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# Activating the private clean innovation machine

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***Abstract***

In view of the sizeable climate change challenge, we need a clean innovation machine operating at full speed. The private clean innovation machine, left on its own, is not up for this challenge. It needs government intervention to address the combination of environmental and knowledge externalities and overcome path dependencies. 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 interventions. It is however not a panacea. 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 government should try to leverage. The evidence is also strongly suggestive of how important the details of the policy design are. Policy interventions are more powerful to induce the adoption and development of new clean technologies when designed time consistently, affecting future expectations.

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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", we need a sufficiently wide portfolio of technologies in action soon. This includes the deployment of already available cleaner technologies as well as the development of radical new clean technologies which are not yet available or still far from commercialization.

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. Research needs to be incentivated 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 effectively turn on the private green innovation machine at the lowest possible cost for economic growth.

Recently developed economic models of directed technological change (eg Acemoglu et al (2009), Bosetti et al (2007), David et al (2011)) strongly supports the case of a *portfolio of instruments including simultaneously 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 developing new clean technologies. Especially the expectations of carbon prices in future are an important lever for research, development and adoption of clean technologies. In tandem with a sufficiently high and long-term time consistent carbon price, R&D support for 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 support framework capable of leveraging the power of the private innovation machine to fight climate change.

In this contribution we look at private clean innovations in more detail and how it can be stimulated by a green mission oriented government policy. The contribution will not discuss the public research infrastructure for clean innovations, as our focus is on how to activate the private sector. We look both at the development of new clean technologies 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 to drive these decisions (section 3). To this end we present new recent 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 activate 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 availability of standard data on clean innovations. No common definitions are being used, with terminology ranging from clean, sustainable to eco-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 involves 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-innovations. In reporting data, our focus is on private firms activities in innovations for climate change, but depending on data availability, we will 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). Also the

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[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.

EC-JRC-IPTS Scoreboard on largest R&D spenders 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 which firms adopt which are elsewhere developed. Unfortunately, the Community Innovation Survey offers few insights into eco-innovation[4]. Only the last wave, CIS-VI (2006-2008), partly 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 directed to the environment[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 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)).

Until the mid-1990s, CET patents have stagnated and even declined, certainly in relative terms as overall patenting activities continued to grow. But since the late nineties, also 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

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[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.

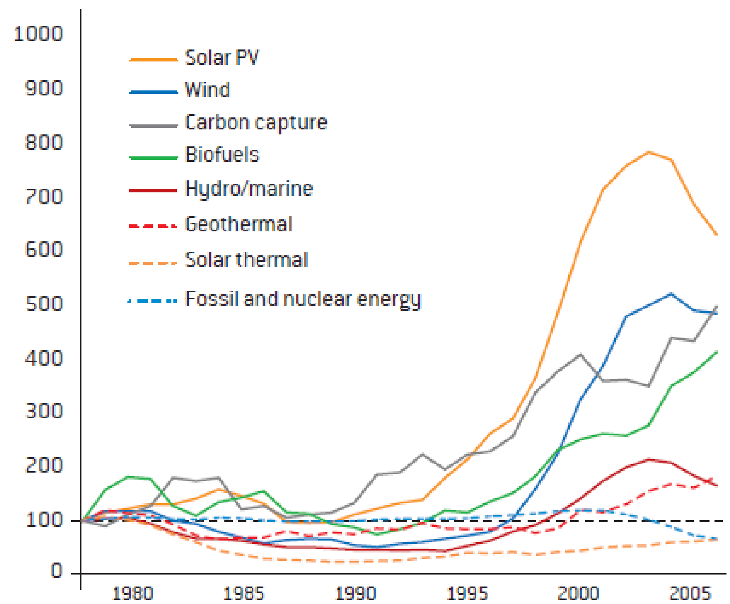
[3] In 2009, among the 1000 largest R&D spenders in the EU, 12 dedicated companies from the alternative energy sector managed to get into the list, another 2 in the 1000 non-EU spenders. They hold an R&D intensity of 3.5%. (EC-JRC-IPTS Scoreboard 2010)). An assessment of R&D for low-carbon energy innovations,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

[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 innovation motive relates to environmental benefits, but does not necessarily reflect an explicit green motive. The more direct question on "reducing environmental impact" as innovation motive, is unfortunately merged with health and safety motives;

[5] There are a number of limitations of 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.

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. IGCC and solar & geo thermal are not yet kicking off, probably reflecting their still premature stage of development.

*Graph 1: Growth rates of patents 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)

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. Also **Korea** is an important player in CET patenting, specialized and heavily concentrated, also on solar PV. The **US**, despite its 16% share of world "clean patents", is not specialized in Clean Energy Technologies. It is more dispersed across various CET technologies. If the **EU** would 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].

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[6] Patents are assigned to countries on the basis of the location of the assignee.

[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);

*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)

This quick glimpse at the data on when clean energy patents have taken off and which countries are most active is suggestive of a positive association with active government policy. But how important has government policy been to explain the patterns in CET patenting? In the next sections we examine in more detail, using econometric analysis, the effectiveness of government policies for turning on private clean innovations. Section 3 presents a review of existing analysis, while Section 4 presents new analysis using the Flemish eco-innovation module results from the latest CIS-VI survey.

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

There is increasing empirical analysis to support the contention that environmental policies do lead to technological innovation: both the creation of new clean technologies as the adoption of already developed clean technologies. Jaffe et al (1995) Newell and Stavins (2002) and Johnston (2008) provide recent reviews of the empirical literature on this theme. The following paragraphs draw heavily on these reviews.

Most of the existing empirical studies concentrate on the impact of environmental policies on the **creation** of new clean technologies, using patents as 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. They found that pollution abatement costs affect the number of patents successfully granted, but with a 1-2 year lag. 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. They examined for a set of US manufacturing industries in the period 1977-1989 the relationship between environmental stringency (as measured by higher level of Pollution Abatement Costs and Expenditures (PACE)) and innovation. Their measure innovations in terms of both R&D expenditures and patents, without however specifying 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, by narrowing innovation down to purely "environmental" patents. As policy indicators, they used pollution abatement costs (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, 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 consistently more patent applications were placed 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 – to explore whether these regulations affected (inter)national innovation and diffusion.

More recent work by Aghion et al (2010) studies clean versus dirty technology 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 more so for firms with a larger stock of dirty patents. This is consistent with the need for government intervention to break the path dependency in the old dirty technologies.

Very few studies have examined the policy instrument choice. 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 of improved efficiency.

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 environmental policy to have an effect on technological innovation, but whether a policy instruments is effective or not varies across the various 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. 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. Interestingly, eco-labelling did not appear to have an influence on innovation in this case. The case studies did not report on any possible complementarity effect from combining R&D grants with carbon pricing and/or regulation.

In a follow-up econometric analysis, Johnstone et al. (2010) 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. For example, Germany has seen a dip in wind patenting despite the existence of feed-in tariffs.

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. 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, achieving an accreditation, 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 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 straightforward 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. CO2 emissions versus energy efficiency) all seem to matter for effectiveness, we still have a very incomplete view on which combination of policy instruments governments should use to stimulate clean innovation creation and diffusion.

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

In this section we present new recent evidence on which firms have been creating and adopting clean innovations, and how strong which types of government interventions have been to drive these decisions. To this end, we use the Flemish CIS eco-innovation module.

EUROSTAT/OECD introduced in the 6the Community Innovation Survey, covering the period 2006-2008, an eco-innovation module. This module surveyed the firms on what important drivers were for introducing eco-innovations, including government intervention. It thus allow 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 to control for other innovation related characteristics of the firms surveyed. The disadvantage of the CIS data is that it is a cross section.

The module was not mandatory for countries to include. Belgium was one of the countries that did include the eco-innovation module. We will use the Flemish data to investigate the impact of government policies on firm's clean innovation behavior. Flanders is one of the three Belgian regions. With about 2% of its GDP spend on R&D and Government Expenditures (GBAORD) at 0.70% of its GDP, it is about average in terms of innovation among other European Union countries. In its Innovation Communication for 2009-2013 it expressed its ambition to be part of the top 5 regions in Europe. 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 is Energy and Environment, with large scale innovation projects around smart grids and electric vehicles. We will not be evaluating all dimensions of the clean energy industrial policy of the Flemish government. We will only be looking at the extent to which is it has been able with which instruments to leverage the private sector's incentive to create and adopt clean innovations.

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 interventions for inciting clean innovations (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 identify the adoption of eco-innovations (ECOOWN), the three last types identify the creation of eco-innovations (ECOUSER).

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

- 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).

The second set of questions covers a wide range of government levers, 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... It does however not include the availability of public research infrastructure for stimulating private eco-innovations, which could also be an important instrument for a clean mission oriented innovation policy.

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 of the relative size of the importance of specific drivers. 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 innovation active, 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, 45% are in service sectors.

We linked the Flemish firms in the CIS-data to whether they were part of the EU Emission Trading System to allow including an assessment of the impact of the EU-ETS scheme on firm's environmental innovative behavior. The match resulted into only 6 companies in the CIS that also are in the ETS scheme.

## 4.2. Research questions

The Flemish CIS-VI eco-module data allow us to test our main question of interest in this paper: the impact of clean government policy on the likelihood of firms introducing clean innovations, either own or elsewhere developed. More specifically, it allows to investigate and compare 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 to analyse the impact of the long-term consistency of policy to be effective.

As the CIS data miss a panel data structure, 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 drivers for clean innovations which are not related to government policies: the importance of demand from customers (ENDEM) and voluntary agreements (ENAGREE). Secondly, we control for firm characteristics that can influence the decision to introduce innovations, like firm size, firm age and technology/sector of the firm. We also control for the innovative profile of the firm, ie 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, have responded 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 innovators**. 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. For instance, energy saving (ECOEN) accounts for 22%, reducing CO2 (ECOCO) for 20%, reducing pollutants (ECOPOL) 21%, reducing pollution (ECOSUB) 22%.

Furthermore companies are also significantly mixing different types of 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 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. 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.

*Table 3: 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 into clean innovations. The transport sector is overrepresented in terms of clean innovations[8].

## 4.4. Motives for clean innovations

The motive which is most frequently identified by firms as having driven their introductions of eco-innovations, are sectoral voluntary agreements. This puts the importance of government policy in perspective. Nevertheless, government regulations and taxes are mentioned by almost one third of all eco-innovators as motive. Financial incentives are least often mentioned: in 15% of the cases. They are somewhat more influential for CO2 and energy saving innovations. Also regulations and taxes, current and future, are more influential for CO2 reductions than for energy saving.

*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 |

For large enterprises, regulations are significantly more important drivers, almost as important as voluntary agreements. Also grants are more influential for large companies to incite them to eco-

[8]Also the paper industry is more than expected active in eco-innovations (54%), but because of the low number of observations, this sector is included in other manufacturing.

innovations: one third of all large enterprises listed grants as a factor having induced their eco-innovation activities.

Government related motives are significantly correlated[9]. 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%) [10]. 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 only list current regulations and taxes as influential and only 6 % 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 [11].

When comparing across sectors, the sector 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. 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 |

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

In the last part of the analysis, we analyze the impact of government policy on clean innovations multivariately. We are particularly interested which of the government policy instruments survive as significant drivers for clean innovations, controlling for other non-government related motives: demand

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

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 disentangle 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<br>.036<br>*** | .079<br>.034<br>** | .306<br>.038<br>*** | .082<br>.029<br>*** | .058<br>.028<br>** |
| **ENREGF** | .266<br>.050<br>*** | .130<br>.039<br>*** | .217<br>.051<br>*** | .146<br>.035<br>*** | .075<br>.032<br>*** |
| **ENGRA** | .218<br>.061<br>*** | .095<br>.043<br>** | .098<br>.060<br>+ | .087<br>.034<br>*** | .115<br>.036<br>*** |
| **ENDEM** | .315<br>.043<br>*** | .279<br>.038<br>*** | .186<br>.049<br>*** | .119<br>.032<br>*** | .126<br>.032<br>*** |
| **ENAGR** | .380<br>.026<br>*** | .237<br>.029<br>*** | .421<br>.027<br>*** | .211<br>.027<br>*** | .225<br>.027<br>*** |
| | Firm size (Emp06), Firm age (Young), Innovative inputs (InnovIn) and Sector dummies included[12].<br>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)[13].[14]

Table 6 confirms the highest sensitivity for demand-pull (ENDEM) and voluntary agreements (ENAGR) as drivers for ECO innovations. Voluntary agreements are the most sensitive driver for all types of eco-innovations. Government instruments are in general less important as driver 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 the less significant driver.

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[12] A full report of all coefficients is reported in appendix.

[13] 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.

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

When we zoom in on 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 to 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 government lever. When looking at the sector dummies, the results confirm a significant sector effect for chemicals, utilities and transport for the adoption 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<br>.041 | .160<br>.040 | .360<br>.043 | .226<br>.038 | .112<br>.035 |
| **ONLY ENREG** | .386<br>.032 | .181<br>.044 | .411<br>.038 | .139<br>.038 | .121<br>.037 |
| **ONLY ENREGF** | .439<br>.030 | .343<br>.061 | .426<br>.048 | .264<br>.060 | .202<br>.058 |
| | Firm size (Emp06), Firm age (Young), Innovative inputs (InnovIn), Sector dummies, ENDEM, ENAGR included.<br>N=2893 | | | | |

Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA). 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. Also for innovations aimed at reducing energy consumption, future regulations are a stronger driver than current. The same holds for development of eco-innovations for users. We interpret this as evidence of the importance of the long-term nature of regulations & taxes to have the power to illicit innovations.

In table 8 we test whether there is any extra incentivizing power when subsidies and regulations & taxes are combined as motives. Again we do this 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 | ECOUSER | ECOOWN | ECOCO | ECOEN |
|---|---|---|---|---|---|

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

Marginal effects reported (discrete change of dummy variables from 0 to 1) (Dprobit (robust) command in STATA). 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 point to the highest contribution coming from a combination of regulations & taxes with subsidies. In contrast, the combination is not very potent for instigating developments of eco-innovations for users.

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

In view of the real and sizeable climate change challenge, we need a clean innovation machine operating at full speed. The private clean innovation machine, left on its own, is not up for this challenge. It needs government intervention to address the combination of environmental and knowledge externalities and overcome path dependencies. The evidence on current clean innovation performance hints at the failure so far of government intervention to fully active 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, regulations and public funding. With current heavily constrained public budgets, it is all the more important that any public funding is allocated as cost effective as possible.

The evidence from earlier micro-econometric studies, on patent data and from selected environmental technologies shows that private innovations are responsive to government intervention, albeit with a substantial variance in which types of intervention matters for which clean 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. It is however not omnipotent. The evidence is strongly 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, at least for the adoption of innovations to reduce CO2 emissions. This complementarity between policy instruments for inciting CO2 reducing innovations is particularly important to take into account for the design of public clean subsidy policies as the evidence in general does not support a strong leverage power of subsidies for clean 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.

A strong results across all types of eco-innovations, but more so for climate change innovations and more so for creators than for adopters, is the importance of time consistency of the policy. Policy interventions will be more powerful to induce the adoption and development of new clean technologies when designed time consistently, 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.

As this contribution has focused on how to design a clean tech policy for activating the private sector in creating and adopting eco-innovations, it has less implications for the design of a mission-oriented public R&D infrastructure policy in this broad field, other than signaling that any mission-oriented clean R&D policy should be designed in close association with a clean tech policy, if its results will be further developed and adopted by the market.

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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)