Global Journal of human social science
Geography, Geo-Sciences, Environmental Disaster Management
Volume 13 Issue 4 Version 1.0 Year 2013
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-460X & Print ISSN: 0975-587X

Strategic Trade Policy as Response to Climate Change?

By Andreas Freytag & Leo Urban Wangler
University of Jena, Germany and Institut für Innovation und Technik (iit) in der VDI/VDE-IT

Abstract - Based on German experiences, this paper discusses the political economy of climate protection. The objective is to come to a better understanding of why climate change has become one of the main topics at the domestic agenda in some countries, despite the fact that there are obvious free-riding problems resulting in increasing difficulties for international policy coordination. Using a strategic trade policy framework, the paper theoretically discusses the incentives for domestic policymakers to advocate an ambitious climate policy and assesses these incentives empirically with econometric methods.

GJHSS-B Classification : FOR Code : 960301

STRATEGIC TRADE POLICY AS RESPONSE TO CLIMATE CHANGE?

Strictly as per the compliance and regulations of:

Strategic Trade Policy as Response to Climate Change?

An Empirical Assessment of the Political Economy of Climate Policy

Andreas Freytag [α] & Leo Urban Wangler [σ]

Abstract - Based on German experiences, this paper discusses the political economy of climate protection. The objective is to come to a better understanding of why climate change has become one of the main topics at the domestic agenda in some countries, despite the fact that there are obvious free-riding problems resulting in increasing difficulties for international policy coordination. Using a strategic trade policy framework, the paper theoretically discusses the incentives for domestic policymakers to advocate an ambitious climate policy and assesses these incentives empirically with econometric methods.

I. Introduction

The problem of climate change is of a global nature. As long as economic growth is not disentangled from an increase in greenhouse gas (GHG) emissions, the problem of climate change is likely to increase. One common argument is that the global problem encourages free-riding and reduces national incentives to contribute to climate change mitigation policies. Thus, international policy coordination is an attempt to reduce the related problems.

One example of international cooperation aiming to reduce coordination problems is the Kyoto-Protocol (KP). Even though the KP was an attempt to make countries act cooperatively, strategic behavior could be observed at the ratification stage (decision to ratify or to free-ride on the agreement) as well as the implementation stage (over or underinvestment to fulfill the requirements agreed by ratification). Differences in national cost structures combined with strategic interaction between countries makes coordination difficult. A recent example was the negotiation for a follow-up agreement to the KP which took place in December 2009 in Copenhagen (e. g. Macintosh; 2010; Nicoll et al.; 2010). Despite the global nature of the problem, some governments did start to restructure their energy policies. It seems that they take the climate change problem seriously (e. g. the German government by supporting diffusion of green technologies (GTs)[1]). Interestingly, it turns out that the same countries argue forcefully in favor of more strict environmental standards on the international platform.

The fact that some countries invest relatively more than others in the abatement of climate change is somehow counterintuitive if we apply the general wisdom that free-riding of particular countries negatively affects the international competitiveness of non-free-riding-countries. Investment costs related to GTs seem to be a burden that increases the costs of energy consumption within a country. It is, therefore, an interesting question why some countries are more motivated than others in implementing policy measures that have a seemingly positive impact on the problem of global warming and promote actively high environmental standards at the international level instead of free-riding themselves.

We argue that the initiative for structural change at the national level can be an outcome of international environmental agreements (IEAs) aimed at reducing problems related to climate change. However, as we also observe free-riding, not all countries are able to restructure their energy policy. Differences in political systems as well as cultural aspects might be a reason for the observed heterogeneity. In contrast to the common view, the main argument of our paper is that free-riding by some countries may encourage other countries to increase investment in abatement measures instead of reducing it. Our arguments are based on a political economy framework in combination with international trade policy.

The paper is organized as follows. In section 2, we briefly discuss the costs of global climate change and the global attempt to solve the problem. In section 3, we focus on the particular German case. Different political economy explanations that help to explain the observed heterogeneity among countries follow in section 4. In section 5, we use a simple theoretical framework to explain a country's solo run to provide a global public good in climate policy. Our political economy reasoning is empirically assessed with the help of a negbin model in section 6 where we use the patent applications of German green technology firms as a proxy for their expectations about future export sales. Conclusions round off the paper.

Author α : Friedrich-Schiller-University Jena, Germany, and University of Stellenbosch, South Aifrca. E-mail : a.freytag@wiwi.uni-jena.de
Author σ : Institut für Innovation und Technik (iit) in der VDI/VDE-IT. University of Sellenbosch. E-mail : Wangler@iit-berlin.de

[1] In this paper we define GTs as technologies able to produce electricity using renewable energy sources (e.g. photovoltaics, solar, geothermie, biogas, water, wind mills etc.) and therefore, have the potential to substitute for GHG emitting conventional energy sources.

II. Climate Change Problem and Climate Policy

There are studies trying to make predictions about the costs related to climate change (e. g. Latif; 2010; Stern; 2007). Without policy response, costs of changes in temperature are expected to increase at a level of from 5-20 percent of global annual gross domestic product (GDP). These costs can be reduced by climate policies. However, there are substantial differences between regions (cf. Hope; 2006; Mendelsohn et al.; 2000; Nordhaus and Boyer; 2003; Nordhaus and Yang; 1996; Tol; 2002). The allocation of costs has further an intertemporal dimension. Estimates came to the result that it is "cheaper" to react today than in the near future because doing nothing will increase costs (Kemfert; 2005).

Another problem is related to non-cooperative behavior of particular countries and changes in relative prices. As stated by Sinn (2008), it may be the case that the abatement of industrialized countries does not affect the speed of global warming as initially intended because the reduced demand for energy by some industrialized countries simply lowers world market prices and increases the demand for energy by those countries which do not intervene to reduce energy consumption (the so-called "rebound effect"). Problems to coordinate international policies lead Lomborg (2006) to suggestions of alternatives to the option of cutting GHG emissions.

It can be seen that costs related to climate change depend strongly on the policy measures implemented. Country specific costs can be reduced significantly if there is international cooperation. However, free-riding on the international level increases country specific costs of climate abatement policies. Based on these arguments, global environmental problems constitute an international prisoners' dilemma. Climate protection has the characteristics described as "tragedy of the commons" (Hardin; 1968) and countries have to cooperate to find solutions for the common pool problem (e. g. Ostrom; 1990). The Kyoto Protocol is an attempt to coordinate international policies.

By signing the KP countries agreed to a reduction in the emission of GHGs to a specified level measured in percentages of the base year 1990. Between 2008 and 2012 countries are supposed to reduce the average emission of GHG by about 5.2 percent of the 1990 reference-level. Europe agreed to reduce the emissions of GHG by 8 percent in comparison to the emissions of 1990. The KP was coupled with the condition that at least 55 member states, which altogether produce more than 55 percent of the global emissions of CO_2, have to ratify the protocol before it can enter into force (Kyoto Protocol; 1998, p. 19).[2] The 55 percent rule was fulfilled when Russia ratified the KP in November 2004. Therefore, the KP came into force in February 2005. In 2011 188 countries and other governmental entities have ratified the KP. The United States, the largest single emitter of GHG signed but did not ratify the KP at the national level.

III. Climate Policy in Germany

Once international treaties are negotiated, countries have to implement policies to fulfill what has been agreed. The alternative is to free-ride on the international agreement. Germany has chosen a mixed strategy to reduce the emission of GHG. On the one hand, there is the market solution (implemented in Europe) of trade with certificates related to GHG emissions.[3] Germany has the target to reduce emissions by about 21 percent in 2012 compared to 1990 baseline emissions. On the other hand, the government is using incentives to encourage the application of particular (allegedly) climate friendly technologies. For instance, the former "red-green" government coalition[4] passed the so-called "Renewable Energy Sources Act" (EEG) to support renewable energies by the use of technology specific feed-in tariffs. In what follows, we will focus on the promotion of GTs and its connection to climate change as this is an interesting case from a political economy perspective.

From a theoretical point of view most GTs available, even today, are costly alternatives compared to conventional energy technologies (wind turns out to be an exception). The political argument for investment into GTs is to foster the development of GTs and to reduce global warming (EEG; 2009, section 1, purpose). There is an obvious connection between the problem of climate change and industrial policy, as feed-in tariffs are set on different levels what allows for the diffusion of more cost-intensive GTs. The range of feed-in tariffs in 2003 was from 6.5 Cent/KWh for electricity produced by using water and biogas up to 51.62 Cent/KWh for electricity produced with solar.[5] This has led to a remarkable diffusion of GTs (comparefigure 3 and figure 4, Appendix, page 16). From 2000 to 2011 electricity produced with renewable energies increased from 6.4% to 17% (BMU; 2011, p. 12). This is puzzling and needs an additional explanation.

Another observation, that can be made, is that the German government takes an active role in

[2]The so-called 55 percent rule has important implications: It gives countries the opportunity to free-ride without nullifying the whole agreement. The free-rider problem is, thus, mitigated and it is more likely that the agreement will be implemented.

[3]The importance of defined property rights as an efficient solution for the externality problem has been highlighted by Coase's (1960) seminal paper. For theoretical considerations compare Baumol and Oates (1988).

[4]The coalition between the Social Democrats and the Green party from 1998 to 2005.

[5]The average market price for electricity in 2003 was reported by the German statistical office to be 8.78 Cent/KWh (including the costs for GTs).

international environmental negotiations. First of all, it can be seen that the German government established one of the highest GHG emission reduction targets within Europe. Second, at the G8 summit at Heiligendamm (Germany) in June 2007, the German government tried to use its role as an agenda setter to actively promote climate policies (e. g. Freytag and Wangler; 2011). There is further evidence that Germany as a member of the European Union is one of the leading industrial countries with respect to climate change and renewable energy policies (e. g. Weidner and Mez; 2008). With the recent event of the nuclear catastrophe in Fukushima (Japan) the current energy policy in Germany changed even more in favor of renewable energies. According to a new energy concept by the German government it is the aim to reduce GHG emissions until 2020 by about 40%, until 2030 by about 55%, until 2040 by about 70% and until 2050 by about 80-95% compared to 1990 baseline emissions (BMWI; 2011, p. 5). These GHG reduction targets are ambitious and are also surprising due to the fact that international policy coordination is confronted with difficulties.

Interestingly, the German government tries to foster actively the export of green technologies. For this purpose, in 2002 the German Bundestag nominated the German Energy Agency to be responsible to promote actively the export of GTs. Under the label "Renewable Made in Germany" there is a whole concept of marketing for the related products and there is active support to create international networks, to create knowledge about potential export markets of GTs and to provide active services facilitating foreign market entrance (e.g. by active lobbying). The support by the German Energy Agency is not limited to German companies alone, criteria for support is in close connection to the job creation in the GT sector within Germany.[6]

The findings of the previous sections can be summarized as follows: With respect to the climate change problem, there is the need for international policy coordination. This coordination, however, turns out to be difficult and perceived as a failure. If we follow this line of arguments, it is surprising that an industrialized country like Germany takes a leading position in climate policies despite the fact that coordination failures increase country specific marginal abatement costs. It seems that politicians in Germany have a long term time horizon by actively promoting the diffusion of GTs as this policy (if at all) will only have in the long run a positive impact on the world climate. This behavior is somehow puzzling as the general wisdom suggests that politicians are rather short term oriented.

IV. Political Economy Considerations

a) Behavioral Assumption

From a political economy point of view politicians are considered as rational actors that are mainly concerned about re-election (Schumpeter; 1987b). Incentives to foster structural change in the energy sector are rather low as this is costly and reduces the political influence of conventional energy producing companies. This helps to understand the difficulties in particular countries to invest into climate abatement policies. Due to the free-riding of other industrialized countries, we also should not expect that politicians in Germany seriously support diffusion of GTs. Obviously, this is not the case. As stated in the previous section there was an observable diffusion of GTs and in the future they will be of increasing importance. The aim is to achieve a share of 35% by 2020, in 2030 the share shall be 50% and in 2050 the share of renewable energies of cross electricity consumption shall achieve 80% (BMWI; 2011, p. 5).

Theory suggests huge difficulties for policies aiming to foster structural change in the energy system. Today the support for most GTs is still not profitable under current relative prices. The described empirical observation is therefore counterintuitive and needs an additional explanation.

A standard political economy explanation refers to the median voter model (Black; 1948; Downs; 1957). The government follows the median voters' preferences which are increasingly directed to protect the climate. Therefore, the government invests relatively more than other countries into climate protection as this is in line with median voter preferences within the country. The likelihood of such a political preference for early investment into abatement policies is doubtful, due to international free-riding behavior and the relatively high investment costs that are related to GTs.

If we take into account that international preferences are characterized through a game with national elections on a first stage and the delegation of representatives to international levels on a second stage, there is still some explanatory power related to the median voter theorem. The described model is known as strategic delegation model of IEA formation. In the underlying game voters delegate their decision power to agents representing the country at international negotiation tables. The agents, usually the government, then have the power to negotiate the terms and conditions of an international agreement.

This setting is generally applied as a two-stage game within a two country setting. At the first stage voters (using majority rule) elect their preferred politician who, at the second stage, is responsible to negotiate the international treaty. Foreign election outcomes are taken as given for the election on the national level. This allows voters to select the candidate that represents most favorable their position in the international policy game.

One basic feature of the underlying game is that it is rational for voters to elect a politician with different preferences than their own; with the result that

[6]To get more insights see DENA (2011), p. 14.

international outcomes deviate from the median voter's 'true' preferences. It is rational for voters to strategically misrepresent individual preferences if the election outcome gives an advantage at international policy negotiations (see Persson and Tabellini; 2000, Chapter 12). There are different economic phenomena such as international tax policies and the provision of transboundary public goods to which the strategic delegation approach has been applied to (e. g. Böhringer and Vogt; 2004; Buchholz et al.; 2005; Dolado et al.; 1994; Kempf and Rossignol; 2010; Persson and Tabellini; 1992; Roelfsema; 2007; Segendorff; 1998).

Segendorff (1998) finds that voters will choose politicians that have stronger preferences for the private good compared to themselves. The idea behind is that this lowers the reservation utility and thus, weakens the bargaining position of the other agents participating in negotiations. They find a gap between cost and actual willingness to pay in particular for the USA what might serve as an explanation for the withdrawal of the USA from the Kyoto agreement. Buchholz et al. (2005) study the effect of strategic delegation with a focus on IEAs. They find that in the equilibrium the median voter in each country chooses a government that is less concerned about environmental problems compared to himself, with the intuition that this improves a country's position at the international bargaining stage.

The results described allow to explain why investment into climate protection might be too low. This is different from the described German position within the international climate policy-game. However, models of strategic delegation are also helpful to explain why countries might support rather strict environmental standards on international levels. Roelfsema (2007) studies the effects of strategic voting within a two country setting and non-cooperative behavior with a focus on the Kyoto protocol. Two equilibria are possible. One where politicians are less concerned about the environment than the median voter and one in which politicians have a higher preference for the environment compared to the median voter. There will either be a 'race to the bottom' or a 'race to the top', depending on the strength of the environmental preferences of the median voter.

Models of strategic delegation can help to explain why politicians in some particular countries are highly engaged for environmental protection also at international levels. In Germany it seems that strategic delegation leads to high preferences for international climate standards. Median voters' preferences might be different from those of the delegates.

Strategic delegation allows delegates to promote long term environmental targets as long as in the short run partial gains at the regional level exist, like short term employment in the GT industries (generating directly observable growth in the GT industry). Politicians are not directly sanctioned by the voters if they convincingly argue that diffusion of GTs is related to future export sales. The job creation in a particular GT industry (Blanco and Rodrigues; 2009; Hillebrand et al.; 2005; Lehr et al.; 2008; Lund; 2009) very likely creates stable (or increasing) transfer flows to the particular GT industries (lock-in effect). Politicians can maximize their political support function (in the short run) with this job increase and at the same time justify these transfers by expected future payoffs (e. g. future exports) related to the investment. This relationship between short term employment and long term export expectations might be the main reason for the observable diffusion of GTs within Germany and the strong preference for high international standards to protect the climate.

The described policy will only pay off in the future if other countries also adapt to the high German standards. This explains why the German government has to support a rather strict environmental position on international meetings. The aim is to prepare future export markets in order to make the (over) investment into GTs profitable. Thus, for investment into GTs it mainly holds in a one-shot game that free-riding behavior of other countries is problematic for the domestic government and its climate abatement targets. From a dynamic perspective, this free-riding behavior in the short run may further encourage governments for ambitious unilateral political action, as long as it can be expected that other countries over time have to increase their environmental standards, as well. Such an increase seems to be likely in the context of climate change with its long term time horizon.

What still has to be answered is the reason for the observed heterogeneity between countries with respect to be able to start investment into GTs. One explanation might be that governments act ideology driven or that under particular circumstances they have the opportunity to implement partisan policies. As climate change requires structural change within the economic system, some governments are not able to overcome the resistance of the interest groups within the system in the short run. These governments are obviously forced to free-ride on international environmental agreements. Over time the government composition might change and policy reforms might be established. Especially partisan politics seem to be a good explanation why the GT sector in Germany could initially become possible. There was a kind of window of opportunity when the green party for the first time became part of the German government under the so called red-green coalition as the green party could express its preferences for climate friendly policies (from 1998 to 2005).

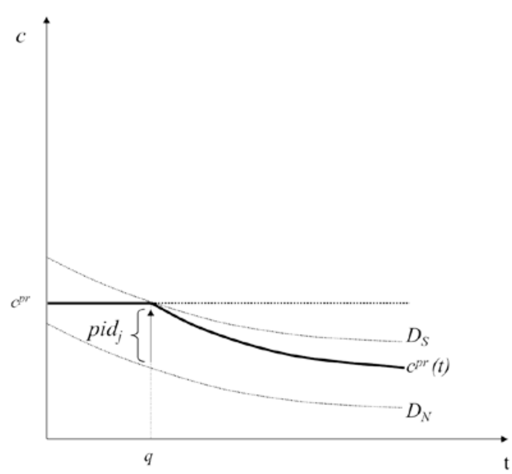
b) *Strategic Interaction*

There are existing theoretical papers that use game theory to evaluate strategic interaction between countries in the case of environmental policy (e. g. Barrett; 1994; Rege; 2000; Ulph; 1996; Ulph and Ulph;

2007). In this paper we focus on the German case and try to explain the political calculus behind the climate policy of the German government.

Without any policy induced demand for a certain GT *j*, there is no intersection between supply and demand and marginal production costs are assumed to be constant. Diffusion of GTs is not observable. Diffusion is related to the regulations within the energy system allowing GTs to diffuse. We further assume learning curve effects, thus, the cost curve has a negative slope (compare Madsen et al.; 2005; Nemet; 2006).[7] This is depicted in Figure 1 (page 12), where *t* stands for time, c^{pr} represents the marginal production costs, D_N stands for the demand for a certain GT *j* without policy induced demand (pid_j) and D_s stands for the demand for a certain GT *j* with policy induced demand. We refer to pid_j as diffusion of GTs that results from domestic political intervention. What we have in mind can be interpreted as command and control policies with characteristics similar to those of the *EEG*. Theoretically, however, pid_j could also represent diffusion of GTs as a result of market-based instruments such as tradable certificates or subsidies. In any case, the parameter is exogenous and can be directly influenced by national legislation.

Figure 1 : Learning curve effect



To start with, we assume that only one country – in our framework the home country (*H*) – implements measures that allow for diffusion of GTs. The measure taken is a policy induced demand for renewable energy at a level that allows the GT industry to establish. There is no international trade in GTs as the foreign country (*F*) free-rides on climate change mitigation policies. The resulting effect is a comparative advantage for the national GT industry (first mover advantage) as it moves rightwards on the learning curve.

Concentrating on the domestic consequences of supporting renewable energy beyond the market demand for GTs (under the assumption that *F* does not support the GT sector), the balance is negative. Because conventional substitutes for producing energy exist, the creation of the GT sector generates costs in *H* that can be translated into a reduction in the level of national GDP. In addition to the environmental regulation, these costs reduce the initial comparative advantages of other industries (that use energy as input and compete in international markets). Additional pressure comes from the short run free-riding strategy in country *F*. In other words: $Y_H^{n1} < Y_H^i$ (Y_H^{n1} stands for "new GDP" with policy induced demand for GTs and without exports, the latter for the GDP without policy induced demand for GTs).

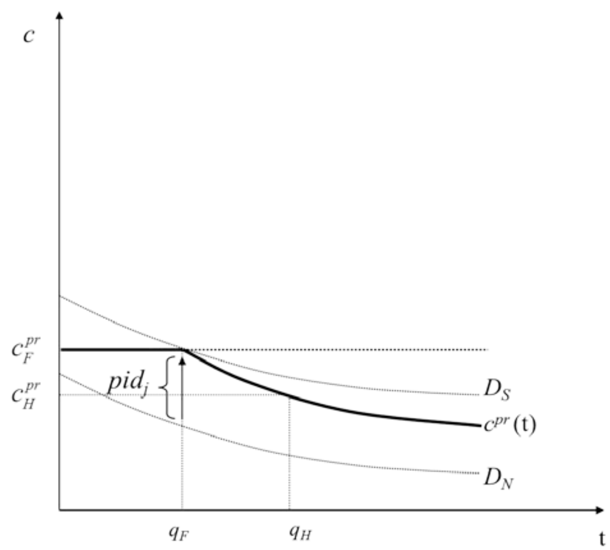
We get further insights when comparing both countries. Without any support being given to the GT sector the initial GDP of both countries is the same. This means that $Y_H^i = Y_F^i$ (Y_F^i stands for the GDP without any support for the GT industries in *F*). *H* is the first who implements GTs.[8] If we compare the GDP levels of both countries after *H* has decided to implement a GT sector, in the short run we have the case that $Y_H^{n1} < Y_F^i$. This line of arguments is well known and can directly be applied as an explanation for the free-riding problem, resulting in an international prisoners' dilemma.

We now turn to the open economy. Because we assume that *H* enters the market of GTs before *F*, it moves rightward on the cost curve. Hence, considering exports does lead to a change in the results. If *F* decides later to enter the GT market and starts its own production, it has to start at a higher point on the cost curve. Figure 2 shows that c_F^{pr} are expected to be higher than c_H^{pr}. The support for a certain GT industry in *F* could have different reasons. One striking argument is that knowledge creation about the problem of climate change makes free-riding over time more and more difficult to be maintained. Changes in *F*' s policy can be supported by international attempts of *H*' s government to "lobby" internationally for global environmental standards. A change in the government composition in *F* is one further explanation.

[7]For a general discussion of learning curve effects and competitive markets see Rasmusen et al. (1997).

[8]We argue that this is due to the political process. Apart from this, both countries can be assumed to be symmetric.

Figure 2 : Different marginal production costs



It is highly sensible to use a framework of strategic trade policy to explain why *H*'s government has strong incentives to support high environmental standards on an international platform. The first mover advantage stems from the chance to increase market power within markets with incomplete competition (e. g.Brander and Spencer; 1985). Thus, political support (or more generally a policy induced demand) can help the industry to exploit the rents that might be related to early market entrance.[9]

Different scenarios are plausible. For instance, one could expect a scenario in which *F* decides in a later phase than *H* to implement a transfer scheme per unit of energy produced (e. g. a FIT) by a particular GT (what is captured by pid_j). We assume that producers located in *F* are also able to produce GTs, but they operate on a higher marginal cost curve. This allows the GT sector in *H* to enter the market in *F* as a Stackelberg leader (scenario 1). Alternatively, high environmental standards might be the result of supranational negotiations (scenario 2). The high environmental standards increase the demand for GTs indirectly. Results for plausible other scenarios are summarized in table 4 (Appendix, page 23).

Based on the previous reasoning, it becomes obvious that politicians in *H* have strong incentives to (1) make use of industrial policy to support the national GT industry even though other countries free-ride, (2) to support high environmental standards at an international level and (3) to cooperate with the GT industry on international interests.

We now look at the expectations related to exports of GTs (scenario 1 and scenario 2). The expected price-demand function is given by $p^e = A^e - q^e_{H_j} - q^e_{F_j}$ (where p^e is the expected prices, A^e represents the expected size of the GT market with exports, $q^e_{H_j}$ stands for the expected quantity sold by the GT industry *j* located in *H* and $q^e_{F_j}$ stands for the expected quantity sold by the GT industries$_j$ (*j*=photovoltaics, …,windmills) located in *F*. Expected profits (π^e) of the GT industry$_j$ located in *H*, due to export of its technology to *F*, can be formulated as follows:

$$\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^{pr}_{H_j} + pid^e_{F_j}) - c_{l_j}. \quad (4.1)$$

Note that we do not assume a monopolistic market in the GT sector in *H*. What we assume is that all GT industries in *H* are supposed to be symmetric and able to supply GTs at the same marginal costs and therefore, $\pi^e_{H_j}$ represents aggregated profits. Politicians and representatives of the different GT industries in *H* are aware of their advantage in international competitiveness. Therefore, both groups expect to benefit from an increase in environmental standards in *F*. Obviously, gains are related to the export of GTs.

If industries in *H* and *F* are operating on different cost curves, as depicted in figure 2 (page 13), then equation 4.1 can be solved as a Stackelberg game (compare Appendix b 2, page 23). We assume that *H* enters the export market as Stackelberg leader.

We then get as an expected outcome that $q^{e*}_H > q^{e*}_F$ and exports (in contrast to the short term considerations) contribute positively to *H*' s level of GDP. The result $q^{e*}_H > q^{e*}_F > 0$ can be interpreted as potential extra gains for the GT industry in *H* (if *F* was free-riding in the short run and decides later to support diffusion of GTs without discriminating against *H*' s industry). This is one reason why there might be a strong interest in *H* to invest heavily in the diffusion of GTs and "to lobby" internationally for high environmental standards internationally.

How does this result translate into *H*' s changes in GDP (*Y*)[10]? We can substitute the calculated values for $q^{e*}_{F_j}$ and $q^{e*}_{H_j}$ into equation 4.1 and obtain the expected profit $\pi^e_{H_j} > 0$. This profit can be directly translated into national welfare gain ($\pi^e_{H_j} = y^e_H > 0$). This leads to the result that $y^e_H > 0$ reduces the loss in GDP related to the pid_{H_j} without any exports in the short run. With exports, the expected new GDP $Y^{e^{n2}}_H$ ($Y^{e^{n2}}_H = (Y^{n1}_H + y^e_H)$) is bigger than Y^{n1} (the GDP without any exports of GTs). So far we have the case that $Y^i_H > Y^{e^{n2}}_H > Y^{n1}_H$. The model implies that exports of GTs can generate welfare gains which enter positively into the GDP of *H* compared to the first situation which

[9]Only if countries subsidize their industries in order to be the first to enter into the market, a prisoners' dilemma is present and both countries would be better off without the subsidy (Brander and Spencer; 1985, p. 95)

[10]Note that the welfare analysis is limited to the GDP and, therefore, ignores welfare gains due to the reduction of GHGs. In our study benefits of climate change protection are not taken into account. A cost-benefit analysis therefore would come to very different results.

is described by Y_H^{n1}.[11] Thus, once the GT industry has been successful in establishing itself at the national level, the GT industry (in both, *H* and *F*) and the government (in *H*) have common interests at the international level.

Finally, just how realistic the expectation is that there is a long run net benefit for country *H* from subsidizing its GTs, has to be discussed. As table 4 (Appendix 4, page 23) shows, "only" in scenario 3, case (a), does the first mover advantage not lead to higher exports because of direct support in *F* for the GTs there. However, as q_F^{e*} is also bigger than zero, one can expect that the industry in *F* also gains. This implies less resistance in *F*.[12] All other scenarios are characterized by increasing exports. Thus, there are, at least, three political economy arguments that politicians in *H* use in support of the GTs, strategically:

1. GT industry *j* expects higher profits,
2. national governments can reduce the political costs caused by the policy induced demand for GTs,
3. The GT industry in *F* can also generate profits which is important to reduce resistance against international standards.

The intuition behind the framework presented is to analyze political incentives which we now try to incorporate into an econometric model.

V. Econometric Model

To test our theoretical argument, we propose an econometric model. With this model, we try to assess empirically whether the alleged strategy of the government and the GT interest groups is indeed observable in reality. The question is whether or not the link between climate policy and industrial policy has an influence on export expectations related to GTs (eventually leading to an increase of GDP beyond the free-riding status quo). This is, of course, difficult to estimate, as expectations cannot be modeled easily. We argue that expectations about future export sales and thus profits ($\pi_{H_j}^e$) are best expressed in patent applications and grants in foreign target countries ($PATENT^{HF}$). The econometric model is, therefore, constructed in a way that it tries to proxy equation 4.1 ($\pi_{H_j}^e = q_{H_j}^e(A^e - q_{H_j}^e - q_{F_j}^e - c_{H_j}^{pr} + pid_{F_j}^e) - c_{l_j}$) econometrically.

We build the model on the assumption that diffusion of GTs (as a result of *pid*) reduces marginal production costs. This relationship $pid_{H_j} : c_{H_j}^{pr} \rightarrow c_{H_j}^{pr}(pid_{H_j})$ is proxied with installed capacity (measured in MW) of industry specific technologies (pid_{H_j}) in *H*. We further assume that in the equilibrium without trade in GTs, pid_{F_j} is lower than pid_{H_j} (such that $c_{H_j}^{pr} < c_{F_j}^{pr}$) and politicians located in *H* make use of international "lobbying" to create and/or to further increase pid_{F_j} in order to be able to exploit their comparative advantage in future trade sales (in the model described as intra-industry trade). Formally: $\pi_{H_j}^e$ proxied by $PATENT^{HF}$ and $c_{H_j}^{pr}(pid_{H_j})$ proxied by $(INCAP^H)$ gives the functional form that we are interested in. This then leads to the relationship $(INCAP^H : PATENT^{HF} \rightarrow PATENT^{HF}(INCAP^H))$ Thus, if there is a positive correlation between $PATENT^{HF}$ and $INCAP^H$, we see a rationale for politicians located in *H* to actively support the interests of the different GT industries at the international level.

As controls we add public expenditures on research and development in the home country (RuD^H), energy prices in the foreign country $(CPIE^F)$, as well as electricity consumption in the foreign country (ELC^F). We also control for structural change in the patent system by including all patents applied in the foreign country $(APATENT^F)$ which measures all patent applications in the specific country (this variable can also be interpreted as a proxy for A^e). Due to a lack of information, we have to ignore the costs of lobbying (c_{l_j}). As our model makes use of future expectations, we do not have information on $q_{H_j}^e$, $q_{F_j}^e$, and $pid_{F_j}^e$ which is expected to be significantly higher than the observed variable pid_{F_j}.

In the following paragraphs, we describe in more detail our data-sources. The time frame of the dataset is from 1992 to 2002.[13] The institutional settings analyzed are the SEG (1990-1999) and the EEG (2000-2002). The four sources of the data are the German Patent Office, the International Energy Agency (IEA), Eurostat and the Federal Ministry for the Environment (BMU). The industries of interest are wind, solar, water & ocean, geothermal and biomass.

The empirical approach we use to test the theoretical framework looks at the patents, with a priority on the German Patent Office (GPO) applied by German inventors and which are also protected at the European

[11] Above a certain threshold, it might be the case that the gains are bigger than the losses, such that $Y_H^{e^{n2}} > Y_H^i > Y_H^{n1}$.

[12] In addition, legal contracts for *F* might render scenario 3, if *F* is a WTO member and cannot just increase restrictions on GTs. That reduces incentives for opposition in *F*. This might also stiffen opposition in *F* as it cannot easily protect its own industry.

[13] We are limited to this time span even though the data range is from 1990-2005. We drop the observations before 1992 as we assume that patenting abroad before 1992 was not related to diffusion of GTs under the SEG. Another problem is related to the huge time lag between patent application in Germany and the date when the patent is granted in a foreign country. As the dataset we use contains patent counts of patents that have already been granted in Germany and the foreign countries, after 2002 the dataset is biased. The reason for this is that there might be patents that have been applied for in foreign countries but have not been granted, so far. We therefore restrict the dataset to the observations until 2002. A summary of the data included in our dataset is provided in Appendix, page 24.

Patent Office (EPO), Japanese Patent Office (JPO) and/or the American Patent Office (APO), respectively. Therefore, we are able to consider the protection of knowledge in different markets. The patent counts we use also contain information about the dynamics of patent application over time. The number of patents issued can, therefore, also be interpreted as diffusion of innovation and expectation for future export receipts.

For the regression, we propose to use patent applications, $PATENT^{HF}$, as a dependent variable. $PATENT^{HF}$ measures patents filed to German inventors at the EPO, the JPO and the APO. As for the timing, we use the priority date which is the date of the patent application at the GPO.[14] If the patent is granted in the foreign country, protection begins with the priority date. The huge time lag that may occur by regressing patents applied in foreign countries on their priority dates is not as problematic as it seems to be at first glance. This is related to the patent cooperation treaty (PCT). Inventors, who desire patent protection in other countries, usually make use of the PCT. According to the PCT, there is only a time span of one year to name the foreign countries in which protection is desired. Note that this information is very important with respect to our assumptions about the time lags implemented in the regression analysis. For patents granted in a foreign country, the protection will go back to the application date in the home country. The rationality behind patenting abroad should be positively correlated with export expectations or the aim to sell licenses of a certain technology to the foreign country.[15]

For the study, we use a predefined list of patent classes from table 5 (Appendix, page 25) to extract the patents of the overall sample. Even though key words have been used to find out whether these groups are exactly the international patent classification (IPC) classes where the technologies of interest will be patented, it might be that patents are applied in other groups which are not captured by our list.[16]

The evidence presented at figures 5-9 (Appendix, page 22) shows that patents in the wind mill mill industry, solar industry and biomass industry have generally increased after 1998. For the other two industries, there is no observable trend. The presented figures display the development since 1990-2005. It can be seen that, especially in the case of WIND, patent counts have decreased considerably since 2002. One possible explanation lays within the huge time lag we are confronted with when looking at patent applications that have been granted in foreign countries. We, therefore, drop observations after 2002 and assume that within a three year time span most foreign patent applications are granted.

The previous arguments are now summarized to formulate our hypotheses. We use $PATENT^{HF}$ as a proxy for export expectations as described in our strategic trade policy framework. Strategic knowledge protection in foreign countries represents the first "mover advantage" from the theoretical part. We argue that feed-in tariffs in Germany are used strategically under the EEG to generate comparative advantages. $INCAP^{H}$ is, therefore, used as a proxy to test whether it is true that the strategic use of feed-in tariffs did generate positive export expectations captured by $PATENT^{HF}$. Hypothesis 1 (H1) is formulated as follows:

H1: There is a positive relationship between installed capacity of GTs in Germany $INCAP^{H}$ and international patent applications ($PATENT^{HF}$).

The second variable of the model is the installed capacity of renewable energies in the specific region $INCAP^{F}$. As an increase of $INCAP^{F}$ enhances export expectations to the foreign region it should be positively correlated with patents filed in this region in order to protect knowledge. This leads to hypothesis 2 (H2):

H2: An increase in installed capacity abroad $INCAP^{F}$ has a positive impact on international patent applications.

In addition to these two hypotheses there is the general assumption that there are significant differences with respect to region (*r*) and time (t).

H3a: There are differences between EPO, JPO and APO because the markets are different from each other.

H3b: Most dynamics take place in Europe.[17]

H3c: International patent applications caused by $INCAP^{H}$ are significantly higher under the EEG compared to the SEG.

H3a and H3b capture the spacial dimension. H3c is related to the time dimension. To test H3c, we implement time dummies for the SEG and the EEG. We suppose a significant change in coefficients as Germany started to connect industrial policy with the climate change issue under the EEG.

We now turn to the estimation of our econometric model. The core model that shall be estimated is

$$PATENT^{HF} = f(\underset{+}{INCAP^{H}}, \underset{+}{INCAP^{F}}).$$

[14]Because nearly all patent applications are first filed in the home country of the inventor (Popp; 2006, p. 52), we can look at patents with priority at the GPO applied for protection in other countries.

[15]This is somehow clear, because if H is the leader in a certain technology, the follower F cannot export to H as long as inventors in H have applied for a patent. Because patent applications are costly, it is plausible to assume that patent applications abroad go in hand with the commercial value of the invention related to the foreign marketplace.

[16]Note that the extraction of the data has been done by an algorithm able to get rid of the problem of double counting of a certain patent. Therefore, double counting cannot be considered to be a problem in our study.

[17]Europe has the highest share of renewable energies (6.9 percent) compared to the other countries of the analysis (Johnstone et al.; 2010, p. 134).

$RuD^{H}{}_{+}$, $APATENT^{F}$, $CPIE^{F}$ and ELC^{F} are added to the core model as controls.[18] The dataset is constructed on three dimensions: (1) Time *t*, (2) Technology *i* and (3) Region *r*. A simple approach would be to estimate the regression for the EPO, JPO and APO separately. In this case there would be the estimation of three different panels. For each panel the estimation would be

$$PATENT_{i,t}^{F^r} =$$
$$\beta_0 + \beta_1 RuD_{i,t-1/2}^{H} + \beta_2 INCAP_{i,t}^{H} + \beta_3 INCAP_{t-1}^{F} + \beta_4 APATENT_{t-1}^{F} + \beta_5 ELC_{t-1}^{F} + \beta_6 CPIE_{t-1}^{F} + \alpha_i + \varepsilon_{i,t}. \quad (5.1)$$

The cross-section with different technologies (*WIND*, *SOLAR*, *WATER*, *GEO*, *BIO*) is indexed by $i = 1,\ldots,5$, and $t = 1993,\ldots,2002$ represents time. For RuD^{H} and $INCAP^{H}$, as well as for $CPIE^{F}$, we implement period dummies from 1992-1999 (for the SEG) in the first period, and 2000-2002 (for the EEG) in the second period. The dependent variable is a vector with patent applications by German inventors in the other regions ($PATENT_{i,t}^{r}$), measured by the number of patents granted in *r* (at priority date). The independent variables include a vector with German technology specific public *R* & *D* expenditures ($RuD_{i,t}^{H}$), diffusion of the specific technology in Germany measured in MW ($INCAP_{i,t}^{H}$), diffusion of all green technologies (not industry specific) in region *r* ($INCAP_{t}^{F}$) and all patents filed at region *r* ($APATENT_{t}^{F}$). ELC_{t}^{F} is a vector with electricity consumption per capita in region *r* and $CPIE_{t}^{F}$ is a vector with the price index for energy. Because of collinearity of patent applications regarding *r* = *EPO*, *JPO*, *APO*, we integrate the third dimension with the same regression. In order to do so, we build region specific interaction terms. Fixed effects are integrated into the model by α_i in order to capture unobservable technology specific heterogeneity. All the residual variation is captured with the error term $\epsilon_{i,t}$.

Important for our model are the assumptions made about time lags and the implemented period dummies. Because our dataset allows for dynamic model specifications, time lags have to be implemented to be in line with economic theory.[19] As the priority date indicates the application date in Germany, we expect a one year or a two year time lag for RuD^{H}. For $INCAP^{H}$ no time lag is assumed. This assumption makes sense, as the diffusion of the technology in Germany can only take place when the technology is already developed. For $INCAP^{F}$, $APATENT^{F}$, ELC^{F} and $CPIE^{F}$ a one year time lag is assumed. We justify our assumptions on the time lags with reference to the PCT. According to the PCT, most of the patents applied at the national level extent to patent applications in foreign countries within a time frame of one year. We overcome this problem by just looking at those patents that already have been granted in Germany. This is a very pragmatic way of dealing with the problem of a time lag of four or five years between the patent application at a national patent office and the patent granting of a foreign patent office.

As proposed by Johnstone et al. (2010), we use a negative binomial regression for estimation of the model from equation 5.1 but extend the panel by the third dimension (*r*). The events we "count" are the patent applications in different international levels indicated by *r*. The estimation is done for five technologies and eleven years (1992-2002) with three regions. This leads to a sample with 180 observations.

In what follows, we take a closer look on the estimation outcomes. The results of our reference model are presented in table 1, page 16 (estimation results under assumption of a one year time lag for RuD^{H}). Under the SEG and EEG, we find support for hypothesis 1. As seen, the evidence for hypothesis 2 is mixed but rather weak. Only for JPO such evidence is found. There is no evidence that can be found for hypothesis 3a and hypothesis 3b. To test hypothesis 3c we use a Chow-test and compare $INCAP_{1992-1999}^{H}$ with $INCAP_{2000-2002}^{H}$. We find significant differences for EPO ($p = 0.0580$) and JPO ($p = 0.0713$). For APO the difference is not significant under conventional statistical terms ($p = 0.1220$). However, if we look at the coefficients, we can see that the relationship under the EEG is smaller compared to the SEG what contradicts our hypothesis. We, therefore, have to reject H3c.

[18] Compare also Popp (2001; 2002).

[19] For a more detailed discussion on time lags related to patent data compare Hall et al. (1986). Brunnermeier and Cohen (2003) also make an econometric study and make the assumption that there is no lag at all. The result from Griliches (1998) also suggests that with respect to *R* & *D* the time lag can be assumed to be rather small.

Table 1 : Fixed effects negative binomial regression

$PATENT^{HF}$	EPO	JPO	APO
$lag1RuD^{H}_{1992-1999}$	-0.0049777	-0.0033792	-0.000487
	(0.0084893)	(0.0104979)	(0.0082184)
$lag1RuD^{H}_{2000-2002}$	-0.0181687	-0.0207956	-0.0241105
	(0.0131117)	(0.0178787)	(0.0147366)
$INCAP^{H}_{1992-1999}$	0.0002195***	0.0003652***	0.0003087***
	(0.0000659)	(0.0000929)	(0.0000816)
$INCAP^{H}_{2000-2002}$	0.000108***	0.0002239***	0.0002005***
	(0.0000263)	(0.0000361)	(0.0000313)
$lagINCAP^{F}$	0.0000161	0.0008603**	-0.0000788
	(0.0000279)	(0.0005283)	(0.000058)
$lagAPATENT^{F}$	-194e-06	-0.0000594	0.0011413**
	(0.0003891)	(0.0002586)	(0.0005508)
$lagCPIE^{F}_{1992-1999}$	0.0022767	-0.0023875	0.0011234
	(0.0185545)	(0.0178013)	(0.020191)
$lagCPIE^{F}_{2000-2002}$	0.0092491	0.0009691	0.0070262
	(0.0158542)	(0.0177275)	(0.0170407)
$lagELC^{F}$	-0.0084317	-0.0087497**	0.0025994***
	(0.0054865)	(0.0040787)	(0.0008591)
β_0	32.48477		
	(28.06769)		
Wald chi2	214.33		
Nr. of observations:	165		

Significance: ***≤1%, **≤5%, *≤10%

As a robustness check we present an additional model (table 2, page 17) with a two-year time lag for public $R\&D$ expenditures. It can be observed that compared to our reference model (table 1, page 16), the results for $R\&D$ change. Under the SEG, public $R\&D$ gets significant for EPO and APO. For our main variable of interest, $INCAP^{H}$, under the SEG hypothesis 1 is only confirmed for JPO. For EPO and APO it has to be rejected. Under the EEG, $INCAP^{H}$ remains significant, confirming hypothesis 1. It can be seen that the right specification of the lag structure for public $R\&D$ is crucial for the econometric model. The comparison between the different lag structures shows that for the EEG our findings remain significant. There is a robust finding for our strategic trade hypothesis for the time frame related to the EEG.

In order to control for first order serial correlation, we show in table 7 (Appendix, page 26) a model estimated by a simple first differences ordinary least squares (OLS) model. We still get significant results for $INCAP^{H}_{2000-2002}$ in JPO and APO. This demonstrates the relatively robust finding for hypothesis 1 (table 7, Appendix, page 26). If we run a Poisson model instead of a negbin model (Table 6, Appendix, page 26) some of the results change and become significant but the overall picture remains the same.

Even though the model is sensitive to model specification, different estimations have shown that $INCAP^{H}$ is a quite robust predictor for $PATENT^{F}$ under the EEG. As the theoretical model from section 4 mainly refers to this time period, the econometric model offers important insights related to our theoretical reasoning.

VI. Conclusion

We analyze the climate change debate from a perspective of political opportunity and economic rationality. We use a strategic trade policy framework to explain the political interests behind the climate change debate. We argue that the main reason behind active support of green technologies in Germany (until Fukushima) was related to the positive export expectation for GTs. This also explains why high environmental standards are in the political

Table 2 : Fixed effects negative binomial regression

$PATENT^{HF}$	EPO	JPO	APO
$lag2RuD^{H}_{1992-1999}$	0.0124475*	0.0112177	0.0169526**
	(0.0072587)	(0.0100838)	(0.007521)
$lag2RuD^{H}_{2000-2002}$	0.007152	0.0037132	0.0048226
	(0.0107887)	(0.0160282)	(0.0126935)
$INCAP^{H}_{1992-1999}$	0.0000967	0.0002333**	0.000125
	(0.0000729)	(0.000104)	(0.0001025)
$INCAP^{H}_{2000-2002}$	0.0000872***	0.0001909***	0.0001545***
	(0.0000283)	(0.0000389)	(0.0000395)
$lagINCAP^{F}$	0.0000675	0.0035497	0.0002025
	(0.0001194)	(0.003328)	(0.0003636)
$lagAPATENT^{F}$	0.0028577	-0.001055	0.0038894
	(0.0040687)	(0.0010724)	(0.0037222)
$lagCPIE^{F}_{1992-1999}$	-0.0023775	-0.009236	-0.0082064
	(0.0250123)	(0.0233636)	(0.0258147)
$lagCPIE^{F}_{2000-2002}$	0.0649717	0.0547221	0.0583138
	(0.0790413)	(0.0794015)	(0.079379)
$lagELC^{F}$	-0.0458226	-0.0312807	0.0048331
	(0.0539446)	(0.0298639)	(0.0030676)
β_0	147.7299		
	(173.8297)		
Wald chi2	163.21		
Nr. of observations:	150		

Significance: $^{***}\leq 1\%$, $^{**}\leq 5\%$, $^{*}\leq 10\%$

interest of countries benefiting from exporting GTs. International climate change policy is complementary to export expectations for GTs. The theoretical welfare effects of one country's industrial policy, therefore, strongly depend on the policy reaction of other countries.

Different to the common view, we argue that free-riding of other countries encourages the German government to foster diffusion of GTs. The empirical evidence shows that for the time span analyzed, positive export expectations could be observed. The main driver we identify for this behavior is the installed capacity of GTs in Germany. This seems fairly plausible and can be interpreted as positive experience that helps also to stabilize international environmental agreements.

The theoretical reasoning in combination with the empirical evidence suggests that one can expect Germany producing positive GT spillovers as long as this goes in hand with job creation on the national level in combination with future exports. International experience, however, also suggests that other countries will not open their markets easily. Instead, the German policies may be replicated and other countries may subsidize their own GT industry which renders the German policy unsuccessful. For this case we should expect that Germany reduces its ideal role in international climate policies.

References Références Referencias

1. Barrett, S. (1994).Strategic environmental policy and international trade, *Journal of Public Economics* **54**: 325–338.
2. Baumol, W. and Oates, W. (1988). *The theory of environmental policy*, Cambridge Univiversity Press, Cambridge.

3. Black, D. (1948). On the rationale of group decision-making, *The Journal of Political Economy,* **56** (1): 23–34.
4. Blanco, M. I. and Rodrigues, G. (2009). Direct employment in the wind energy sector: An EU study, *Energy Policy,* **37** (8): 2847–2857.
5. BMU (2007). *Erneuerbare Energien in Zahlen: Nationale undInternationale Entwicklung*, Bundesministeriumfür Umwelt, Naturschutzund Reaktorsicherheit.<http://www.erneuerbare-energien.de/files/erneuerbare_energien/-downloads/application/pdf/broschuere_ee_zahlen.pdf>.
6. BMU (2008). *Erneuerbare Energien in Zahlen: Nationale undInternationale Entwicklung*, Bundesministeriumfür Umwelt, Naturschutzund Reaktorsicherheit.<http://www.erneuerbare-energien.de/files /erneuerbare_energien/-downloads/application/pdf/ broschuere_ee_zahlen.pdf>.
7. BMU (2011). *Erneuerbare Energien in Zahlen: Nationale undInternationale Entwicklung*. <http:// www.bmu.de/files/pdfs/allgemein/application/pdf/ broschuere_ee_zahlen_bf.pdf>.
8. BMWI (2011). *Energy Concept: For an Environmentally Sound, Reliableand Affordable Energy Supplys*. <http://www.bmwi.de/English/ Redaktion/Pdf/energy-concept, property=pdf, bereich=bmwi, sprache=en, rwb=true.pdf>.
9. Böhringer, C. and Vogt, C. (2004). The dismantling of a breakthrough: the Kyoto Protocol as symbolic policy, *European Journal of Political Economy* **20** (3): 597–617.
10. Brander, J. A. and Spencer, B. J. (1985). Export Subsidies and International Market Share Rivalry, *Journal of International Economics,* **18**: 83–100.
11. Brunnermeier, S. and Cohen, M. (2003). Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management* **45** (2): 278–293.
12. Buchholz, W., Haupt, A. and Peters, W. (2005). International Environmental Agreements and Strategic Voting, *Scandinavian Journal of Economics* **107** (1): 175–195.
13. Coase, R. H. (1960). The Problem of Social Cost, *Journal of Law and Economics,* **3**: 1–44.
14. DENA (2011). *Efficiency - our focus: Introducing the German Energy Agency.* German Energy Agency. <http://www.dena.de/fileadmin/user_upload/Downl oad/-Dokumente/dena/Imagebroschuere_ dena. pdf>.
15. Dolado, J. J., Griffiths, M. and Padilla, A. (1994). Delegation in international monetary policy games, *European Economic Review* **38**(5): 1057–1069.
16. Downs, A. (1957). *An economic theory of democracy*, Harper and Row, New York.
17. EEG (2009). *Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector and Amending Related Provisions*, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. <http://www.bmu.de/files/pdfs/ allgemein/-application/pdf/-eeg_2009_en.pdf>.
18. Freytag, A. and Wangler, L. (2011). G8 and the Move to a Globalised International Economy, *in* B. Mc Kercher (ed.), *Diplomacy and Statecraft*, Routledge, New York, pp. 338–348.
19. Griliches, Z. (1998). *R & D and Productivity: The Econometric Evidence*, University of Chicago Press.
20. Hall, B., Griliches, Z. And Hausman, J. (1986). Patents and R & D: Is There a Lag? *International Economic Review,* **27** (2): 265–283.
21. Hardin, G. (1968). The tragedy of the commons, *Science* **162** (859): 1243–1248.
22. Hillebrand, B., Buttermann, H. G., Begringer, J. M. and Bluel, M. (2005). The expansionof renewable energies and employment effects in Germany, *Energy Policy,* **34**: 3483–3494.
23. Hope, C. (2006). The marginal impact of CO2 from PAGE 2002: An integrated assessment model incorporating the IPCC's five reasons for concern, *Integrated Assessment,* **6**(1): 19–56.
24. Johnstone, N., Hascic, I. and Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts, *Environmental and Resource Economics* **45** (1): 133–155.
25. Kemfert, C. (2005). Weltweiter Klimaschutz - Sofortiges Handeln spart hohe Kosten, *DIW-Wochenbericht,* **72. Jahrgang** (12-13): 209–215.
26. Kempf, H. and Rossignol, S. (2010). National Politics and International Agreements, *Post-print and working papers,*, Université Paris1 Panthéon-Sorbonne.
27. Kyoto Protocol (1998). *Kyoto Protocol to the United Nations Framework Convention in Climate Change*, United Nations. <http://unfccc.int/-resource/docs/conv-kp/kpeng.pdf>.
28. Latif, M. (2010). Die Herausforderung globaler Klimaw-andel, *Perspektiven der Wirtschaftspolitik* **11**(s1): 4–12.
29. Lehr, U., Nitsch, J., Kratzat, M., Lutz, C. and Edler, D. (2008). Renewable energy and employment in Germany, *Energy Policy,* **36** (1): 108–117.
30. Lomborg, B. (2006). *The skeptical environmentalist: measuring the real state of the world*, Cambridge University Press, Cambridge, New York.
31. Lund, P. (2009). Effects of energy policies on industry expansion in renewable energy, *Renewable Energy,* **34** (1): 53–64.
32. Macintosh, A. (2010). Keeping warming within the 2°C limit after Copenhagen, *Energy Policy* **38** (6): 2964–2975.
33. Madsen, E. S., Jensen, C. and Hansen, J. D. (2005). Scale in technology and learning-by-doing in the windmill industry, *Journal for International Business and Entrepreneurship Development (JIBED),* **1**(2): 27–35.

34. Mendelsohn, R., Morrison, W., Schlesinger, M. and Andronova, N. (2000). Country- specific market impacts of climate change, *Climatic Change,* **45** (3): 553–569.
35. Nemet, G. (2006). Beyond the learning curve: factors influencing cost reductions in photovoltaics, *Energy Policy,* **34**: 3218–3232.
36. Nicoll, A., Delaney, J. and Strategic, R. (2010). Copenhagen Accord faces first test, *Strategic Comments* **16** (1): 1–3.
37. Nordhaus, W. and Boyer, J. (2003). *Warming the world: economic models of global warming*, MIT Press, Cambridge.
38. Nordhaus, W. and Yang, Z. (1996). A regional dynamic general-equilibrium model of alternative climate-change strategies, *The American Economic Review,* **86**(4): 741–765.
39. Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*, Cambridge University Press, Cambridge.
40. Persson, T. and Tabellini, G. (1992). The Politics of 1992: Fiscal Policy and European Integration, *The Review of Economic Studies* **59** (4): 689–701.
41. Persson, T. and Tabellini, G. (2000). *Political economics*, MIT press. Popp, D. (2001). The Effect of New Technology on Energy Consumption, *Resource and Energy Economics,* **23**(4): 215–239.
42. Popp, D. (2002). Induced Innovation and Energy Prices, *American Economic Review,* **92**(1): 160–180.
43. Popp, D. (2005). Using the Triadic Patent Family Database to Study EnvironmentalInnovation, *Environment Directorate Working Paper ENV/EPOC/WPNEP/RD (2005)2*, OECD, France, Paris.
44. Popp, D. (2006). International innovation and diffusion of air pollution control technologies: The effects of *NOX* and *SO*2 regulation in the US, Japan, and Germany, *Journal of Environmental Economics and Management* **51**(1): 46–71.
45. Rasmusen, E. B., Petrakis, E. and Roy, S. (1997). The Learning Curve in a CompetitiveIndustry, *The RAND Journal of Economics,* **28**: 248–268.
46. Rege, M. (2000). Strategic Policy and Environmental Quality: Helping the Domestic Industry to Provide Credible Information, *Environmental and Resource Economics,* **15** (3): 279–296.
47. Roelfsema, H. (2007). Strategic delegation of environmental policy making, *Journal of Environmental Economics and Management* **53** (2): 270–275.
48. Schumpeter, J. (1987b). *Kapitalismus, Sozialismus und Demokratie*, Francke, Tübingen. Segendorff, B. (1998). Delegation and Threat in Bargaining, *Games and Economic Behavior* **23** (2): 266–283.
49. Sinn, H. (2008). Public policies against global warming: a supply side approach, *International Tax and Public Finance* **15** (4): 360–394.
50. Stern, N. (2007). *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, New York.
51. Tol, R. (2002). Estimates of the damage costs of climate change, Part II. Dynamic estimates, *Environmental and Resource Economics* **21**(2): 135-160.
52. Ulph, A. (1996). Environmental Policy and International Trade when Governments and Producers Act Strategically, *Journal of Environmental Economics and Management,* **30** (3): 265–281.
53. Ulph, A. and Ulph, D. (1997). Global Warming, Irreversibility and Learning, *The Economic Journal,* **107**(442): 636–650.
54. Ulph, A. and Ulph, D. (2007). Climate change- environmental and technology policies in a strategic context, *Environmental and Resource Economics,* **37**(1): 159–180.
55. Weidner, H. and Mez, L. (2008). German climate change policy, *The Journal of Environment & Development* **17** (4): 356–378.

Appendix

a) Symbols, Figures and Tables

Abbreviations

APO	American Patent Office
BMU	German Ministry of Environment
CO_2	Carbone Dioxide
EEG	Renewable Energy Source Act
EPO	European Patent Office
FDI	Foreign Direct Investment
FIT	Feed-in Tariff
GDP	Gross Domestic Product
GHG	Green House Gas
GPO	German Patent Office
GT	Green Technologies
IEA	International Energy Agency
IPC	International Patent Classification
IPCC	Intergovernmental Panel on Climate Change
JPO	Japanese Patent Office
KP	Kyoto Protocol
NO_2	Nitrogen Dioxide
PCT	Patent Cooperation Treaty
R&D	Research and Development
SEG	Electricity Feed Law
SO_x	Sulfur Dioxide

Symbols Math

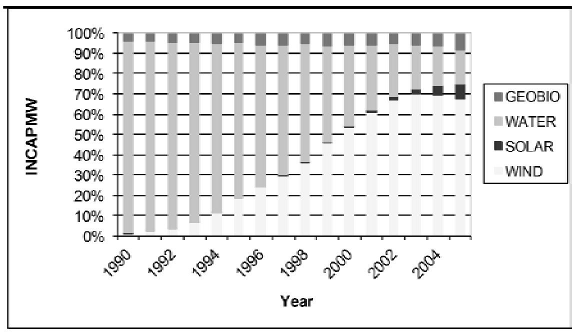
π^e	Export Expectations
A^e	Expected Market Size
c_{l_j}	Costs of Lobbying
c^{pr}	Marginal Production Costs
D_N	Demand for GT *j* without pid_j
D_S	Demand for GT *j* with pid_j
F	Foreign country
GT_j	Green Technology Index $j = 1,\ldots,n$
H	Home-country
p	Price
pid_j	Policy Induced Demand
q^e	Expected Quantity Exported
r	Region
t	Time
Y	GDP
j	Different GT Industries

Symbols Econometrics

$PATENT^{HF}$	Patent Applications (Dependent Variable)
RuD^H	Research and Development (Home Country)
$INCAP^H$	Installed Capacity of Industry Specific Technology (Home Country)

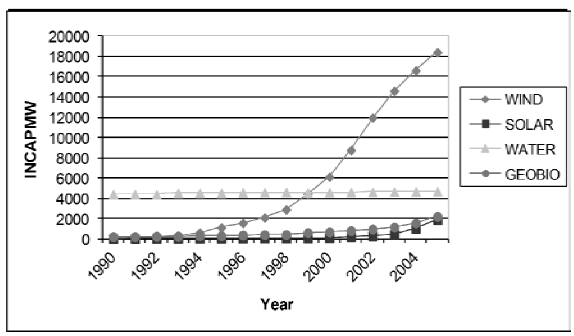
$CPIE^F$	Index for Energy Prices (Foreign Country)
ELC^F	Electricity Consumption (Foreign Country)
$INCAP^F$	Installed Capacity of Industry Specific Technology (Foreign Country)
$APATENT^F$	All Patent Applications (Foreign Country)

Figure 3 : Diffusion of GTs as percentage of total capacity of all GTs measured in MW



Source: Own illustration, data source BMU (2008).

Figure 4 : Diffusion of GTs measured in MW of all GTs installed



Source: Own illustration, data source BMU (2008).

Table 3 : Remuneration (FIT) for different GTs in 2003

Technology j	Remuneration (2000-2003) (ct/KWh)	Annual Reduction (d)
Wind (WIND)	9.1	1.4%
Solar (SOLAR)		
Capacity<100KW	51.62	5.0%
Plants on building capacity <5 MW	48, 1	5.0%
Biomass (BIO)		
Capacity<500KW	10.0	1.0%
Capacity>500KW<5MW	9.0	1.0%
Capacity>5MW<20MW	8.5	1.0%
Hydro (WATER)		
Capacity<500KW	7.67	0%
Capacity>500KW<5MW	6.5	0%
Landfill and sewage gas (BIOGAS)		
Capacity<500KW	7.67	1.5%
Capacity>500KW<5MW	6.5	1.5%
Geothermal plants (GEO)		
Capacity<20MW	8.5	0%
Capacity>20MW	7.0	0%

Figure 5 : Patent applications in WIND

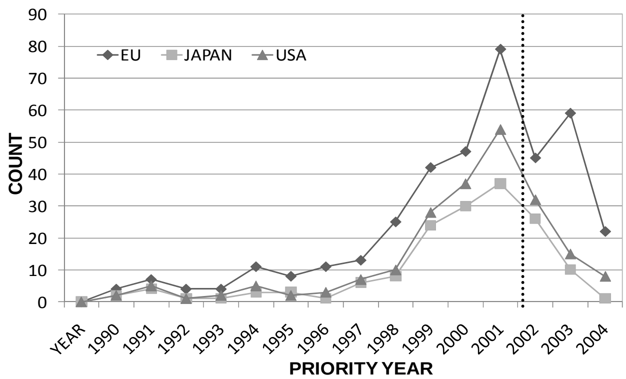


Figure 6 : Patent applications in SOLAR

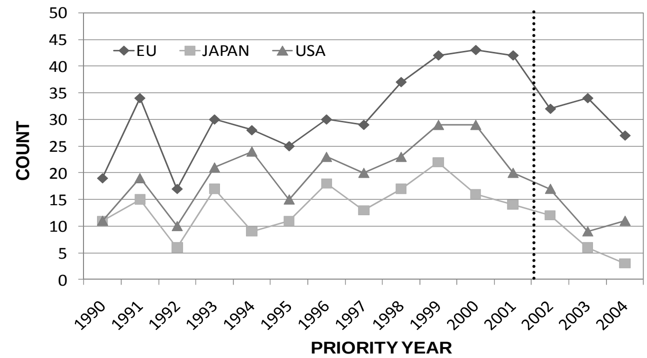


Figure 7 : Patent applications in BIO

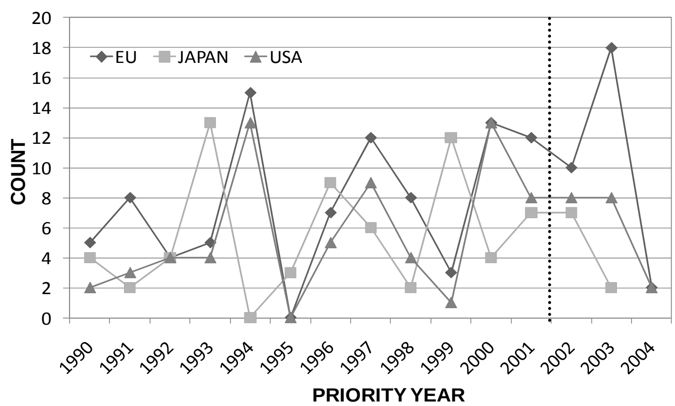


Figure 8 : Patent applications in GEO

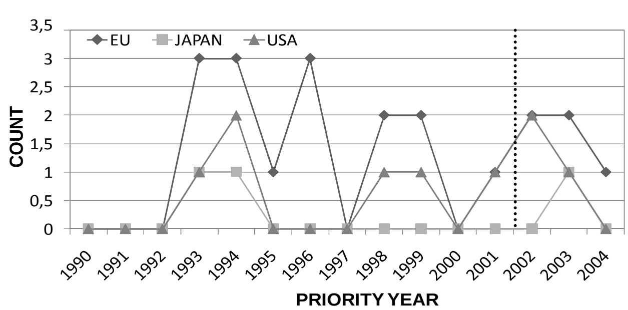
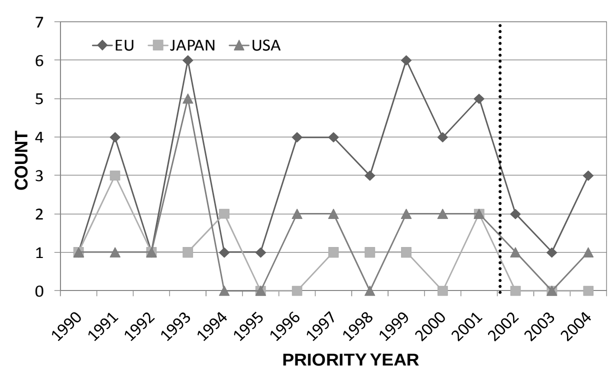


Figure 9 : Patent applications in WATER



Source figure 5-9: EPO, compare App. C, p. 24.

b) *Theoretical Framework*

i. *Different Scenarios in Subsection 4.2*

Table 4 : Scenarios 3-5

	Description		Expectations
Scenario 3	F decides to support firms located in F directly to produce GTs	Case (3a): $$\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^H_{pr_j}) - c_{l_j} \leq 0.$$ No additional exports.	Case (3a): The first mover advantage does not lead to exports.
		Case (3b): $$\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^H_{pr_j}) - c_{l_j} > 0.$$ If the GT industry is so competitive that it was already exporting GTs to F without any subsidies $\rightarrow$ In this case it can continue to export, if it is still able to compete with the GT industries$_j$ located in F.	Case (3b): Decreasing exports of GTs compared to the case without local content clause.
Scenario 4	H competes with the GT industry located in another country (country I) in a "third" market in F. In this case F is not able to produce GTs but is forced to buy them (e. g. because of high international environmental standards).	Case (4) There is competition between H and I. The underlying game depends on which cost curve H and I are operating. They can play Stackelberg, or if they have the same marginal costs, the market has the characteristic of a duopoly with simultaneous market entrance.	Case (4) Increase in market size $\rightarrow$ export of GTs.
Scenario 5	There is also the possibility that a firm located in H is making a direct contract with politicians in L	Case (5a): $$\pi^e_{H_j} = \hat{q}^e_{H_j}\hat{p}_j - c^H_{pr_j}\hat{q}^e_{H_j} - c_{l_j} > 0.$$ $\hat{q}_{H_j}$ stands for "agreed quantity of GTs" which the GT industries j located in H can sell at the agreed price $\hat{p}_j$.	Case (5a) F buys the technology from the GT industries$_j$ located in H. In this case the GT industry would sell a package of GTs to $F \rightarrow$ Increase in market size $\rightarrow$ export of GTs.
		Case (5b): $$\pi^e_{H_j} = \hat{q}^e_{H_j}\hat{p}_j - c^H_{pr_j}\hat{q}^e_{H_j} - c_{l_j} - ttr > 0.$$ ttr stands for "technology transfer".	Case (5b): The contract is combined with a local content clause $\rightarrow$ Increase in market size $\rightarrow$ export of GTs, but less compared to scenario (a).

ii. *Stackelberg Game*

In our framework, the GT industry j in H benefits from pid_{F_j} and enters the foreign market as a Stackelberg leader. The Stackelberg game can be solved as follows: the GT industry in H and F are assumed to maximize profits. For F the profit function is given by equation 4.1.

The profit maximization problem leads to

$$\frac{\partial \pi^e_{F_j}}{\partial q^e_{F_j}} = A^e - q^e_{H_j} - 2q^e_{F_j} - c^{pr}_{F_j} + pid^e_{F_j} = 0$$

$$q_{F_j} = R_F\left(q_{H_j}\right) = \frac{A - q_{H_j} - c^{pr}_{F_j} - pid_{F_j}}{2}. \quad \text{(B.1)}$$

$R_F\left(q^e_{H_j}\right)$ represents the response function for F. H maximizes its expected profits with respect to $q^e_{H_j}$ by taking equation B.1 into account. It follows

$$\frac{\partial \pi^e_{H_j}}{\partial q^e_{H_j}} = A^e - 2q^e_{H_j} - \frac{1}{2}A^e + q^e_{H_j} + \frac{1}{2}c^{pr}_{F_j} - \frac{1}{2}pid^e_{F_j} - c^{pr}_{H_j} + pid^e_{F_j}$$

$$q^{e*}_{H_j} = \frac{A^e + c^{pr}_{F_j} - 2c^{pr}_{H_j} + pid^e_{F_j}}{2} \quad \text{(B.2)}$$

Finally, we can solve the maximization problem for the industry j in F. The solution for F is given by

$$q_{F_j}^{e*} = \frac{A^e - c_{F_j}^{pr} + pid_{F_j}^e}{4}. \quad \text{(B.3)}$$

If we substitute the values for $q_{F_j}^{e*}$ and $q_{H_j}^{e*}$ into the equation 4.1, we obtain

$$\pi_{H_j}^e = \left[\frac{A^e + 3\left(c_{H_j}^{pr} - pid_{F_j}^e\right)}{4} - c_{H_j}^{pr} + pid_{F_j}^e\right]\left[\frac{A^e - c_{H_j}^{pr} + pid_{F_j}^e}{2}\right] - c_{l_j}$$

$$\pi_{H_j}^e = \frac{1}{8}\left(A^e - c_{H_j}^{pr} + pid_{F_j}^e\right)^2 - c_{l_j}. \quad \text{(B.4)}$$

The expected contribution to the national GDP oh H through exports of GTs is simply denoted as Y_H^e. This leads to

$$y_H^e = \pi_{H_j}^e = \frac{1}{8}\left(A^e - c_{H_j}^{pr} + pid_{F_j}^e\right)^2 - c_{l_j}. \quad \text{(B.5)}$$

In contrast to the costs which go in hand with policy induced demand for GTs at the national level, y_H^e enters positively into the GDP of H.[20]

c) Econometric Model

i. Empirical Data

Patents ($PATENT^{HF}$), source EPO: Table 5 on page 25 contains the list of patent classes from which the dataset is extracted. The "renewable energy industry specific technologies" of interest are for electricity production with wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO) and biomass (BIO). The original table on patent classes comes from Johnstone et al. (2010).[21] The dataset contains patents which are *granted* in at the EPO, JPO and APO with priority in Germany (including the "Neue Bundes länder").[22] The dataset includes patents and utility patents. The data we use comes from a freely available dataset of the European Patent (DOC- DB).[23] Information captured with $PATENT^{HF}$, therefore, is industry specific (WIND, SOLAR, WATER, GEO, BIO) and country/territory specific (EP, JPO and APO).

Patent counts about patents applied in region r ($APATENT^F$), source OECD: The variable $APATENT^F$ contains information about the overall number of patents applied in the specific territory (EPO, JPO, APO). This variable captures all patents applied for at the EPO, JPO and APO with the inventor's country of residence and fractional counts. The patent counts are based on the earliest priority date. The data mainly derives from EPO Worldwide Statistical Patent Database (April 2007).[24] Information captured with $APATENT^F$ is country/territory specific (EP, JPO and APO).

German R&D expenditures (RuD^H), source IEA: The data about industry specific expenditures concerning public expenditures on research and development related to R & D in the different G T industries comes from the international energy agency.[25] The data for Germany is in million Euro on exchange rates from 2006.[26] Information captured with RuD^H is at the German level and industry specific (WIND, SOLAR, WATER, GEO, BIO).

German installed capacity of industry specific technology $INCAP^H$, source BUND: $INCAP^H$ is used as a proxy for the induced demand implemented by institutional changes because of laws such as the EEG. The data contains information about the installed capacity measured in megawatt-hours (MWh). It measures the overall installed capacity of the industry specific technology per year. The data comes from the Ministry of Environment.[27] Information captured with $INCAP^H$ is at the German level and industry specific(WIND, SOLAR, WATER, GEO, BIO).

Energy price index ($CPIE^F$), electricity consumption (ELC^F) and installed capacity of renewable energies in the foreign country ($INCAP^F$), source IEA: $CPIE^F$ is a consumer price index for energy. $CPIE^F$ is country specific. Year 2000 is set to 100, taxes are included in the calculation. ELC^F measures the electricity consumption in KWh per capita. ELC^F is country specific. $INCAP^F$ measures the overall installed capacity of renewable energies in the foreign country. Information captured with $CPIE^F$, ELC^F and $INCAP^F$ is country/ territory specific (EP, JPO and APO).

---

[20] This is true as long as $A^e + pid_{F_j}^e > c_{H_j}^{pr}$ and $c_{l_j} < (A^e - c_{H_j}^{pr} + pid_{F_j}^e)^2$.

[21] Note that the list is extended in the case of patent classes for WATER, because the law for renewable energy which is analyzed for Germany also changed the institutional framework for energy produced with water. On the other hand, we excluded WASTE, because we focus on GTs and therefore, WASTE is not really considered as a renewable energy source.

[22] Note that the date for the patents that are granted goes back to the date when inventors applied for the patent. Even though information about patents until 2006 is available, the analysis is restricted from 1992 to 2002. The information about the last three years is dropped to get rid of the problem that granted patents always go back to the priority date. Therefore, it is plausible to assume that the data from 2004 and 2006 contains a lack of information (Popp;2005, p. 5).

[23] For further information see http://www.epo.org/patents/patent-information/free.html.

[24] For more detailed information see Organization for Economic Co-Operation and Development (OECD), Patent Database, June 2007.

[25] For further information see http://www.iea.org/.

[26] The data for Germany at the national level does not contain information about the expenditures of regional governments.

[27] Compare BMU (2007).

Table 5 : IPC codes for Renewable Energy Technologies*

WIND	Class	Sub-Classes
Wind motors with rotation axis substantially in wind direction	F03D	1/00-06
Wind motors with rotation axis substantially at right angle to wind direction	F03D	3/00-06
Other wind motors	F03D	5/00-06
Controlling wind motors	F03D	7/00-06
Adaptations of wind motors for special use	F03D	9/00-02
Details, component parts, or accessories not provided for in, or of interest apart from, the other groups of this subclass	F03D	11/00-04
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L	8/00
Effecting propulsion by wind motors driving water-engaging propulsive elements	B63H	13/00
SOLAR		
Devices for producing mechanical power from solar energy	F03G	6/00-08
Use of solar heat, e.g. solar heat collectors	F24J	2/00-54
Machine plant or systems using particular sources of energy - sun	F25B	27/00B
Drying solid materials or objects by processes involving the application of heat by radiation -e.g. sun	F26B	3/28
Semiconductor devices sensitive to infra-red radiation - including a panel or array of photoelectric cells, e.g. solar cells	H01L	31/042
Generators in which light radiation is directly converted into electrical energy	H02N	6/00
Aspects of roofing for the collection of energy - i.e. solar panels	E04D	13/18
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L	8/00
WATER/OCEAN		
Engines of impulse type, i.e. turbines with jets of high-velocity liquid impinging on bladed or like rotors, e.g. Pelton wheels	F03B	1/00-04
Machines or engines of reaction type; Parts or details peculiar thereto	F03B	3/00-18
Water wheels	F03B	7/00
Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus	F03B	13/00-10
Controlling	F03B	15/00-22
Adaptations of machines or engines for special use - characterized by using wave or tide energy	F03B	13/12-24
Mechanical-power producing mechanisms - ocean thermal energy conversion	F03G	7/05
Mechanical-power producing mechanisms - using pressure differentials or thermal differences	F03G	7/04
Water wheels	F03B	7/00
GEOTHERMAL		
Other production or use of heat, not derived from combustion – using natural or geothermal heat	F24J	3/00-08
Devices for producing mechanical power from geothermal energy	F03G	4/00-06
Electric motors using thermal effects	H02N	10/00
BIOMASS		
Solid fuels based on materials of non-mineral origin - animal or vegetable	C10L	5/42-44
Engines operating on gaseous fuels from solid fuel - e.g. wood	F02B	43/08
Liquid carbonaceous fuels - organic compounds	C10L	1/14
Anion exchange - use of materials, cellulose or wood	B01J	41/16

*From the original table WASTE has been excluded and WATER has been added.

Own presentation, oriented on Johnstone et al. (2010)

ii. *Alternative Estimations*

In table 6, we use a fixed effects Poisson-model which more or less replicates our results (table 1, page 16). Using a first differences model (OLS) as shown in table 7, still shows significant results for $INCAP^{H}_{2000-2002}$ in JPO and APO.

Table 6 : Fixed effects Poisson regression

$PATENT^{HF}$	EPO	JPO	APO
$lagRuD^{H}_{1992-1999}$	−0.003891	−0.0053209	−0.0027717
	(0.0050035)	(0.0070105)	(0.0059082)
$lagRuD^{H}_{2000-2002}$	−0.0218788***	−0.0205298*	−0.0242853**
	(0.0076388)	(0.0113637)	(0.0096594)
$INCAP^{H}_{1992-1999}$	0.0001682***	0.0003202***	0.0002738***
	(0.0000476)	(0.000074)	(0.0000645)
$INCAP^{H}_{2000-2002}$	0.0000832***	0.0002117***	0.0001901***
	(0.0000172)	(0.0000279)	(0.0000242)
$lagINCAP^{F}$	4.78e−06	0.0005027*	−0.000037
	(0.0000164)	(0.0003115)	(0.0000375)
$lagAPATENT^{F}$	−0.0001206	−0.0001457	0.0007427**
	(0.000266)	(0.000173)	(0.000334)
$lagCPIE^{F}_{1992-1999}$	0.0190602	−0.003186	−0.0009674
	(0.025742)	(0.0246747)	(0.0269702)
$lagCPIE^{F}_{2000-2002}$	0.023799	−0.0020967	0.0032361
	(0.02162)	(0.0249417)	(0.0220473)
$lagELC^{F}$	−0.0035969	−0.0058992**	0.0023531***
	(0.003572)	(0.0024022)	(0.0005705)
Wald chi2	411.06		
Nr. of observations:	165		

Significance: *** ≤ 1%, **≤ 5%, * ≤ 10%

Table 7 : OLS fixed effects first differences model

$PATENT^{HF}$	EPO	JPO	APO
$lag1RuD^{H}_{1992-1999}$	−0.2735567	−0.0252574	−0.053742
	(0.1733541)	(0.0849316)	(0.1719576)
$lag1RuD^{H}_{2000-2002}$	−0.2446132	−0.0247744	−0.1965391
	(0.2085309)	(0.1635901)	(0.2077007)
$INCAP^{H}_{1992-1999}$	0.0001368	0.0021967	0.0017532
	(0.0013486)	(0.0013473)	(0.0013839)
$INCAP^{H}_{2000-2002}$	−0.0007135	0.0012767**	0.0013259**
	(0.0005851)	(0.0005684)	(0.0013259)
$lagINCAP^{F}$	0.0009494	0.0024222	0.0013545
	(0.0106794)	(0.0238106)	(0.0095546)
$lagAPATENT^{F}$	0.0060522	−0.0036444	0.0060825
	(0.0559459)	(0.0571749)	(0.0470171)
$lagCPIE^{F}_{1992-1999}$	−0.538605	0.0867416	−0.0706172
	(10.112697)	(0.7568268)	(0.5441484)
$lagCPIE^{F}_{2000-2002}$	−0.3647433	0.1282116	0.0190248
	(10.356288)	(10.207714)	(0.8598966)
$lagELC^{F}$	0.0091146	−0.0480379	0.0228105
	(0.0829318)	(0.2854876)	(0.1428906)
β_0	−8.647436		
	(88.44358)		
R-sq:	0.3082		
F(27,108)	1.89		
Nr. of observations:	150		

Significance: *** ≤ 1%, **≤ 5%, * ≤ 10