What innovation policies for ecological transition?
Powering the green innovation machine

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Contribution to the Project

The paper contributes on how green innovation policy can turn on the green innovation machine to facilitate the shift onto a new inclusive and sustainable growth path?

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What innovation policies for ecological transition?

Powering the green innovation machine

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In this contribution we describe how green policies should be designed to activate private innovation forces for ecological transitions. We look at the evidence on the current deployment of green policies and the current performance of the private green innovation machine. We try to assess how strong which types of government interventions have and can be to power the green innovation machine. An important insight from the economic analysis of the effectiveness of the public intervention for green innovations, is the complementarity between policy instruments, requiring an adequate policy mix of instruments, rather than a focus on individual instruments. The evidence provides little support for the efficacy of single instruments, like subsidies, when used in isolation. For the EU, this is perhaps the biggest challenge for its green technology policy: the lack of a sufficiently high carbon price. And as the evidence has shown that the world of green science and technologies is an emerging global, multipolar one, with many geographically dispersed sources in the various green scientific fields and technologies, coordination of green policies internationally should therefore be high on the policy agenda.

1. Why we need the private innovation machine for climate change and why we need government policy to power the green innovation machine?

How to limit climate change is one of the most pressing policy challenges facing the world today. Simulation exercises ((eg Bosetti et al (2009))) clearly confirm that to keep the costs of mitigation and adaptation "manageable", we need a sufficiently wide portfolio of technologies in action soon.

For mitigation these include (i) technologies to reduce emissions such as energy efficiency, carbon capture and storage, and (ii) low-carbon technologies such as renewable-energy generation. Although much can be done if existing technologies are further developed and faster diffused (McKinsey, 2009), these also include new technologies that are still far from large-scale commercialisation or not yet developed.

For clean technologies to be created, developed and diffused sufficiently fast and at the appropriate scale, policy intervention will be needed. In view of the pervasive environmental and knowledge externalities characterizing green innovations, the private green innovation machine cannot be expected to be socially effective in time on its own. In addition, new green technologies face competition from the existing dirty technologies, who enjoy an initial installed base advantage, favoring the innovation machine left on its own to work on improving these existing, dirty, technologies, impeding the take-off of new clean technologies (Acemoglu, Aghion, Bursztyn and Hemous (2009)).

Government intervention does however not come at zero cost. The cost of supporting cleaner technologies is that it may slow down growth in the short run investment phase. But the benefit from supporting cleaner technologies is that it will bring about greener (and therefore more sustainable) growth in the future.

In this contribution we to describe how environmental policies should be designed to activate private innovation forces for climate change. We then look at the evidence on the use of major policy instruments for green innovations and examine whether they are well designed to power the green innovation machine. We subsequently look at the evidence on the performance of private innovations for climate change and try to assess how strong which types of government interventions have been to power the green innovation machine. We close with some suggestions for improving government policy to activate private green innovations.

In this contribution we first describe in section 2 how green policies should be designed to activate private innovation forces for ecological transitions. Section 3 looks at the evidence on the current deployment of green policies, while section 4 looks at the current performance of the private green innovation machine. Section 5 assesses how strong which types of government interventions have and can be to power the green innovation machine. Section 6 closes with suggestions for improving government policy to activate private green innovations.

2. How should climate change policies look like?

The issue is not whether or not we need government intervention to activate the green innovation machine, but how this government intervention should be designed to effectively turn on the private green innovation machine at the lowest possible cost for growth.

How government intervention should be designed in order to effectively turn on the private green innovation machine is discussed in Aghion, Hemous and Veugelers (2009). The authors draw on the insights from recently developed economic models of directed endogeneous technological change, to identify optimal policy paths. We summarize the main insights here.

In particular the analysis strongly supports the case of a *portfolio of instruments including simultaneously carbon prices, R&D subsidies and regulation.* Carbon prices will address the environmental externality, by putting a price on the negative effects on the environment. Carbon prices not only will reduce the production/consumption of dirty technologies, they will also be important as incentive for developing new technologies to reduce the environmental externality. Especially the expectations of carbon prices in future are an important lever for firms to be engaged in R&D and adoption of green technologies. A price for carbon can be obtained through a carbon tax or a cap-and-trade system.

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

It is important that the two policy instruments, carbon pricing and public support for clean R&D, are deployed simultaneously and in coordination, as there are important complementarities to exploit. Acemoglu et al (2009) show that, while a carbon tax alone could deal with both externalities at the same time, using the carbon tax alone will lead to excessive consumption reduction in the short run, and would therefore be a more "costly" policy scenario, compared to using the two policy instruments simultaneously. Similarly, when using only the subsidy instrument, keeping the carbon price instrument inactive, would imply that subsidies would have to be much higher compared to their level when used in combination. A way of showing the higher costs when using only 1 instrument (i.e. 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.

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

The directed endogeneous growth model also has prescriptions on the international dimension of policy intervention (Aghion, Hemous and Veugelers (2009)). If developed countries' governments direct change towards clean technologies and subsequently facilitate the diffusion of new clean technologies to developing countries, a major step towards overcoming global climate change can be taken. Indeed it may not be necessary to price dirty-input production in the developing countries in order to avoid a global environmental disaster: unilateral government intervention in developed countries can turn on the green innovation machine in the developed world, which will in turn allow the developing countries to adopt the cleaner technologies developed in the developed world. The greater the innovation spillovers from the developed to the developing countries, the more active the developing countries will be in implementing clean technologies rather than dirty ones. Thus, even in the absence of action by developing countries, a case can be made for policy intervention by developed countries only.

3. Evidence on green government intervention

Are governments deploying the right effective policies for stimulating private green innovation as described in the previous section? Aghion, Veugelers and Serre (2009) examined in detail the record of green government policies for innovation. With low, volatile and fragmented levels of carbon pricing and subsidies, their overall conclusion is that there is still some distance to go before ideal policy support is realized to turn on the private green innovation machine. It is particularly the long term consistency of carbon prices and green subsidies which are important as incentive for the green innovation machine. In this section, we briefly review and update their analysis.

On **carbon prices**, the evidence in Aghion, Veugelers and Serre (2009) showed not only the low level of *carbon taxes* and implicit tax on energy in most EU countries, but there is also a high dispersion in carbon and energy taxes and subsidies to dirty technologies across EU countries. A number of *carbon markets* have developed, such as the Kyoto market for CDM and JI credits . A selection of US States initiated the Regional Greenhouse Gas Initiative.

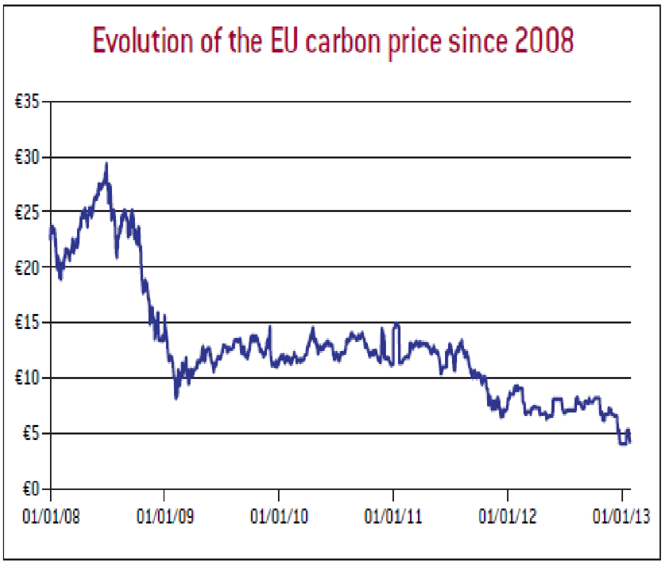
The European Union's **Emission Trading Scheme** (or EU ETS) is the largest multi-national, greenhouse gas emissions trading scheme in the world. The first phase of the EU-ETS scheme covered almost half of the EU's Carbon Dioxide emissions. Phase I, started in 2005 and permitted participants to trade amongst themselves and in validated credits from the developing world through Kyoto's Clean Development Mechanism. The first phase received much criticism due to oversupply of allowances and the distribution method of allowances (via grandfathering rather than auctioning) (eg. Tirole (2009)). As a consequence, carbon prices in this first Phase have been volatile (Figure 1). Carbon prices reached their highest level of 33 Euro in April 2006, but were only 8 Euro in February 2009. The drop in the price in 2007 (the spot price reached almost 0 in April 2007), marked the end of the first phase of the EU ETS. This drop in the price was due to the absence of bankability between periods in the first phase of the EU ETS, as allowances could not be used for later phases.

As part of the EU's 20/20/20 plan, launched in December 2008, where the EU set legally binding targets for each of the 27 Member States to cut greenhouse gas emissions by 20%[1], by 2020, the EU's

[1] The 20% reduction target was set next to a 20% share for renewable energy, and an improvement in energy efficiency by 20% by 2020. The agreement also involved a commitment to move to a 30% reduction in

Emissions Trading System was made more consistent and predictable. The number of allowances was reduced by 6.5% for the period 2008-2012. In 2012 the aviation sector was brought into the system. In 2013 a third phase for ETS was initiated, with the biggest change the introduction of an EU-wide cap on emissions, reduced by 1.74% each year till 2020. The level of auctioning in the system was set to gradually increase. Since 2009 the carbon price has been much more stable, albeit at a low level. This is primarily due to the economic downturn which cut emissions and thus demand for allowances. The price sits currently around 5 euro (Figure 1).

Figure 1



Source: Zachmann, G. (2013), You'd better bet on the ETS, Bruegel Policy Brief 2013/02

Table 1: Public RD&D investments in major countries (2010)

Country	Public RD&D investment (billion euro)	RD&D investment/GDP
Japan	2.364	0.057%
United States	1.764	0.016%.
EU*	1.862	0.017%
France	0.685	0.035%
Germany	0.237	0.010%
UK	0.250	0.015%

Note: EU are the 11 member states with the largest RD&D investments only (FR, DE, UK, IT, PL, NL, ES, DK, SW, FI, BE)

Source: own calculations on the basis of JRC (2012) on the bases of IEA RD&D statistics.

On **subsidies to green R&D,** again the evidence shows the poor performance of the major policy actors. Public R&D spending targeted to environment is a very minor share of total public R&D, less than 3% in the EU. This holds also in the US and Japan (Aghion, Veugelers, Serre 2009). Also on energy, public R&D spending is below 3% in the EU and the US. In Japan however energy accounts

greenhouse gas emissions as part of a comprehensive international agreement when other developed countries undertake similar commitments.

for 15% of public R&D. When looking at the total budgets spent on RD&D for energy, Japan is clearly the frontrunner, spending 0.057% of GDP on this in 2010. A consolidated Europe scores better than the US.

The stimulus packages in the aftermath of the 2008 crisis, lifted expectations on more public attention and funding for the environment, particularly in the US. Nevertheless, the green crisis packages were not of the order of magnitude that an optimal CC&E policy would call for. (Veugelers (2011). Furthermore, a fiscal consolidation wave hit the public R&D budgets more recently in Europe, especially in the weaker economies under more budgetary pressure (Veugelers (2014). With the temporary and uncoordinated character of stimulus spending, the question of long-term commitment weakens the effectiveness of public funding for leveraging private green innovation investments.

The **EU level** is an important level for CC&E R&D spending, representing about one quarter of total public CC&E R&D spending in Europe (Veugelers (2011)).

At the EU level, research funding through the EU's multi-annual Framework Programmes[2], have increased substantially to about €80 billion for the latest 2014-2020 window (compared to €50 billion for the previous FP7 and €18 billion for FP6). Of the H2020 total budget, €5.8 billion is dedicated to energy, € 3.2 billion for climate and € 1.6 billion for nuclear. To compare: in the FP7 budget, € €2.35 billion was dedicated to energy research, €1.89 billion to environment (including climate change), and €2.7 billion for Euratom. While the numbers for H2020 represent a serious increase over past budgets, in relative terms the share of energy and environment has remained around 9% in the H2020 compared to FP7. When comparing across FPs over a longer period, it shows a decrease over successive FPs, as the first FP was heavily concentrated on energy (in the context of the oil crisis). The focus in the FP programs has gradually shifted to ICT, health and broader applications in support of industrial competitiveness.

The European Economic Recovery Package adopted in 2009 included a substantial budget for carbon capture and storage and for offshore wind power projects, as well as for some of the cross-border infrastructure electricity connections[3]. Also the announced 300 billion investment package of the incoming Juncker Commission, is expected to include a share for energy networks and renewables projects.[4]

Beyond FP funding, the technological approach to climate change is developed at the EU level through the SET plan, with the intention of overcoming the barriers hindering the development of environmental technologies. This includes a coordination of the EU regulatory agenda, with e.g. actions on emissions standards for new passenger cars, fuel quality, as well as energy-efficiency standards. In terms of public funds, no clear EU budget is associated with SET, as it aims to leverage other public and private funding. Beyond FP funding, SET attempts to mobilise green versions of existing EU instruments such as JTI (Joint Technology Initiative), ETP (European Technology Platforms), LMI (Lead Market Initiative) and the CIP (Community Innovation Programme).

[2] The Framework Programmes (FP) represent the EU budget commitment to research. They are multi-annual programmes, where the earlier ones were called FP1-7 and the latest H2020 running from 2014-2020.

[3] The total amount of the package was €5 billion. €3.98 billion was allocated to energy infrastructure projects to strengthen the EU's energy security. Within the energy funding, big energy utilities got €1 billion for carbon capture and storage and €565 million for offshore wind farms. See http://www.euractiv.com/en/en ergy/parliament-approves-4- energy-projects/ article-182096.

[4] http://ec.europa.eu/about/juncker-commission/docs/pg_en.pdf

For the technologies included in the EU's SET plan, the EC JRC, has tried to assess the amounts being invested in these technologies in the EU, both by the public sector (EU members and EU) and the private sector (Table 2).

Table 2: R&D funding for CET technologies in the EU

Technology Area	Share of Area in total Public R&D	Share of EU in total Public R&D funding	Share of Private in total R&D funding
Hydrogen&Fuel Cells	13%	29%	61%
Photovoltaics (PV)	8.5%	17%	58%
Wind	5%	12%	76%
Biofuels	4%	17%	77.5%
CCS	3%	30%	81%
Smart Grids	3%	23%	77.7%
Solar (CSP)	2%	13%	58%
Nuclear Fission	37%	16%	43%
Nuclear Fusion*	25%	42%	0%
TOTAL	100%	25%	53%

Note: * Nuclear Fusion, although a technology closely related to SET priority technologies, is not included in the SET-plan. Source: EC-JRC (2010)

Most of the public R&D budget for energy&environment in the EU goes to *nuclear*. Nuclear also has the highest ratio of public to private investment. For non-nuclear technology areas, *Hydrogen & Fuel cells* and *PV* are the largest recipients of public R&D funds in the EU, they also have the highest ratio of public to private investment. As *PV* is among the most mature technologies in the set of CET, its still high share of public funding is somewhat surprising. *CCS*, closely followed by *Biofuels*, *Grids* and *Wind* have the lowest ratio of public to private investment. The relative position of the EU among public financiers compared to Member States is the highest in *CCS* and *Hydrogen& Fuel Cell*.

4. Evidence on the performance of the green innovation machine

Has the government intervention described in section 3 been able to power the green innovation machine. For this, we look at the evidence on the performance of the innovation machine for green technologies (see also Veugelers (2011)). An important observation to note before showing the evidence is the poor availability of good data on private green innovation activities.

Evidence on green R&D and innovation

A first set of evidence would be the amount of **R&D expenditures** that the business sector invests into green innovations. Unfortunately, the regular OECD data on private R&D expenditures are not reported by technology area [5]

[5] 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 CC&E related innovations, as the innovations in these sectors are also (and even mostly) related to other motives.

The 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 only identifies dedicated green R&D companies, failing to capture the green R&D investments of firms whose major sector of activity is in another sector (like GE or Siemens)[6].

Another widely used data source for measuring private sector innovations is the Community Innovation Survey, organized bi-annually by EUROSTAT/OECD. Unfortunately, the early versions of the Community Innovation Survey offer few insights into eco-innovation[7]. The CIS-VI (2006-2008) wave and later, partly overcome this problem, as they include an optional one-page set of questions on environmental innovation.

Evidence on green patents

Information on patent applications can be used to measure inventive activities directed to the environment. To be picked up as an eco-patent, the environmental effects should be described in the patent application or there must be pre-existing information on the environmental benefits of a patent class. While the OECD and WIPO use the latter technology class approach, EPO has followed the first patent application approach. We will use a recently developed and published dedicated categorization of green patents provided by UNEP/EPO/ICTSD (2010). UNEP/EPO/ICTSD examine 6 main categories of clean energy technologies which are either already commercially available or have strong prospects of commercialization in the near-to-medium term. These are solar (both thermal and PV), wind, carbon capture and storage, hydro, geothermal, biofuels and integrated gasification combined cycle (IGCC). These technologies are labeled as CET (Clean Energy Technologies).

There are a number of limitations of using information from patents that need to be taken into account. First, patents measure inventive activity, not innovations. Second, eco-patents mainly measure identifiable inventions that underlie green product innovations and end of pipe technologies, whose environmental impacts are specific aims and motivations of the inventions. For other types of innovations, such as process changes, which are often adoptions of already existing inventions, patent analysis is less useful because many of these innovations are not patented.

Overall, Clean Energy Technologies represent a very small share of total patents, less than 1% (Veugelers (2011)). 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, particularly after the Kyoto protocol, also CET patents have trended upwards. 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. IGCC and solar & geo thermal are not yet kicking off, probably reflecting their still premature stage of development.

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[6] 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)).

[7] 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;

If we look at which countries are active in green patenting, **Japan** is the clearest positive outlier (Table 3). 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 (cf infra). Also **Korea** is an important player in CET patenting, but it is almost exclusively specialized in solar PV. The **US**, despite its 16% share of world "green patents", is not specialized in Clean Energy Technologies and it is more dispersed across various CET technologies. In Europe, **Germany** is by far the largest country for CET patents, being somewhat specialized in Clean Energy Technologies. Like the US, it is more dispersed across various CET technologies[8].

Table 3: Who's who in CET patenting?

1988-2007	Share of country in World CET patents	RTA in CET patents
Japan	29.7%	0.99
US	15.9%	0.87
Korea	5.6%	1.21
China	0.9%	1.11
EU	*32.0%*	*1.01*
Germany	15.2%	1.05
France	3.9%	0.70
UK	3.6%	0.98

Source: Adapted from Veugelers (2011)

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)

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;

If the **EU** would be counted as a homogeneous block, it would be the block with the largest share of CET patents, with a slight specialized and relatively dispersed portfolio across CET technologies.

Overall, the BRICs countries are still dwarfs in CET patenting. Of the BRICs countries, **China** is the most important active country in CET patents. It has particularly increased its position in recent years. It is also specializing in clean energy patents. It is less concentrated on solar PV, as compared to Japan and Korea. Although China has leading manufacturers in solar PV and also in wind technologies, these companies are less active in patenting. Either they may still be heavily reliant on technology transfer to develop their products or they are largely manufacturing-based.

Table 4 looks at the who's who by the various clean energy technologies. By far the most important CET in terms of patents is *Solar PV*, which represented over the period 88-07 57% of all CET patents. Solar PV is a technology that is concentrated in a few countries. Especially Japan is a dominant and specialized player in Solar PV patents. *Wind* is the second largest CET technology in terms of patents. But in this sector concentration is much lower. Germany holds the largest position and is specialized in wind, but there are many other European countries specializing in wind technology. The strong patenting activities in solar PV and wind suggest that these technologies are extensively used and can therefore be considered as the more mature Clean Energy Technologies. *Geo & solar*

[8] 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)

thermal, *hydro* and *biofuels* all have lower dominant positions of the big players, with many countries active and specializing in these technologies. *CCS* is a sector with a high level of concentration. In this sector the US is a strong and specialized player, although also several European players are specializing in CCS, including FR and UK. The share of CCS patents in total CET patents is low, reflecting the still early stage of technology development for CCS.

Table 4: Country patenting by CET technology

1988-2007	Share of technology in total CET patents	Share of top 3 countries C3 (2)	EU RTA	US RTA	JP RTA	GER RTA
Solar PV	57	69	0.62	0.79	1.47	0.71
Wind	14	52	1.24	0.95	0.37	1.07
Hydro	12	44	1.36	1.11	0.35	0.94
Solar Thermal	10	47	1.70	0.57	0.28	1.90
Biofuels	5	52	1.39	1.00	0.51	1.26
CCS	4	61	1.05	0.54	0.55	0.85
GeoThermal	2	44	1.80	0.78	0.29	2.01
All CET	**100**	**61**	**1.01**	**0.87**	**0.99**	**1.05**

Source: Adapted from Veugelers (2011)

Notes: (1) Only countries with at least 1% of world patents in technology; Specialization if RTA >1; (2) although relative positions vary across technologies, the top 3 countries are always JP, US, GE;

If taken as an integrated unit, the EU would hold a specialized position in all CETs excluding Solar PV. It is particularly specialized in Geo-and Solar-Thermal, and, but to a lesser extent, in Biofuels, Hydro/Marine, Wind and CCS. [9] When comparing these fields to the share of public funding to these areas (cf supra), *Hydrogen & Fuel cells* and *PV,* the most developed technology areas, are the largest recipients of public R&D funds in the EU, they also have the highest ratio of public to private investment, but the EU holds no RTA in this sector. In the less developed technology areas, *CCS*, closely followed by *Biofuels*, *Smart Grids* and *Wind* have lower ratios of public to private investment. CCS . In these areas, the EU holds a RTA.

Evidence on green science

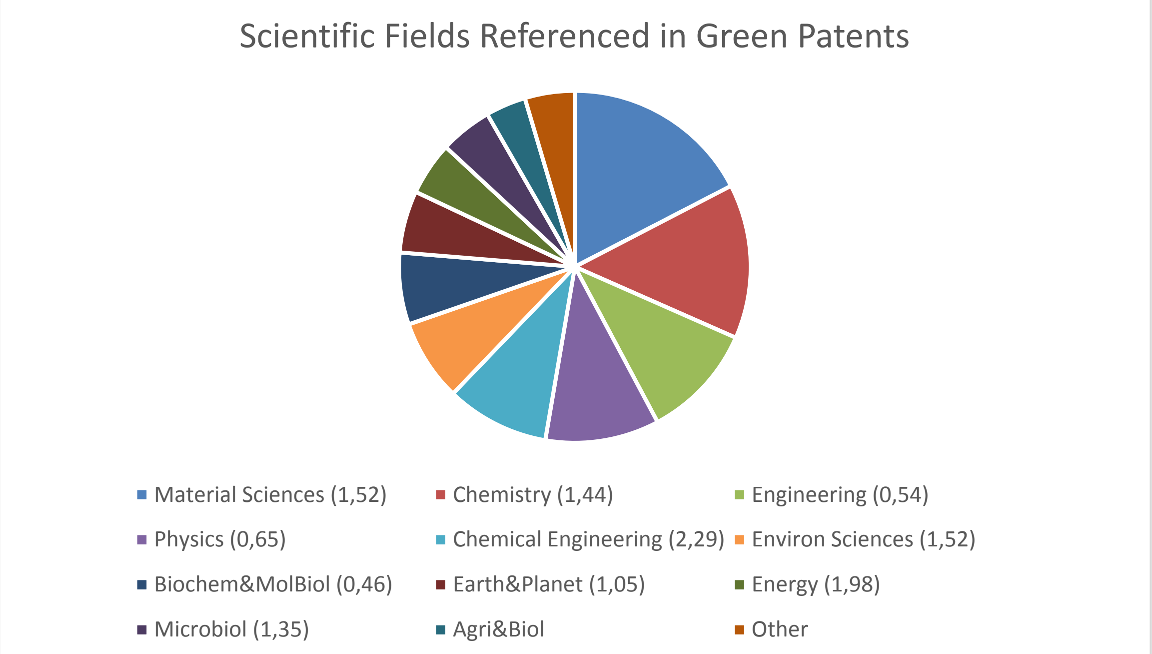
Science is often the source for new inventions, also for clean energy inventions. The OECD (2010) performed an exercise mapping the scientific fields that go into CET papers as relevant prior art. It uses the references to scientific literature in the patent applications to trace the scientific origins for new inventions. Figure 2 shows the results.

The results firstly show how multidisciplinary the science base is that goes into green patenting. It goes far beyond energy and environmental sciences, covering a range of sciences from physics, chemistry, engineering, chemical engineering, biochemistry, molecular and macro biology etc... It

[9] The values for the RTA index, reflecting the EU's specialization pattern are 1.80 (Geo-Thermal), 1.70 (Solar-Thermal), 1.39 (Biofuels), 1.35 (Hydro/Marine), 1.23 (Wind), 1.05 (CCS), 0.62 (Solar PV)

shows that the areas of materials science and chemistry & chemical engineering are more important for green technologies than the area of energy and the environmental sciences. But compared to the size of the fields (see numbers in brackets in Figure 2) , all four areas receive more citations from patents than their share in total publications. They are therefore all fields that can be considered to be specialized in serving for green patents. For these fields, the following table details which countries are strongest in these scientific disciplines.

Figure 2: The science behind green patents



Source: Own calculations on the basis of OECD (2012) and Elsevier's SCIMAGO database.

Note: Share of scientific discipline in total number of scientific references in green patents. In brackets (share of the scientific discipline in green patent scientific references relative to the share of the scientific discipline in total scientific publications)

Table 5: Who's who in scientific disciplines for green technology

	Share in total World Scient. Pubs		RSA						
	US	China	US	China	Japan	Korea	Ger	Fra	UK
Material Sciences (17.4%)	17.2	15.2	0.74	1.54	1.50	1.79	1.14	1.05	0.69
Chemistry (14.2%)	16.0	13.3	0.69	1.35	1.30	1.37	1.13	1.05	0.71
Chemical Engineering(9.5%)	18.7	14.5	0.81	1.47	1.08	1.68	1.00	0.94	0.74
EnvironSc (7.5%)	23.1	8.4	0.99	0.85	0.62	0.69	0.85	0.81	1.04
Earth &Planet (5.7%)	22.3	10.9	0.96	1.01	0.63	0.43	1.08	1.19	1.11
Energy (4.9%)	19.4	18.7	0.83	1.90	1.15	1.22	0.78	0.75	0.69
MicroBio (4.8%)	24.7	4.6	1.06	0.46	1.01	1.12	1.01	1.14	1.15

Note: In between brackets the size of the field measured as the share of the scientific field in total publications. Source: Own calculations on the basis of Elsevier, Scimago (downloaded oct 2014)

In terms of scientific size, the US is the largest country for all scientific fields for green inventions, but China is closely following, particularly in the areas of material sciences, energy, chemistry and chemical engineering. In all of these scientific areas, China is not only big in size, it is also specializing. The US, although it is the largest producer of science in the green disciplines, it specializes in none of them. The three large EU countries (Germany, France and the UK) have no outspoken specialization in energy or environmental sciences. Germany does have a strong hold in Material Sciences and Chemistry.

Overall, the sources of scientific knowledge for the green innovation machine are not only multidisciplinary but also multinational, where the Asian (ie China) pole can not be underestimated.

5. Evidence on the impact of government policies to induce green innovations

The evidence on the performance of the green innovation machine shows that although it is taking off, it is not at full speed (yet). To which extent has government intervention been effective to kickstart the green innovation machine? How effective can government intervention be to bring the private green innovation machine to full speed? How responsive is the green innovation machine responsive to government intervention?

There is increasing empirical evidence to support the contention that environmental policies do lead to technological innovation. Veugelers (2012), Jaffe et al (1995) Newell and Stavins (2002) and Johnston (2008) provide recent reviews of the empirical literature on this theme. The following section draw heavily on these reviews.

Evidence from patent data

Using US industry-level data, Jaffe and Palmer (1997) examined the relationship between stringency and innovation more broadly (not only environmental patents) for a set of US manufacturing industries in the period 1977-1989, where innovation was captured in terms of both R&D expenditures and patents. They found that increased environmental stringency (as measured by higher level of Pollution Abatement Costs and Expenditures (PACE)) 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 (SO2) control. They found that consistently more patent applications were placed after SO2 regulation was introduced in the 1970s. Popp (2006) examined NOX regulation in the US, as well as the German and Japanese electricity sectors – to explore whether these regulations affected (inter)national innovation and diffusion. One of Popp's main findings was that it is mainly domestic regulation that fosters patenting in the home country. But he also found an important role being played by foreign actors in the development of these patents. Popp (2003) examined the effects of the introduction of the tradable permit system for SO2 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, beyond regulation, particularly subsidies for environmental R&D, is 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 the effects are very much dependent on the policy specifics: their fit into a mix of policy instruments; the type of green technology innovation considered and the life cycle of the technology. For instance, for 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. 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.

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.

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

Evidence from innovation data

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 technologies, for instance through the instrument of carbon pricing. The introduction of new cleaner technologies, whether own developed or adopted from elsewhere, is better captured with innovation measures than with patent measures. Unfortunately, as already raised supra, the standard information source for innovation, the CIS survey, is poor on identifying eco-innovations.

Determinants for different kinds of eco-innovation have been studied in the IMPRESS through interviews with randomly selected industry and service firms in eight sectors in five European countries (Germany, the United Kingdom, Italy, the Netherlands, and Switzerland) and this for the year 2000 (Arundel (2009)). The survey found that there are many more important reasons besides complying with regulations or other policy instruments for introducing an eco-innovation. These are: improving the firm's image, reducing costs, achieving an accreditation, and, for product and service innovations, securing existing markets and increasing market share. Compliance with environmental regulations was more important for pollution control innovations than for the other types of eco-innovation, especially service, distribution, and product innovations. 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.

Veugelers (2012) uses firm-level evidence on the motives for introducing clean innovations from the Flemish CIS eco-innovation survey (2008-2010). Of all the innovative active firms in the survey, 46% responded that they introduced a clean innovation in the period 2006-2008 (ECO)[10]. These eco-innovators were surveyed on their motives for introducing their clean innovations. The following set of motives were surveyed:

- 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 set of motives considered 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.

A full (econometric) analysis of the motives for eco-innovations is reported in Veugelers (2013). Overall, the evidence is very supportive of firms to be responsive to eco-policy interventions. At the same time, the evidence is also suggestive of how important the details of the policy design are.

The motive which is most frequently identified as having driven eco-innovations, are voluntary agreements (Panel A). 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. Grants are least often mentioned: in 15% of the cases.

For large enterprises (Panel B), 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-innovations: one third of all large enterprises listed grants as a factor having induced their eco-innovation activities.

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,

[10] 43% of the total 2894 firms in the sample respond have introduced a clean innovation in their own operations, 8% report having developed clean innovations for their users (ECOUSER). Of these, 20% introduced innovations that reduced CO2 (ECOCO2) energy saving (ECOEN) 22%, reducing pollutants (ECOPOL) 21%, reducing pollution (ECOSUB) 22%.

Table 6: Which motives for introducing eco-innovations?
Panel A

	All ECO	Eco-Innovations for reducing CO2 emissions (ECOCO2)	Eco-innovations for saving energy (ECOEN)
ENREG	32	42	38
ENREGF	25	37	32
ENGRANT	15	22	21
ENDEMAND	21	29	28
ENAGREE	39	51	50

Panel B

	SMEs	LARGE	FOOD	CHEM	ELEC	AUTO	NUTS	TRANS PORT
ENREG	28	61	52	45	43	25	28	32
ENREGF	22	49	30	41	28	21	33	28
ENGRANT	14	33	20	21	12	19	17	23
ENDEMAND	19	38	15	28	31	23	28	13
ENAGREE	35	67	44	51	47	50	39	34

Note: Numbers reflect the share of innovators reporting motive as important for introducing their eco-innovation.
Source: On the basis of Veugelers (2012)

The impact of 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. 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. This evidence supports that policy interventions will have greater influence on the adoption and particularly on the development of new clean technologies when designed to be consistent over time, affecting future expectations.

The evidence further supports the increased leverage of policies when combining regulations & taxes with subsidies. 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. This is consistent with complementarity between government instruments, as also discussed in section 2.

6. DESIGNING POLICIES FOR A GLOBAL GREEN TECHNOLOGY MARKET

If governments want to leverage the needed private innovations for green technologies, they will have to provide a well designed time consistent policy, reducing commercial and financial risk by a combination of consistent carbon pricing, regulations and public funding. With current heavily constrained public budgets, it is all the more important that this public funding is allocated as cost effective as possible. This implies that public funding will have to be as effective as possible in leveraging private funding.

The evidence on the performance of the green innovation machine, reviewed in this contribution, provides good and bad news for green policy making. The bad news is that the evidence shows we are not there yet. It shows that although the private green innovation machine is taking off, it is not at full speed (yet). This correlates with a deployment of government policies for green innovations, which has, despite increasing attention, so far been far from optimal. With low, volatile, fragmented and uncoordinated levels of carbon pricing, green subsidies and regulations, there is still some distance to go before ideal policy support is realized to have a private green innovation machine at full speed.

The good news is that the evidence shows government interventions, when properly designed, have the power to turn on the private green innovation machine. The evidence is favorable for the impact which green policies can have on motivating the private sector to develop and adopt green innovations. But it also highlights that government policies need to be seen as part of a full set of motives for the private sector to introduce green innovations. Demand for clean products and lower cost clean processes are also an important, if not more important lever for the development and adoption of green innovations by the private sector.

The evidence also highlights how the details of the policy intervention matter for effectiveness. The required details include a long-term, time consistent policy framework to be able to leverage the incentives of the private sector to engage in long-term green innovation investments. This holds particularly in technology areas with bigger infrastructure investment requirements. The details also include efficiently targeting public budgets to address the major areas of market and systems failure, ie particularly addressing the early stage high risk technology areas, supporting the emerging, still fragile eco-systems of science and technology suppliers, technology and product users in these areas to further develop into critical scale.

An important insight from the economic analysis of the effectiveness of the public intervention for green innovations, is the complementarity between policy instruments, requiring an adequate policy mix of instruments, rather than a focus on individual instruments. The evidence provides little support for the efficacy of single instruments, like subsidies, when used in isolation.

The complementarity between policy instruments is important to take into account for the design of public green subsidy policies. A well-functioning carbon market is essential for driving low-carbon investments and achieving global mitigation objectives in a cost-efficient manner, particularly for investments in development, demonstration and deployment of later stage technologies. It is a reminder for those governments contemplating a public green R&D support 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.

For the EU, this is perhaps the biggest challenge for its green technology policy: the lack of a sufficiently high carbon price. To this end, a larger effort should be devoted to integrate carbon taxes among EU MS. At the same time, the ETS system and the emission of allowances should be designed with a long-term perspective, to leverage private green innovation, i.e. taking into account the need to reinforce innovation incentives.

The evidence has shown that the world of green science and technologies is an emerging global, multipolar one, with many geographically dispersed sources in the various green scientific fields and technologies. Coordination of green policies internationally among the major players, should therefore be high on the policy agenda. What would benefit the development of green technologies most, is an international carbon price established on a globally integrated carbon market, or at least internationally linked domestic cap-and-trade systems.

Also the global coordination of public science and R&D programs for green innovations would help, to pool resources and know-how, avoid duplication and speed up the diffusion of results. While on public R&D programs, a certain level of competition between countries could be healthy to allow the nurturing of a larger set of potential scientific and technology trajectories, eventually, the best science and technologies that emerge from this competition should be diffused as broad and fast as possible. This implies well functioning global markets for green ideas.

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Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs change. The financial crisis has exposed long-neglected deficiencies in the present growth path, most visibly in the areas of unemployment and public debt. At the same time, Europe has to cope with new challenges, ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundation for a new development strategy that will enable a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four-year research project within the 7th Framework Programme funded by the European Commission was launched in April 2012. The consortium brings together researchers from 34 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). The project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

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