are raised by the analysis of Sapio.

First, He suggests that the assumption of fully rational, autarkic agents can be misleading in view of growing experimental evidence on the role played by social norms and reciprocity in human behavior. In particular, it is likely that, as, e.g., in Cantono and Silverberg (2009), consumers' willingness to pay (WTP) for green products is affected by the WTPs of their neighbors. Including peer effects in consumption would certainly have relevant implications for our analysis giving an active role both to local (*i.e.* spatial) and aggregate income inequality. The spatial distribution of agents endowed with different income levels would affect the distribution of preferences for a given aggregate level of inequality.

In spite of its relevance, this extension would deliver quite intuitive implications. Consider, for sake of simplicity, two populations characterized by the same level of aggregate inequality and different levels of segregation by incomes, which is here a sufficient statistics for broader socio-economic conditions. It is clear then that the first population would display a stronger pioneer consumer effect, while the second a larger mass of potential adopters, i.e. larger market size effect. From a purely theoretical perspective, all our results for technology diffusion apply to this more general case. Relevant implications would emerge, instead, by allowing the government to intervene in both the sorting process and in the determination of the income distribution. However, such analysis would lack realism: policies explicitly affecting sorting are not feasible in market economies where the house market determines the level of segregation.

Finally, the empirical evidence in support of peer effects in consumption is still scant, see footnote 4 in the paper, so this assumption would be difficult to justify. In turn, including other behavioral assumptions that are empirically observable, i.e. altruistic agents are more willing to buy green goods, would add realism without adding further insights. Indeed, binding income constraints prevent the consumption of the green good of those 'environmentalists' with low incomes.

The second comment regards the way in which we model the supply side that, we agree, is over-simplified. Including heterogeneous firm in our analysis would allow to study the joint effect of environmental and industrial policies. This extension will also be more in the spirit of recent theoretical analysis of the effect of environmental policies (*i.e.* Acemoglu et al. 2010, Fisher and Newell 2009). We found particularly interesting the possibility of including firm dynamics in a context of (truly dynamic) endogenous policy determination as the one suggested by Sapio. Such structure will allow us to analyze the crucial question of the co-evolution of technology and policy, as we believe ABM models would be the most suitable tool to analyse this interesting issue.

Moreover, considering the policy game behind the determination of environmental policies has also a strong empirical motivation. In the energy sector, for instance, there is a large and growing case study and empirical evidence showing the opposition of exiting incumbents against the approval of ambitious renewable energy policies (e.g. Jacobsson and Bergek 2004, Nilsson et al. 2004, Lauber and Mez 2004, Nicolli and Vona 2012), that stimulate innovation (Johnstone *et al.* 2010). The reason of this opposition is that renewable energy production is partially decentralized and hence destructive for the centralized model of energy production that ensures high profit to electric utility. The same argument applies for the link between the large distribution of food and the intensive, very polluting, methods of food production. A possible extension with heterogeneous firms can consider the complementarities between entry barriers and environmental policies. For instance, reducing the entry will reinforce green innovators and increases the lobbying effort in favour of ambitious environmental policies.

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