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Reinhilde Veugelers

Empowering the Green Innovation Machine

This contribution will discuss how green policies should be designed to activate private innovation forces for ecological transitions. An assessment is made as to how effective various types of government interventions have been and can be to power the green innovation machine. An important insight from the economic analysis of the effectiveness of public intervention for green innovations is the complementarity between policy instruments, indicating the need for an adequate policy mix of instruments rather than a focus on individual instruments. The evidence provides little support for the efficacy of single instruments, like subsidies, when used in isolation. For the EU, the biggest challenge for its green technology policy is the lack of a sufficiently high carbon price.

Government policy must power green innovation

How to limit climate change is one of the most pressing policy challenges facing the world today. Simulation exercises clearly confirm that to keep the costs of mitigation and adaptation "manageable",[1] we need a sufficiently wide portfolio of technologies in action. Although much can be done if existing technologies are further developed and more rapidly diffused, the portfolio must also include new technologies that are still far from large-scale commercialisation or not yet developed.

For clean technologies to be created, developed and diffused with sufficient speed and at the appropriate scale, policy intervention is necessary. In view of the pervasive environmental and knowledge-based externalities characterising green innovations, the private green innovation machine cannot be expected to be socially effective on its own in time. In addition, new green technologies face competition from the existing "dirty" fossil fuel-based technologies, which enjoy the advantage of already being installed. This creates a market environment that favours leaving the innovation machine on its own to work on improving these dirty technologies and consequently impedes the take-off of new clean technologies.[2]

Government intervention does not come without costs, though. The cost of supporting cleaner technologies is that it may slow down growth in the short-run investment phase. This must be balanced against the benefit from supporting cleaner technologies, namely the greener (and therefore more sustainable) growth they will bring about in the future. With currently constrained public budgets, it is all the more important that this public funding be allocated as effectively as possible in leveraging private funding.

This contribution examines how environmental policies should be designed to activate private innovation forces for climate change solutions. The evidence on the use of major policy instruments for green innovations is explored, and the question of whether they have been effective to power the green innovation machine, both to create new green technologies as well as to adopt green technologies, is examined. Following this, some suggestions are offered for improving government policy to fully activate private green innovations.

What should green innovation policies look like?

The issue is not whether or not we need government intervention to activate the green innovation machine, but how this government intervention should be designed to effectively turn on the private green innovation machine at the lowest possible cost to growth. This was discussed in Aghion, Hemous and Veugelers,[3] in which the authors drew on the insights from recently developed economic models of directed endogeneous technological change to identify optimal policy paths. We summarise the main insights here.

In particular, the analysis strongly supports the case of a portfolio of instruments including carbon pricing, R&D subsidies and regulation. Carbon pricing will address the environmental externality by putting a price on the negative effects on the environment. A price for carbon can be obtained through a carbon tax or a cap-and-trade system. Carbon pricing not only will reduce the production/consumption of dirty technologies; they will also be an impor-

1 V. Bosetti, C. Carraro, R. Duval, A. Sgobbi, M. Tavoni: The Role of R&D and Technology Diffusion in Climate Change Mitigation: New Perspectives Using the WITCH Model, OECD Economics Department Working Papers No. 664, 2009.

2 D. Acemoglu, P. Aghion, L. Bursztyn, D. Hemous: The Environment and Directed Technological Change, in: American Economic Review, Vol. 102, No. 1, 2012, pp. 131-166.

3 P. Aghion, D. Hemous, R. Veugelers: No Green Growth Without Innovation, Bruegel Policy Brief, No. 2009/07, 2009.

Reinhilde Veugelers, University of Leuven, Belgium; and Bruegel, Brussels, Belgium.

tant incentive for developing new technologies in order to reduce negative environmental externalities. In particular, future expectations of carbon prices are an important lever for firms to invest in R&D and thus speed up the adoption of green technologies.

In tandem with a sufficiently high and long-term time-consistent carbon price, R&D support for clean technologies is needed. R&D support will address the knowledge externality associated with the creation of new "clean" innovation. Public R&D support is especially crucial for clean technologies which are still in the early stages of development, as it will help to neutralise the base advantage of the older and dirtier installed technologies.

It is important that the policy instruments – carbon pricing, regulation and public support for clean R&D – are deployed simultaneously and in coordination, as there are important complementarities to exploit. Acemoglu et al. show that using a carbon tax alone will lead to excessive consumption reduction in the short run and would therefore be a more "costly" policy scenario compared to using carbon pricing and public support simultaneously.[4] Similarly, when using only the subsidy instrument and keeping the carbon price instrument inactive, the subsidies would have to be much higher compared to their level when used in combination. A way of showing the higher costs when using only one instrument, rather than a combination of carbon pricing and subsidies, is to express how high the optimal carbon price or subsidies would have to be relative to their optimal levels when used in combination. Calibrating this scenario in the Acemoglu et al. model, Aghion, Hemous and Veugelers show that the carbon price would have to be about 15 times higher during the first five years, while subsidies would have to be on average 115% higher in the first ten years.[5]

Equally important is that government intervention is done quickly. Delaying policy intervention not only leads to further deterioration of the environment; in addition, the dirty innovation machine continues to build on its lead, thus making the dirty technologies more productive and widening the productivity gap between dirty and clean technologies even further. This widened gap in turn means that a longer period is needed for clean technologies to catch up and replace the dirty ones. As this catching-up period is characterised by slower growth, the cost of delaying intervention, in terms of foregone growth, will accordingly be higher.

The directed endogeneous growth model also has prescriptions on the international dimension of policy intervention. If developed countries' governments direct change towards clean technologies and subsequently facilitate the diffusion of new clean technologies to developing countries, a major step towards overcoming global climate change can be taken. Indeed, it may not be necessary to price dirty-input production in the developing countries in order to avoid a global environmental disaster: unilateral government intervention in developed countries can turn on the green innovation machine in the developed world, which will in turn allow the developing countries to adopt the cleaner technologies. The greater the innovation spillovers from the developed to the developing countries are, the more active the developing countries will be in implementing clean technologies rather than dirty ones. Thus, even in the absence of action by developing countries, a case can be made for policy intervention by developed countries based on the diffusion of clean technologies.

4 D. Acemoglu et al., op. cit.
5 P. Aghion et al., op. cit.

The impact of government policies to induce green innovations in practice

There is increasing empirical evidence to support the contention that environmental policies do lead to technological innovation. We review some of this evidence here.[6]

Evidence on the creation of new clean technology

Using US industry-level data, Jaffe and Palmer examined the relationship between stringency and innovation more broadly (not only environmental patents) for a set of US manufacturing industries in the period 1977-1989, where innovation was captured in terms of both R&D expenditures and patents.[7] They found that increased environmental stringency, as measured by higher levels of pollution abatement costs and expenditures (PACE), did increase R&D expenditures in the US manufacturing sector, but not the number of patents. Brunnermeier and Cohen built on Jaffe and Palmer's work by narrowing innovation down to purely "environmental" patents.[8] As policy indicators, they used PACE and the number of inspections undertaken by the direct regulatory institutions. Contrary to Jaffe and Palmer, they found that the PACE variable has a statistically significant (and positive) effect on environmental patents,

6 R. Veugelers: Which policy instruments to induce clean innovating, in: Research Policy, Vol. 41, No. 10, 2012, pp. 1770-1778; A. Jaffe, R. Newell, R.N. Stavins: Technological Change and the Environment, in: Environmental and Resources Economics, Vol. 22, No. 1, 2002, pp. 41-69; N. Johnstone, I. Hascic, D. Popp: Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts, in: Environmental and Resource Economics, Vol. 45, No. 1, 2010, pp. 133-155.
7 A. Jaffe, K. Palmer: Environmental Regulation and Innovation: A Panel Data Study, in: The Review of Economics and Statistics, Vol. 79, No. 4, 1997, pp. 610-619.
8 S.B. Brunnermeier, M.A. Cohen: Determinants of environmental innovation in US manufacturing industries, in: Journal of Environmental Economics and Management, Vol. 45, No. 2, 2003, pp. 278-293.

whereas subsequent monitoring does not. Popp examined the effects of the introduction of the tradable permit system for sulfur dioxide emissions as part of US Clean Air Act Amendments on the technological efficiency of fluid-gas desulphurisation.[9] Comparing patent applications after the introduction of the tradable permit scheme with those submitted under the previous technology-based regulatory system, Popp found evidence of improved efficiency.

The empirical evidence with respect to the use of other policy measures beyond regulation, particularly subsidies for environmental R&D, is more limited. Johnstone et al. confirm that policies such as feed-in tariffs, renewable energy credits, carbon taxes and R&D subsidies are found to significantly affect innovators in a country, although the strength of the effects varies over technologies, instruments and countries.[10] For example, Germany has seen a dip in wind-based technology patenting despite the existence of feed-in tariffs.

Overall, the evidence on the impact of green policies on green innovations is not unfavourable. But it also highlights that policies are no straightforward panacea for stimulating green innovations. The details of the policy intervention matter for effectiveness.

Evidence on the adoption of new clean technologies

Government policy is not only important to induce the creation of new cleaner technologies. It is also important to drive the adoption of already developed technologies, for instance through the instrument of carbon pricing. The introduction of new cleaner technologies, whether independently developed or adopted from elsewhere, is better captured with innovation measures than with patent measures. Unfortunately, the standard information source for innovation, the EUROSTAT/OECD Community Innovation Survey (CIS), is poor at identifying eco-innovations.

Veugelers uses firm-level evidence on the motives for introducing clean innovations from the Flemish CIS eco-innovation survey (2008-2010).[11] Of all the innovation-active firms in the survey, 46% responded that they had introduced a clean innovation in the period 2006-2008.[12] Different types of green innovations show similar penetration rates. For instance, energy saving accounts for 22% of eco-innovations, reducing CO_2 for 20%, and reducing pollution 22%.

Table 1
Motives for introducing eco-innovations
in %

	Eco-innovators	Reducing CO_2 emissions	Saving energy
Current regulations	32	42	38
Expected regulations	25	37	32
Grants and subsidies	15	22	21
Consumer demand	21	29	28
Voluntary agreements	39	51	50

Note: Numbers reflect the share of innovators reporting the respective motive as important for introducing their eco-innovation.

Source: R. Veugelers: Which policy instruments to induce clean innovating, in: Research Policy, Vol. 41, No. 10, 2012, pp. 1770-1778.

These eco-innovators were surveyed on their motives for introducing clean innovations (see Table 1), including the following:

- current environmental regulations or environmental taxes
- expected environmental regulations or environmental taxes
- grants, including R&D subsidies, or other public financial incentives for environmental innovations
- existing or expected demand from customers for environmental innovations
- voluntary codes of practice used in the sector or sectoral agreements to stimulate eco-friendly practices.

This set of motives covers a wide range of government policies, including regulations, taxes and public financial incentives. The latter can include R&D subsidies as well as subsidies for the adoption of clean technology, tax credits or other clean innovations.

Overall, the survey results identify government intervention as an important motive for firms to introduce clean innovations, even more so for innovations aiming to reduce CO_2 emissions and to save energy. Nevertheless, the most frequently identified motives driving the adoption of eco-innovations are voluntary agreements. This puts the importance of government policy in perspective.

9 D. Popp: Pollution Control Innovations and the Clean Air Act of 1990, in: Journal of Policy Analysis and Management, Vol. 22, No. 4, 2003, pp. 641-660.
10 N. Johnstone, I. Hascic, D. Popp, op. cit.
11 R. Veugelers, op. cit.
12 Of the 2,894 firms in the sample, 43% responded that they had introduced a clean innovation in their own operations, and 28% reported that they had developed new clean innovations for their users. The latter group was also significantly more likely to introduce green innovations in their own operations as well, with 85% responding that they had done so.

Still, despite the importance of "private" motives for adopting clean innovations, government regulations and taxes are mentioned by almost a third of all eco-innovators as a motive. Grants are least often mentioned as an important motive, although they are somewhat more influential for CO_2 and energy saving innovations. However, across all types of clean innovations, regulations and taxes – both current and future – are more influential than grants.

The evidence further supports the increased leverage of policies when combining regulations and taxes with subsidies. Companies that rate regulations and taxes as a decisive motive are significantly more likely to also rate grants as decisive – and vice versa – indicating complementarity between government instruments, as also discussed above.

The impact of the consistency of government interventions over time can be analysed by looking at the impact of current and future policy interventions. Eco-innovators who list current regulations and taxes as influential are also significantly more likely to list future regulations as important. The intertemporal consistency of policy is relevant to all types of eco-innovations, but it is especially important for climate change innovations and more so for developers than for adopters.

Overall, the evidence is very supportive of the thesis that firms are responsive to eco-policy interventions.[13] At the same time, the evidence also suggests just how important the details of the policy design are, particularly the policy mix and the consistency over time.

Designing policies for a green innovation machine

In view of the real and sizeable climate change challenge, we need a green innovation machine operating at full speed. The private green innovation machine, left on its own, is not up for this challenge. It needs government intervention to address a combination of environmental and knowledge externalities.

The good news is that the evidence shows government interventions, when properly designed, have the power to turn on the private green innovation machine. The evidence is favourable for the impact that green policies can have on motivating the private sector to develop and adopt green innovations. But at the same time, the evidence highlights that government policies need to be seen as merely one part of a full set of motives for the private sector to introduce green innovations. Demand for clean products and lower-cost clean processes are also important levers for the development and adoption of green innovations by the private sector. The importance of demand pull from customers and voluntary codes of conduct or voluntary sector agreements as drivers for introducing green innovations is a reminder of the endogenous strength of the private innovation machine, indicating that green policy should not try to permanently substitute for private incentives. It should have an exit strategy, designed to leverage private forces as soon as possible, a point also made by the directed technological change models for green innovations.

The evidence also highlights how the details of the policy intervention matter for effectiveness. The required details include a long-term, time-consistent policy framework to be able to leverage the incentives of the private sector to engage in long-term green innovation investments. This is particularly important in technology fields which still require substantial early-stage research and development, as well as for larger infrastructure projects with correspondingly large investment requirements.

An important insight from the economic analysis of the effectiveness of public intervention for green innovations is the complementarity between policy instruments. The evidence provides little support for the efficiency of single instruments, like subsidies, when used in isolation. A well-functioning carbon market is an essential component of a policy mix driving low-carbon investments and achieving global mitigation objectives in a cost-efficient manner, particularly for investments in development, demonstration and deployment of later-stage technologies. It is a reminder for those governments contemplating a public green R&D support programme that the lack of a strong carbon price that is expected to prevail in the future will seriously reduce the effectiveness of subsidies as a policy instrument to leverage private innovative incentives for climate change.

For the EU, this is perhaps the biggest challenge for its green technology policy: the lack of a sufficiently high carbon price. To this end, a larger effort should be devoted to coordinating carbon taxes among EU member states. At the same time, the EU Emissions Trading System and the issuing of allowances should be designed with a long-term perspective to leverage private green innovation, i.e. taking into account the need to reinforce innovation incentives. What would further benefit the development and adoption of green technologies is an international carbon price established on a globally integrated carbon market, or at least internationally linked domestic cap-and-trade systems. The coordination of green policies internationally among the major players should be high on the policy agenda.

13 A full (econometric) analysis of the motives for eco-innovations, controlling for firm and sector characteristics, confirms this. See R. Veugelers, op. cit.