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Inducing private clean innovations

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Abstract

In view of the sizeable climate change challenge, we need a clean innovation machine operating at full speed. Beyond the supply of public clean R&D infrastructure and clean public purchases, the development and adoption of new clean technologies by the private sector needs to be assured to reduce Green House Gas (GHG) emissions. The private clean innovation machine, left on its own, is not up to this challenge. It needs government intervention to address the combination of environmental and knowledge externalities and overcome path dependencies. A technology policy for climate change requires a combination of technology supply side instruments next to demand-inducing instruments. The firm level evidence presented in this contribution on the motives of private sector firms for introducing clean innovations from the latest Flemish CIS eco-innovation survey confirms that firms are responsive to eco-policy demand interventions. The high importance of demand pull from customers and voluntary codes of conduct or voluntary sector agreements as drivers for introducing clean innovations, is a reminder of the internal strength of the private innovation machine, which governments need to leverage. Policy interventions are more powerful to induce the adoption and development of new clean technologies when designed in policy mix and time consistently, affecting future expectations.

Keywords: clean innovations, private, development, diffusion, policy mix, demand-inducing instruments

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1. Why we need the private innovation machine for climate change and how to turn it on

How to limit climate change is one of the grand policy challenges facing the world today (Stern (2007)). Simulation exercises ((eg Bosetti et al (2009))) confirm that to keep the costs of mitigation and adaptation "manageable", a wide portfolio of technologies needs to be available and used by polluters soon. Radically new clean technologies which are not yet available or still far from commercialization will be needed to tackle climate change, but these require a longer-term perspective. In the shorter term, we also need the deployment of already available cleaner technologies and the development of near to market cleaner technologies.

For clean technologies to be developed and diffused sufficiently fast and at the appropriate scale, policy intervention will be needed. In view of the pervasive combination of environmental and knowledge externalities characterizing clean innovations, the private clean innovation machine cannot be expected to be socially effective on its own. In addition, new clean technologies face competition from the existing more dirty technologies, who enjoy an initial installed base advantage. Private actors need to be provided incentives to switch from existing dirty technologies to new clean technologies (Acemoglu, Aghion, Bursztyn and Hemous (2009)).

The issue is not just whether we need government intervention, but also how this government intervention should be designed to lower emissions at the lowest possible cost for economic growth. Crucial is for the government to leverage the private sector into adopting and developing clean innovations.

Recently developed economic models of directed technological change (eg Acemoglu et al (2009), Bosetti et al (2007), David et al (2011)) strongly support the case for a *portfolio of instruments including carbon prices, R&D subsidies and regulation* (see Aghion, Hemous and Veugelers (2009)). Carbon prices, obtained through a carbon tax or a cap-and-trade system, will not only reduce the production/consumption of dirty technologies, they will also be important as incentive for the private sector to develop new clean technologies and accelerate the adoption of existing cleaner technologies. Expectations of future carbon prices and regulations in are an especially important lever for private sector research, development and adoption of clean technologies. In tandem with a sufficiently high and long-term, time consistent carbon price as well as performance based regulation, public support for the development and adoption by the private sector of clean technologies is needed. Public R&D support is especially crucial for clean technologies which are still in the early stages of development, neutralizing the installed base advantage of the older, dirtier technologies. It is important that policy instruments are deployed simultaneously, as there are important complementarities to exploit. Acemoglu et al (2009) show that, while a carbon price alone could deal with both the environmental and the knowledge externalities at the same time, using the carbon price alone would be a more "costly" policy scenario, in terms of resulting in lower economic growth. Similarly, when using only the subsidy instrument, keeping the carbon price instrument inactive, would imply excessively high levels of subsidies would compared to their level when used in combination[1].

Are governments deploying the right effective policies for stimulating clean innovations? Aghion, Veugelers and Serre (2009) examined the record of government policies for clean innovation. With low, volatile and fragmented levels of carbon pricing and subsidies, their overall conclusion is that we are still far off from an effective policy framework capable of leveraging the power of the private sector to research, develop and deploy cleaner technologies.

In this contribution we look at private clean innovation in more detail and how this process can be stimulated by a green mission oriented government policy. Climate change has unique features that differentiate this challenge from other mission oriented government policies (Jaffe (2011)). Unlike in the Manhattan or Apollo projects, the mission is not focused on a specific isolated technological objective. What is needed is a pervasive transformation of the whole energy-economic system, mobilizing polluters to switch to new low-emission systems. It shares with health related missions the need to include support for development of new technologies as well as policies on the demand side to accelerate the adoption of new technologies. In health, the financing of health care affects adoption, but in climate change, different policies may be needed to accelerate adoption by the private sector. The ICT area also lacks the negative externalities associated with pollution, but it provides perhaps the nearest example of a similarly scaled transformation of the socio-economic system that is needed to fully leverage the power of new technologies. In ICT, many OECD governments played a major role beyond supporting (mission-oriented) research through purchases of components and systems, particularly in the early phases of technology development. In energy, one could similarly envisage public purchases of clean solutions in areas where the government has a strong procurement interest (e.g. electric military vehicles). That energy is a highly specific and challenging case for designing a mission oriented technology policy is demonstrated by its history. Jaffe (2011) reports on the 1970s large scale policy initiatives in the US to demonstrate the commercial feasibility of technologies to replace petroleum. The large scale synfuels and related projects failed to result in significant commercial outcomes and because of their poor design and implementation crowded out rather than complemented private investments (see also Yang & Oppenheimer (2007)).

This contribution will not discuss the public research infrastructure, large scale public projects or public procurement for clean innovations part of a technology policy for climate change. Our focus is on the part of a climate change technology policy that aims to leverage the private sector into developing and adopting clean technologies, to induce the needed transformation of the energy-economic system. We look both at the development and the deployment of new clean technologies by the private sector. To this end, we first provide a quick look at available data on clean innovations (section 2). The major part of this contribution is dedicated to a micro-economic analysis of which firms have been creating and/or adopting clean innovations, and how strong which types of government interventions have been in

[1]A way of showing the higher costs when using only 1 instrument (i.c. the carbon price or R&D subsidies), rather than a combination of carbon pricing and subsidies, is to express how high the optimal carbon price or subsidies would have to be when used as a singleton instrument relative to its optimal level when used in combination. Calibrating this scenario in the Acemoglu et al (2009) model, Aghion, Hemous and Veugelers (2009) show that the carbon price would have to be about 15 times bigger during the first 5 years, while subsidies would have to be on average 115% higher in the first 10 years.

affecting these decisions (section 3). To this end we present new evidence from the Flemish CIS eco-innovation module (section 4). We close with some suggestions for a mission oriented green innovation policy on how to leverage the private sector.

2. Data on clean innovations

In this section, we take a look at data on clean innovations. A first important observation to note is the poor quality of standard data on clean innovations. No common definitions are used, with terminology ranging from clean, sustainable production or transportation technologies to eco-technologies (e.g., antipollution technologies[??]) and their innovations. While each source uses its own definitions, a common denominator of clean or eco-innovations is that they are aimed at generating substantial improvements for the environment. These environmental effects include CO2 emission reduction for climate change, but also involve other types of pollution reduction, waste treatment as well as the environmental gains from a better use of resources. Clean energy and energy efficiency are a major subsector of eco-innovation. In reporting data, our focus is on private firms' activities in innovations for climate change, but depending on data availability, we also report broader categories.

Data on private **R&D expenditures** are not reported by technology[2]. There is only information available by the economic sector in which the R&D expending firms are active (NACE classification). The EC-JRC-IPTS Scoreboard on large R&D spenders also classifies firms and their R&D expenditures on the basis of their major sector of activity. Although in this classification, alternative energy is one of the sectors considered, it fails to capture the clean R&D investments of firms whose major sector of activity is in other sectors (like GE or Siemens)[3].

A commonly used data source for measuring private sector **innovations** is the Community Innovation Survey, organized bi-annually by EUROSTAT/OECD. The survey collects evidence on the innovative behavior of companies, not only innovations developed inhouse or in collaboration with others, but also innovations developed elsewhere that are adopted by firms. Unfortunately, the Community Innovation Survey offers few insights into eco-innovation[4]. Only the last wave, CIS-VI (2006-2008), partly

[2] There is only information available by the economic sector in which the R&D expending firms are active. In most sectors important for greenhouse gas emissions (like cars, chemicals, petroleum), overall innovative activities cannot be used as a reliable measure for clean innovations, as the innovations in these sectors are also (and even mostly) related to other motives.

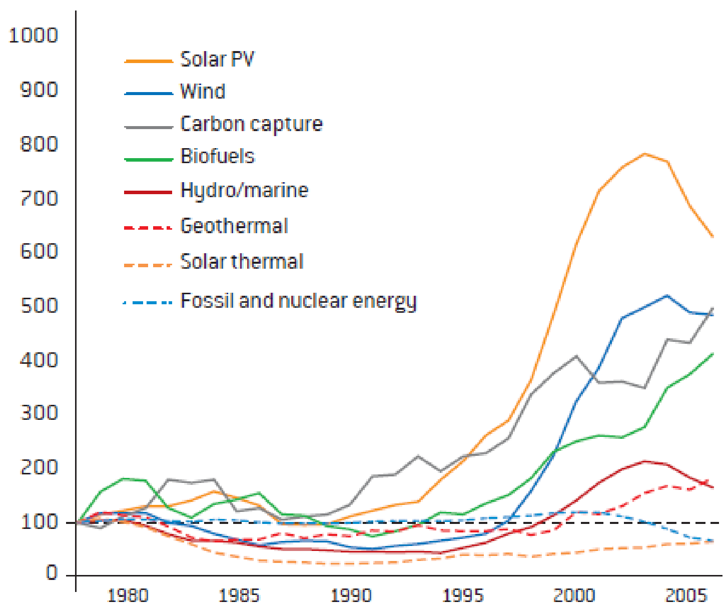
[3] In 2009, among the 1000 largest R&D spenders in the EU, 12 dedicated companies from the alternative energy sector managed to get into the list, another 2 in the 1000 non-EU spenders. They hold an R&D intensity of 3.5%. (EC-JRC-IPTS Scoreboard 2010)). An assessment of R&D for low-carbon energy innovations, using websites and field survey interviews, was performed for an EU funded project (SRS (2008)) and confirmed that innovation in the energy sector may not predominantly be carried out by energy companies. Industries with elevated research activities in low-carbon energy technologies include companies active in industrial machinery, chemicals, and energy.

[4] The previous CIS waves include evidence on motives for innovation, which provides some links to environmental innovations, although very imperfect. The question on "improving energy efficiency" as an innovation motive relates to environmental benefits, but does not necessarily reflect an explicit green motive. The more direct question

overcomes this problem, as it includes an optional one-page set of questions on environmental innovation. In section 4 we will use these results from Belgium, one of the countries that included the "environmental module".

Information on **patent** applications can be used to measure inventive activities related to environmental protection[5]. To be picked up as an eco-patent, the environmental effects should be associated with a patent class linked to clean technologies or environmental effects should be described in the patent application. While the OECD and WIPO use the first approach, EPO also uses the second approach. Applying this approach to clean energy, EPO's classification of Clean Energy Technologies (CET patents) includes 6 main categories: solar (both thermal and PV), wind, carbon capture and storage, hydro, geothermal, biofuels and integrated gasification combined cycle (IGCC) (UNEP/EPO/ICTSD (2010)).

Graph 1: Growth rates of patents (applications) for selected CET



Source: On the basis of UNEP/EPO/ICTSD, 2010, Patents and clean energy: bridging the gap between evidence and policy;

Note: Patents are counted on the basis of claimed priorities (patent applications filed in other countries based on the first filed patent for a particular invention)

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on "reducing environmental impact" as an innovation motive, unfortunately is merged with health and safety motives.

[5] There are a number of limitations in using patents to measure eco-innovations. First, patents measure inventive activity, not innovations. Second, eco-patents mainly measure identifiable inventions that underlie clean product innovations and end of pipe technologies, whose environmental impacts are specific aims and motivations of the inventions. For other types of innovation, such as process changes, patent analysis is less useful because many of these innovations are not patented.

Until the mid-1990s, CET patents stagnated and even declined, certainly in relative terms as overall patenting activities continued to grow. But since the late nineties, CET patents have trended upwards. One cannot ignore the correlation between political decisions and the take-off of CET technologies, as the upward trend started around 1997, when the Kyoto protocol was signed. This upward trend holds particularly when compared to the traditional energy fields (fossil fuels and nuclear) which have trended down since 2000. When looking at individual CET technologies, patenting rates in solar PV, wind and carbon capture have shown the most activity. Biofuels is a more recent growth story. Solar- & geothermal are growing more slowly if at all, reflecting their still premature stage of development.

If we look at which countries are active in clean energy patenting[6], **Japan** is the clearest positive outlier (Table 1). Japan holds about 30% of all CET patents, but it is not particularly specialized in Clean Energy Technologies, and it is heavily concentrated in a particular CET technology, namely solar PV. **Korea** is another important player in CET patenting, specialized in solar PV. The **US**, despite its 16% share of world "clean patents", is not specialized in any single class of Clean Energy Technologies. It is more dispersed across various CET technologies. If the **EU** were to be counted as a homogeneous block, it would be the block with the largest share of CET patents. In Europe, **Germany** is by far the largest country for CET patents[7].

Table 1: Who's who in CET patenting?

	Size	**Specialization**	**Concentration**
	Share of country in World CET patents	**RTA in CET patents**	**Herfindahl across CET technologies**
TOP 6			
Japan	29.7%	0.99	0.72
US	15.9%	0.87	0.33
Germany	15.2%	1.05	0.28
Korea	5.6%	1.21	0.82
France	3.9%	0.70	0.26
UK	3.6%	0.98	0.28
EU	32.0%	1.01	0.25

Source: Own calculations on the basis of UNEP/EPO/ICTSD, 2010, Patents and clean energy: bridging the gap between evidence and policy;

A Top 6 country has at least 2% of world CET; Together the Top 6 represent 74% of world CET patents
RTA= share of the country in world CET patents relative to the share of the country in total world patents; RTA > 1 measures specialization in CET patents;
Herfindahl is the weighted sum of the share of each CET technology in total country's CET patents, with the weights being the share. The Herfindahl ratio varies between 0 (maximal dispersion) and 1 (perfect concentration)

[6] Patents are assigned to countries on the basis of the location of the assignee, which in most cases is a corporation.

[7] Also some other EU countries are specialized in environmental technologies (RTA>1), but are nevertheless small players (<2% of CET patent share) (in order of size): Netherlands 1.19; Denmark 13.46; Spain 1.14; Austria (1.05), Portugal (4.93), Hungary (1.11);

This quick glimpse at the data is suggestive of a positive association with active government policy, particularly when looking at when clean energy patents have taken off, i.e., post-Kyoto, and which countries are most active , i.e. with the relatively weak position of the US and the relatively strong position of the EU and Asia in individual classes of CET technologies. But how important has government policy been in explaining patterns in CET patenting? In the next sections we examine in more detail, using micro-economic evidence, the effectiveness of government policies in motivating private clean innovations. Before we present new analysis using the Flemish eco-innovation module results from the latest CIS-VI survey in section 4, Section 3 presents a review of existing analyses.

3. Evidence on the impact of government policies to induce private clean innovations

The results of an extensive empirical literature support the contention that environmental policies do succeed in incentivizing the private sector to develop and adopt new clean technologies. Jaffe et al (1995), Newell and Stavins (2002) and Johnston (2008) provide reviews of the empirical literature, on which the following paragraphs draw heavily.

Most of the existing empirical studies concentrate on the impact of environmental policies on the **creation** of new clean technologies, using patents as an empirical proxy. An early paper is Lanjouw and Mody (1996), who examined the relationship between the number of environmental patents granted and environmental policy for a series of countries for the period 1971-1988. They use expenditures for pollution abatement as a very indirect and imperfect measure of environmental policy stringency, and find that pollution abatement costs affect the number of patents successfully granted. Unfortunately, their study failed to control for other determining factors. Using US industry-level data, Jaffe and Palmer (1997) extended Lanjouw and Mody's study, by incorporating various factors that potentially affect environmental innovation. Focusing on US manufacturing industries during 1977-1989, Jaffe and Palmer examined the relationship between environmental stringency (as measured by higher level of Pollution Abatement Costs and Expenditures (PACE)) and innovation. They measured innovations in terms of both R&D expenditures and patents, without restricting the investment or patent data to cover only clean innovations. They found that increased environmental stringency does increase R&D expenditures in US manufacturing sectors, but not the number of patents.

Brunnermeier and Cohen (2003) built on Jaffe and Palmer's work, narrowing innovation to purely "environmental" patents. As policy indicators, they used pollution abatement costs (PACE) and the number of inspections undertaken by regulatory institutions. Contrary to Jaffe and Palmer, they found that the PACE variable has a statistically significant (and positive) effect on environmental patents, whereas subsequent monitoring does not. Taylor *et al.* (2003) studied the time path of patents in sulphur dioxide (SO_2) control, especially activities related to fluid gas desulfurization. Analyzing a 100 year time span (1887-1995), they found that more patent applications were filed after SO_2 regulation was introduced in the 1970s. In addition to SO_2 regulation, Popp (2006) also examined NO_X regulation in the US, as well as the German and Japanese electricity sectors, exploring whether these regulations affected (inter)national innovation and diffusion.

More recent work by Aghion et al (2010) studied clean versus dirty innovations in the auto industry, using (taxes on) fuel prices as instrument for government policies, patents for electric vehicles to measure clean innovations and patents for combustion technologies to measure dirty innovations. Their results confirm that fuel prices drive clean patents more than dirty patents, but have a greater effect on firms with a larger stock of dirty patents. This is consistent with the need for government intervention to break firm-level path dependency in the old dirty technologies.

Very few studies have compared the effects on firms' innovative behavior of different policy instruments. Using patent data, Popp (2003) examined the effects of the introduction of the tradable permit system for SO_2 emissions as part of US Clean Air Act Amendments on the technological efficiency of fluid-gas desulphurization. Comparing patent applications after the introduction of the tradable permit scheme with those submitted under the previous technology-based regulatory system, Popp (2003) found evidence the while early regulations did little to improve the environmental effectiveness of the technologies developed, innovations introduced after the introduction of the tradable permit scheme did lead to increased environmental effectiveness.

The empirical evidence with respect to the use of other policy measures, particularly subsidies for environmental R&D, solely and preferably in combination with market based instruments and regulation, is even more limited. Johnstone (2008) reports on three different case studies: abatement technologies for wastewater effluent from pulp production; abatement of motor vehicle emissions; and development of renewable energy technologies. Overall, the case study evidence is supportive of the argument that environmental policy affects technological innovation, but whether a policy instrument is effective or not varies across the clean technologies considered and at which phase of the technology life cycle the instruments was used. For instance, in the study on renewable energy, the implementation of different policy measures had a measurable impact on innovation, with tax measures and quota obligations being statistically significant determinants of patent activity. However, the effect of the different policies varied by the type of renewable energy involved. Public expenditures on targeted R&D were statistically significant for every type of renewable energy. Relative prices are found to induce particular kinds of innovation. In the case of motor vehicle emissions abatement, fuel prices encouraged investment in "integrated" innovation, but not in "post-combustion" technologies. In the case of renewable energy, the role of electricity prices was rarely significant, except for solar energy. Other market factors can also be important spurs to innovation. In the case of bleaching technologies in the pulping process, public concerns about the environment appeared to stimulate the development of new cleaner technologies, pre-dating the introduction of regulatory standards. Eco-labelling did not appear to have an influence on innovation in this case. The case studies did not report on any possible complementarity between R&D grants and demand-side policies such as carbon pricing and/or regulation.

In a follow-up econometric analysis, Johnstone et al. (2010) confirm that overall environmental policies significantly affect private innovators, although the strength of the effects varies over technologies. Quantity-based policy instruments such as obligations and tradable certificates were found to be most effective in inducing innovations in wind power technology. Price-based instruments such as investment incentives, tax measures and tariffs proved most effective in encouraging innovation in solar. Unfortunately, due to too high correlation with the intercept, the effectiveness of R&D support programs could not be isolated.

Government policy is not only important to induce the creation of new cleaner technologies, as measured by patents. It is also important to drive the **adoption** of already developed clean technologies by firms. Far fewer studies exist on the adoption of clean technologies, although it is an important part of the transformation of the energy-economic system that is needed to tackle climate change. A survey of firms in eight sectors in five European countries on motives for adopting eco-innovations confirms the importance of complying with regulations (Arundel (2009)). But the survey found that there are many more important reasons--besides complying with regulations--for introducing an eco-innovation. These are: improving the firm's image, reducing costs, and, for product and service innovations, demand pressure (measured by securing existing markets and increasing market share as motive for adopting clean technologies). Compliance with environmental regulations was more important for adoption of pollution control innovations than for the other types of eco-innovation. Process innovations and recycling were often introduced in response to the need to comply with regulations, but many of them were also introduced to obtain cost savings (not environment-related) or to improve the environmental image of the firm.

Overall, the econometric evidence from the economics literature is not unfavorable for the impact of clean policies on clean innovations. But it also highlights that policies are no panacea for stimulating clean innovations. Although the evidence suggest that the type of policy instrument (e.g. tariffs versus grants), the type of clean technology targeted (e.g. motor vehicle emissions versus solar) and the nature of the environmental effect (e.g. reducing CO2 emissions versus enhancing energy efficiency) all seem to matter for effectiveness, we still have a very incomplete view on which combination of policy instruments is most effective in stimulating clean innovation creation and diffusion. This comes on top of a lack of evidence on the effectiveness of public R&D infrastructure building and public procurement as parts of the technology policy mix for climate change.

4. Micro evidence from Belgian firm level CIS-VI data on the impact of government policies to induce clean innovations

This section discusses new evidence, drawn from the Flemish CIS eco-innovation module, on which firms have been developing and adopting clean innovations, and which types of government interventions have been most effective in influencing these private decisions. EUROSTAT/OECD introduced in the 6the Community Innovation Survey, covering the period 2006-2008, an eco-innovation module. This module surveyed firms on what factors, including government policy, affected the introduction of eco-innovations. These data thus allow us to examine the impact of clean government policy on the likelihood of firms introducing clean innovations. As the module is part of the larger CIS-survey, it also allows us to control for other innovation related characteristics of the firms surveyed. The disadvantage of the CIS data is that it is a cross section for a single period of time rather than a time series or panel.

Belgium was one of the countries that included the eco-innovation module in its CIS, and we use the Flemish data to investigate the impact of government policies on firms' clean innovation behavior. Flanders is one of the three Belgian regions. In its Innovation Communication for 2009-2013 Flanders expressed its ambition to be part of the top 5 regions in European innovation. To this end it has developed a "New Industrial Policy" type of strategic framework ("Flanders in Action") coordinating existing government budgets, instruments and stakeholders around "spearheads"/clusters and large projects. One of these "spearheads" is Energy and Environment, with large scale innovation projects in smart grids and electric vehicles. In addition, Flanders provides incentives for adoption of clean technologies as well as subsidies for R&D generally. Environmental regulations have also been introduced , many of which originate at EU level. In addition to the policy instruments at the Flanders regional level, there are tax incentives and financial support for the adoption of clean or energy efficient solutions at the national (Belgian) level. The EU also has a clean technology policy that includes a mixture of support for cooperative R&D, energy efficiency regulations, carbon pricing (ETS) and renewables targets (see Veugelers (2011)).

We will not be evaluating the individual instruments of the clean energy technology policy framework of these three levels of government. We instead look only at the extent to which the package of instruments has affected the private sector's incentives to create and adopt clean innovations. The data only allow us to separate the effects on firms' behavior of subsidies, regulations and taxes, and voluntary sectoral agreements, many of which are government-induced[8]. We first briefly discuss the data (section 4.1), the research hypotheses (section 4.2), descriptive statistics on who introduces eco-innovations (section 4.3) and why (section 4.4), before presenting the econometric results on the importance of government intervention for clean innovation (section 4.5)

4.1. The CIS-VI eco-innovation data

In the CIS-VI eco-innovation module, a first set of questions asks respondents if they have introduced an innovation with one or more environmental benefits (ECO). Nine types of environmental benefits are being distinguished:

- Six types of environmental benefits that can occur during the use of the innovation by the enterprise (ECOOWN):
    - lower use of materials (ECOMAT), lower energy use (ECOEN), lower CO2 emissions (ECOCO), less use of pollutants (ECOPOL), less pollution of soil, water, air or noise control (ECOSUB), recycling (ECOREC).
- Three types of environmental benefits that can occur during the use of the innovation by the end user (ECOUSER):
    - lower energy use (ECOENU), less pollution (ECOPOLU), recycling (ECORECU).

While the first six types of benefits flow from the adoption of eco-innovations (ECOOWN), the other three types of benefit are associated with the firm's development of eco-innovations (ECOUSER).

A second set of question asks about different motives for introducing environmental innovations. It asks whether the firm introduced environmental innovations as reaction to the following set of factors:

[8] Croci (2005) presents an analysis of examples of environmental voluntary agreements (such as benchmarking convenants on energy efficiency) through a series of case studies. Benchmarking convenants are commonly used in Flanders.

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

This second set of questions covers a wide range of government policies, including regulations, taxes and public financial incentives. The latter can include R&D subsidies, but these could also include subsidies for the adoption of clean technology, tax credits for clean innovations etc. The list of policies does not include the use of public research infrastructure or public procurement to stimulate private eco-innovations, although these also may be important influences on firm-level innovation.

Both sets of questions are asked on a simple 'yes or no' basis, with no information on the relative size of the environmental innovation efforts, nor on the relative importance of specific policies. The simple format of the questions resulted from two rounds of cognitive testing with the managers of 20 enterprises, representing small, medium and large firms in eight EU countries and six sectors (Arundel et al, 2009).

With a response rate of 44%, the Flemish CIS-VI data covering the period 2006-2008, holds 2963 observations. Of these firms, 42% claim to be active in innovation, 33% are engaged in intra-mural R&D activities and 10% have applied for at least 1 patent. 88% of the sample firms are SMEs, and 45% are in the service sector.

We linked the Flemish firms in the CIS-data to data on membership in the EU Emission Trading System to test for the impact of the EU-ETS scheme on firms' environmental innovative behavior. Only 6 companies in the CIS also are in the ETS scheme, which may reflect the fact that a large number of Flemish firms in the ETS scheme are not in the CIS-sample because they are not innovation active (e.g., firms in building material) or did not respond to the CIS survey. It is also a reflection of the highly targeted nature of the ETS system with respect to sectors and firms, concentrating as it does on large polluting sectors and firms. Due to the small number of observations, however, we are unable to evaluate the ETS scheme's influence on firms' innovative behavior.

4.2. Research questions

With all the caveats in mind, the Flemish CIS-VI eco-module data allow us to test the impact of clean government policy on the likelihood of firms introducing clean innovations, either own or elsewhere developed. More specifically, these data allow us to investigate and compare the effects of different clean policy instruments.

- We are particularly interested in analyzing which types of government interventions, if any, are most influential: R&D subsidies (ENGRA) or environmental regulations and taxes (ENREG).

- We will also investigate whether there is any complementary effect from both types of instruments.

- Comparing the effect of current and expected regulations (ENREG versus ENREGF) allows us to analyse the impact on firm behavior of managers' perceptions of the long-term consistency of policy.

As the CIS data are not structured as panel data, it is not possible to test for any path dependency or other dynamic effects.

When testing the importance of clean government instruments for the introduction of clean innovations, we control for other determining factors. First we include other potential influences on clean innovations that are not related to government policies: the importance of demand from customers (ENDEM) and voluntary agreements (ENAGREE). Secondly, we control for firm characteristics that may influence a firm's decision to introduce innovations in general, like firm size, firm age and technology/sector of the firm. We also control for the innovative profile of the firm, i.e., whether the firm has introduced other product, process, organizational or marketing innovations. The main modules of CIS-VI provide the information for these controls.

4.3. Who introduces clean innovations?

Overall 46% of the total 2894 firms in the sample respond that they introduced a clean innovation in the period 2006-2008 (ECO). 43% have introduced a clean innovation in their own operations (ECOOWN). These are the **clean adopters**. 8% report having developed clean innovations for their users (ECOUSER). These are the **clean developers**. Note that the clean developers are also significantly more likely to introduce clean innovations in their own operations: of all ECOUSER firms, 85% have also introduced a clean innovation in their own operations.

If we look at the different types of clean innovations, we see similar penetration rates. Reducing CO2 (ECOCO) holds 20%, energy saving (ECOEN) 22%, reducing pollutants (ECOPOL) 21%, reducing pollution (ECOSUB) 22%.

Companies also report a mix of different types of motives for or benefits from environmental innovations. For instance, those firms that reduce CO2 are also significantly more likely to reduce their energy consumption: 72% of ECOCO firms also are ECOEN and vice versa 67% of ECOEN firms also report ECOCO; 63% of all ECOCO firms also develop clean innovations for their users (ECOUSER).

For all these reasons, although our prime area of interest is CO2 reductions (ECOCO), we will also look at clean process innovators more generally (ECOOWN) as well as clean developers (ECOUSER) and clean innovations overall (ECO).

Table 2: Which sectors introduce clean innovations?

	ALL	**FOOD**	**CHEM**	**ELEC**	**AUTO**	**NUTS**	**OTHER MANUF**	**TRANS PORT**	**OTHER SERV**
ECOCO	20	23	35	19	17	48	17	34	13
ECOOWN	43	47	65	52	59	68	46	46	30

ECOUSER	28	26	41	48	41	46	25	27	24
ECO	46	48	67	59	64	72	49	48	33

Not surprisingly, the chemicals and the utilities sectors score highest on clean innovations, particularly for CO2 reductions. The services sectors are less likely to be involved in clean innovation. The transport sector is overrepresented in terms of clean innovations[9].

Table 3: Which type of firms introduce clean innovations?

	ALL	**SMEs**	**Large**	**YOUNG**	**INNOV**	**PROCESS INNOV**
ECOCO	20	17	43	20	30	36
ECOOWN	43	40	71	38	60	69
ECOUSER	28	26	46	28	42	45
ECO	46	44	76	38	66	72

SMEs are less likely to introduce clean innovations compared to Large Enterprises. This difference in firm size is most pronounced for CO2 reductions. This is perhaps related to the supra reported sectoral distribution, with CO2 sensitive sectors being larger scale. Firms that are active in introducing other innovations, be it product, process, organizational or marketing innovation are also more likely to introduce clean innovations. With the exception of clean developers (ECOUSER), the introduction of process innovations shows the strongest complementarity with clean innovations.

4.4. Motives for clean innovations

The motive most frequently identified by firms as leading to their introduction of eco-innovations is participation in sectoral voluntary agreements between regulators and polluters Government regulations and taxes are mentioned by almost one third of all eco-innovators as motive. Financial incentives (grants) are mentioned least frequently, in only 15% of the cases, although they are somewhat more influential for CO2 and energy saving innovations. Current and future regulations and taxes are more influential for CO2 reductions than for energy saving. This and other findings may reflect the fact that CO2 reduction innovations are relatively capital-intensive, increasing the influence on adoption decisions of financial factors.

Table 4: Which motives for clean innovations?

	ECO	**ECOCO**	**ECOOWN**	**ECOUSER**	**ECOEN**
ENREG	32	42	33	34	38
ENREGF	25	37	37	29	32
ENGRANT	15	22	15	18	21
ENDEMAND	21	29	22	29	28
ENAGREE	39	51	41	45	50

[9]The paper industry also is overrepresented in eco-innovations (54%), but because of the low number of observations, this sector is included in other manufacturing.

For large enterprises, regulations are significantly more important drivers in development or adoption of environmental technologies and appear to be almost as important as voluntary agreements, perhaps reflecting the tendency of government policy to focus on larger firms. Financial grants also are more influential in the involvement by large companies in eco-innovations one third of all large enterprises listed grants as a factor having induced their eco-innovation activities.

Government policies are significantly correlated[10] with one another in affecting firms' behavior. Companies which rate regulations and taxes as decisive motive are significantly more likely to rate grants as decisive (29% compared to 9%) and vice versa, firms that rate grants as important are more likely to rate regulations as important (60% compared to 27%)[11]. This is consistent with complementarity between government instruments.

The time-consistency of government interventions can be analysed by comparing the impact of current and/or future interventions. While 12% of eco-innovators list only current regulations and taxes as influential and no more than 6 % cite as an important influence only future regulations, 19% of eco-innovators list both current and future regulations as decisive. Among the cross-motive correlations, the correlation between current and future regulations is the strongest [12]. This is consistent with the idea that regulations & taxes will be more influential is they are consistent over time, rather than subject to instability.

The sector that appears to be most sensitive to regulation and taxes is the food sector, with more than half of the companies reporting this factor (ENREG) as influential. Also the chemicals sector has a high sensitivity to regulation & taxes, including anticipated regulations and taxes. In the car manufacturing sector, voluntary agreements are the most frequently reported drivers. Grants are in no sector among the most important drivers, although they are somewhat more decisive in transport services, chemicals, food and car manufacturing,

Table 5: Which motives for whom?

	ALL ECO	SMEs	LE	FOOD	CHEM	ELEC	AUTO	NUTS	OTHER MANU	TRANS PORT	OTHER SERV
ENREG	32	28	61	52	45	43	25	28	28	32	22
ENREGF	25	22	49	30	41	28	21	33	21	28	20
ENGRANT	15	14	33	20	21	12	19	17	13	23	10
ENDEMAND	21	19	38	15	28	31	23	28	17	13	27
ENAGREE	39	35	67	44	51	47	50	39	35	34	35
CURR&FUTURE	19	16	43	25	34	24	17	19	16	21	13
REG&GRANT	10	9	27	16	17	10	4	11	8	14	7

[10] All cross-motive correlations are statistically significant at the 1% level.
[11] The Chi-2 test, testing independence between both variables, rejects independence at the 1% level.
[12] The Pearson's correlation coefficient between REGT and FREGT is 0.555 and significant at the 1% level.

4.5. *Econometric analysis of the impact of government policies on clean innovations*

In the last part of the analysis, we examine the impact of government policy on clean innovations in a multivariate analysis. We are particularly interested in which of the direct government policy instruments survive as significant drivers for clean innovations, controlling for other motives: demand push (ENDEM) and voluntary agreements (ENAGR) and controlling for firm and industry characteristics (firm size & age, sector dummies and innovative inputs of the firm). We look at eco-innovations in general, but also separately consider eco-innovations introduced in own operations (ECOOWN) and the development of eco-innovations for users (ECOUSER). For innovations introduced in own operations, we are particularly interested in those aimed at reducing CO2 emissions (ECOCO) and reducing energy consumption (ECOEN).

Table 6: Probit results on the drivers for introducing eco-innovations

	ECO (1)	**ECOUSER (2)**	**ECOOWN (3)**	**ECOCO (4)**	**ECOEN (5)**
ENREG	.302 .036 ***	.079 .034 **	.306 .038 ***	.082 .029 ***	.058 .028 **
ENREGF	.266 .050 ***	.130 .039 ***	.217 .051 ***	.146 .035 ***	.075 .032 ***
ENGRA	.218 .061 ***	.095 .043 **	.098 .060 +	.087 .034 ***	.115 .036 ***
ENDEM	.315 .043 ***	.279 .038 ***	.186 .049 ***	.119 .032 ***	.126 .032 ***
ENAGR	.380 .026 ***	.237 .029 ***	.421 .027 ***	.211 .027 ***	.225 .027 ***
	Firm size (Emp06), Firm age (Young), Innovative inputs (InnovIn) and Sector dummies included[13].[14].[15] N=2893				

Note: Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA). Standard errors reported in the second line, significance levels in the third line. ***, **, *, + represents 1%, 5%, 10%, 15% significance levels

[13] A full report of all coefficients is reported in the Appendix to this paper.

[14] A bivariate probit for estimating (ecouser, ecoown) and (ecoco, ecoen) to take into account the correlation between the dependent variables, cf supra, yields a significant correlation among error terms, but gives very similar results.

[15] We also include the ETS dummy although it is highly skewed, covering only 7 observations. It is strongly significant with a high responsiveness for innovations to reduce CO2 emissions. Inclusion of the ETS dummy does not affect the other coefficients.

The results reported in Table 6 indicate that demand-pull (ENDEM) and voluntary agreements (ENAGR) are the most important motives for ECO innovations. Voluntary agreements between regulators and polluters are the most influential driver for all types of eco-innovations. Government policy instruments are in general less important drivers for eco-innovations compared to demand-pull and voluntary agreements, but they are nevertheless significant. Regulations and taxes (ENREG) are more important to incite the adoption of clean technologies (ECOOWN) than for the development of clean technologies (ECOUSER). Government subsidies (ENGRA) are less significant influences.

When we examine the adoption of eco-innovations, we compare those aimed at reducing CO2 emissions (ECOCO) and those to reduce energy consumption (ECOEN). Voluntary agreements are still the most significant factor for inducing ECOCO and ECOEN. For innovations that reduce energy consumption, financial incentives seem to be the most potent government lever. For innovations aimed at reducing CO2, anticipated future regulations and taxes are the strongest policy influence, corroborating the importance of long-term policies in the implementation of CO2 innovations.

In Table 7 we test the importance of consistency in government policy. We do this by identifying 3 cases:

- both current and future regulations & taxes are drivers,
- only current regulations & taxes are drivers
- only future regulations& taxes are drivers .

the default being no impact form neither current nor future regulations and taxes

Table 7: Bivariate probit results on the importance of time consistency of clean policies

	ECO (1)	**ECOUSER (2)**	**ECOOWN (3)**	**ECOCO (4)**	**ECOEN (5)**
ENREG & ENREGF	.357 .041	.160 .040	.360 .043	.226 .038	.112 .035
ONLY ENREG	.386 .032	.181 .044	.411 .038	.139 .038	.121 .037
ONLY ENREGF	.439 .030	.343 .061	.426 .048	.264 .060	.202 .058
	Firm size (Emp06), Firm age (Young), Innovative inputs (InnovIn), Sector dummies, ENDEM, ENAGR included. N=2893				

Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA). Standard errors in the second row. All coefficients are significant at 1% level ***

For innovations aimed at reducing CO2, we find the highest sensitivity to "only future regulations and taxes", closely followed by a combination of current and future regulations. "Only current regulations and taxes" has the lowest impact. For innovations aimed at reducing energy consumption, future regulations are a stronger driver than current ones. The same holds for development of eco-innovations for users. We interpret this as evidence in support of the argument that the long-term nature of regulations & taxes makes them especially influential in the adoption of clean innovations.

In table 8 we test the combined influence of subsidies and regulations & taxes, again by constructing 3 cases: one where subsidies and regulations & taxes are jointly present, one where only subsidies are present and one where only regulations & taxes are present.

Table 8: Bivariate probit results on policy mixing regulations & taxes with subsidies

	ECO (1)	**ECOUSER (2)**	**ECOOWN (3)**	**ECOCO (4)**	**ECOEN (5)**
REG/TAX & SUBSIDIES	.371 .046	.196 .053	.340 .056	.283 .051	.253 .051
ONLY SUBSIDIES	.343 .045	.312 .065	.265 .058	.183 .054	.158 .055
ONLY REG/TAX	.445 .023	.249 .031	.448 .028	.214 .023	.138 .029
	Firm size (Emp06), Firm age (Young), Innovative inputs (InnovIn), Sector dummies, ENDEM, ENAGR included. N=2893				

Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA). Standard errors in the second row. All coefficients are significant at 1% level ***

For the adoption of eco-innovations aimed at reducing CO2 and for reducing energy consumption, the results clearly suggest that a combination of regulations & taxes with subsidies is most influential, in contrast to the limited effects of this combination on the development of eco-innovations.

Conclusions: Linking clean government policies to private clean innovations: does it work?

The climate change challenge can be met effectively only by a clean innovation machine that is operating at full speed. In addition to publicly support for R&D infrastructure and public procurement, the development and adoption of new clean technologies by the private sector is essential to the needed transformation in the energy-economic system for reductions in Green House Gas (GHG) emissions. The private clean innovation machine, left on its own, is not up to this challenge. Government intervention is needed to address the combination of environmental and knowledge externalities and to overcome path dependencies. The evidence on current clean innovation performance hints at the failure so far of government intervention to fully activate the private clean innovation machine. If governments want to leverage the needed private innovations for clean energy technologies, they will have to provide a well designed, time consistent policy, by a combination of consistent carbon pricing, performance based regulations and public funding.

The evidence from earlier micro-econometric studies, on patent data and from selected environmental technologies shows that government intervention can affect private sector innovations, albeit with substantial variation among policy instruments and technologies.

The firm-level evidence presented in this contribution on the motives for introducing clean innovations from the latest Flemish CIS eco-innovation survey confirms that firms are responsive to eco-policy interventions. The evidence is also suggestive of how important the details of the policy design are.

The evidence supports the increased leverage of policies when combining regulations & taxes with subsidies, particularly for the adoption of innovations to reduce CO2 emissions. This complementarity between policy instruments for accelerating the adoption of CO2-reducing innovations is particularly important to take into account for the design of public clean subsidy policies, as the current evidence provides little support for the efficacy of subsidies for CO2 reducing innovations, when used in isolation. It is a reminder for those governments contemplating a public clean R&D support program that the lack of a strong carbon price expected to prevail in future will seriously reduce the effectiveness of subsidies as policy instrument to leverage private innovative incentives for climate change.

The intertemporal consistency of policy is relevant to all types of eco-innovations, but especially important for climate change innovations and more so for developers than for adopters. Policy interventions will have greater influence on the adoption and development of new clean technologies when designed to be credible and consistent over time, affecting future expectations more than current incentives.

Finally, the high importance of demand pull from customers and voluntary sectoral codes of conduct or voluntary sector agreements as drivers for firms introducing clean innovations, is a reminder of the internal strength of the private innovation machine. Governments should leverage this power, by a time consistent clean-tech policy design affecting the expectations of the market.

This paper has focused on the design of a clean tech policy for activating the private sector in creating and adopting eco-innovations, and accordingly has fewer implications for the design of a mission-oriented public R&D infrastructure policy in this field. Nonetheless, this discussion underscores the need for any mission-oriented clean public R&D infrastructure policy to be designed to be compatible with and supportive of a clean tech demand policy, if the results of this R&D are to be further developed and adopted by the market to ensure the needed transformation of the energy-economic system.

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Appendix: Probit results on the drivers for introducing eco-innovations

	ECO (1)	ECOUSER (2)	ECOOWN (3)	ECOCO (4)	ECOEN (5)
Firm Size (Empl06)	.00025 ** .00012	.00004 .00003	.00023 .00010**	.00014 .00004***	.00011 .00004***
Firm Age (DYoung)	-.033 .029	.010 .023	-.042 .029	.010 .020	-.023 .019
Innov Inputs (InnovIN)	.236 *** .022	.164 .020***	.198 .024	.057 .017***	.135 .018
ENREG	.302 .036***	.079 .034**	.306 .038***	.082 .029***	.058 .028**
ENREGF	.266 .050***	.130 .039***	.217 .051***	.146 .035***	.075 .032***
ENGRA	.218 .061***	.095 .043**	.098 .060+	.087 .034***	.115 .036***
ENDEM	.315 .043***	.279 .038***	.186 .049***	.119 .032***	.126 .032***
ENAGR	.380 .026***	.237 .029***	.421 .027***	.211 .027***	.225 .027***
FOOD	.047 .042	-.032 .036	.116 .041***	.049 .032*	.193 .038***
CHEM	.179 .039***	.024 .036	.243 .038***	.085 .032***	.174 .039***
ELEC	.059 .062	.129 .056**	.076 .062	-.037 .039	.053 .047
CARS	.188 .057***	.089 .061+	.203 .065***	-.067 .040	.094 .064*
NUTS	.337 .045***	.184 .081**	.377 .052***	.322 .084***	.390 .076***
OTH MANUF	.129 .026***	-.009 .022	.164 .026***	.022 .020	.093 .022***
TRANSP	.137 .036***	.049 .034	.191 .024***	.235 .035***	.106 .035***
Pseudo R^2	.303	.210	.289	.247	.234
	N=2893				

***, **, *, + represents 1%, 5%, 10%, 15% significance levels

Note: Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA)