JENA ECONOMIC RESEARCH PAPERS

2010 – 002

Renewables and Innovation
Empirical Assessment and Theoretical Considerations

by

Leo Wangler

www.jenecon.de

ISSN 1864-7057

The JENA ECONOMIC RESEARCH PAPERS is a joint publication of the Friedrich Schiller University and the Max Planck Institute of Economics, Jena, Germany. For editorial correspondence please contact markus.pasche@uni-jena.de.

Impressum:

Friedrich Schiller University Jena
Carl-Zeiss-Str. 3
D-07743 Jena
www.uni-jena.de

Max Planck Institute of Economics
Kahlaische Str. 10
D-07745 Jena
www.econ.mpg.de

Renewables and Innovation

Empirical Assessment and Theoretical Considerations

JEL: L52, O31, O32, Q01, Q5.

Key Words: Renewable Energies, Demand Pull, Structural Change.

Leo Wangler*

E-Mail: Leo.Wangler@uni-jena.de

January 18, 2010

Abstract

This study is about structural change in the energy system. In a first step an econometric model is presented and in a second step diffusion of GTs is embedded theoretically. By focusing on different green technology industries (GT sector) in Germany, we analyze how policy induced demand stimulates innovation. Taking the size of the market as a proxy for demand and patent counts as a proxy for innovation, we find support that the presence of institutions enabling diffusion of GTs are correlated with innovative activity. Public R&D expenditures also play a significant role. We additionally control for a structural break by comparing the two institutional settings incorporated into the legal system in Germany, namely the Stromeinspeisegesetz (SEG) and the Erneuerbare Energiengesetz (EEG). We cannot find support for the supposition that innovative activity significantly differs for diffusion under the SEG and EEG. The empirical findings also show that electricity prices are not the driving force for innovative activity within the GT sector. The discussion at the end of the paper comes to the result that diffusion of GTs – under the EEG – is difficult to be justified theoretically.

*I gratefully acknowledge helpful comments by Andreas Freytag, Frenken Koen, Guido Buenstorf, Jan Nill and Marco Guerzoni. I thank Christina Klose, Sarah Al Doyaili, Lutz Märker and Nils Laub for research assistance.

1 Introduction

Structural change of the energy system is part of the political agenda. The German "Federal Ministry for the Environment, Nature Conservation and Nuclear Safety" (BMU) treats renewable energy technologies as kind of "key technologies" for future energy supply. In Germany the share of renewable energies on total energy production has increased steadily during the last twenty years. From 1998 until 2008, the share of renewable energies on total *electricity* production increased from 4.8 percent to 15.1 percent. In 2008 the share of GTs on total *energy* production was 9.5 percent. The distinction between GTs shows that there are differences among the renewables available. Electricity produced with water (in 2008) had a share of 23.0 percent of all electricity produced with GTs, the share of wind was 43.5 percent, solar had a share of 4.3 percent and biomass accounted for about 22.1 percent (BMU 2008, p. 15).

Even though there has been a remarkable growth in the GT sector during the last ten years, GTs in Germany cannot be treated as adequate substitutes for conventional energy technologies up to now. Most GTs are still operating within a "niche". The following example shall make this point clearer. After the decision about the nuclear phase-out (in the year 2000) electricity producing companies are still heavily dependent on other non-renewable energy sources like COAL or GAS (IEA 2007, p. 120). This is not surprising as transition from non-renewable energy technologies to a system mainly based on renewable energy technologies needs time. So far there is still uncertainty about the point in time for this achievement. Innovations play a highly relevant role for the possibility of transition, its speed and the related costs.

Diffusion of GTs, upon a certain level, depends crucially on the institutional setting. The relatively high production costs for energy produced with GTs as well as monopolistic market structures made it difficult for GTs to diffuse without governmental support. For the first time market entrance became possible under the SEG (implemented in January 1991). Investment into GTs became economically highly attractive under the EEG (implemented in April 2000).[1] Demand is artificial due to the fact that there exist technologies able to

[1] For the different feed-in tariffs under the EEG compare table 12, page 40.

produce the same outcome (namely electricity) "much cheaper". The institutional setting has been designed in a way that electricity produced with GTs can be sold on the market (under the EEG for a guaranteed remuneration).

The managed transition in the energy sector allows to test a theory that has become known in the literature as the so called "Schmookler hypothesis" (Schmookler 1962, 1963): Higher demand (here proxied with the *change* of installed capacity in GTs) has a positive impact on firms being engaged in innovative activities (here proxied with patent counts). The econometric analysis of this paper contributes to the recent literature by looking at four important questions. First, we try to answer the question whether the policy induced demand for GTs was accompanied by innovative activity. This seems to be trivial but there is no reason to take this relationship for granted as diffusion of GTs does not follow natural selection processes of the markets as demand has been created artificially. The next question we try to answer is the impact of public R&D expenditures on innovations. Our third question is related to the impact of electricity prices on innovative activity in the different GT industries. We also take the institutional change under the SEG and the EEG into account and test for a structural break.

In order to embed the econometric model, we proceed by discussing efficiency on the ground of a policy-induced diffusion of GTs. The focus is on two major problems: *externalities* and *non-sustainability*. We come to the result that the externality problem has to be taken into consideration whereas the problem of non-sustainability in the energy sector is a less striking argument for justification of institutions that push demand for GTs artificially. However, because of the fact that the externality problem is still one characteristic related to conventional energy-technologies, monetary transfers directed to GTs (up to a certain level) are needed in order to moderate the distortions in competition.

The paper is structured as follows: In section 2 we analyze studies about the relationship between demand and innovation as well as technological lock-in. We further review institutional change in the German energy sector by studying differences between the SEG and EEG. We use the results as background to formulate the hypothesis for our econometric model. Description of the data, variables, econometric model and estimation results follow in section 3. Section 4 makes a critical assessment of the structural change in the energy system in Germany. Economic theory is applied in order to find arguments in favor for investment into GTs. In section 5 we draw a conclusion.

2 Theoretical Background and Hypothesis

Innovations and the role of demand

One reason for studying innovations is related to the importance they have on endogenous growth and economic development (Schumpeter 1934). Firms (and entrepreneurs) may seek profit and get motivated to innovate or imitate with the aim to continuously increase profits. Economic actors therefore search for better techniques and the selection of successful innovations takes place through the market. The dynamics behind this process are best described with the notion of *creative destruction* (Schumpeter 1942).

From an economic perspective it is in the core of interest to detect the driving forces behind innovations. For many years there was an ongoing debate on the question whether demand drives innovation or if it is the other way around. The importance of demand on innovation is closely connected to the research done by Schmookler and Griliches. However, the argument as such can be traced back to Hicks. He made the observation that "a change in the *relative prices* of factors of production is itself a spur to innovations and to inventions of a particular kind – directed at economizing the use of a factor which has become relatively expensive" (Hicks 1932, pp. 124). The relationship between demand, the timing and the location of an invention, was studied by Griliches (1957). Schmookler focused on the causality between demand and innovation. He stated that "new goods and new techniques are unlikely to appear, and to enter the life of society without pre-existing – albeit possibly only latent – demand" (Schmookler 1962, p. 1).

According to this reasoning, demand is the main driver to stimulate inventive activities. Schmookler used patent statistics to study four different industries (railroads, agricultural equipment, paper and petroleum). He found a linear relationship between demand and investment into capital goods in the particular sectors. His line of argument can be summarized as follows: Market actors have incentives to innovate as long as improvements in production technique or product quality bear the chance to achieve a higher mark-up per unit. The more units are sold on the market, the higher the profits that can be earned. There are more incentives for economic activities, measured as an invention, the bigger the size of the market.[2]

The theoretical argument put forward by Schmookler has been debated for a long time.[3] Early critique on a purely demand side approach comes from Salter (1960). Further critique builds on research done by Rosenberg (1974), Mowery and Rosenberg (1979).[4] Scherer (1982), re-run Schmookler's analysis and found much weaker evidence for the underlying demand hypothesis. The result can be explained by the fact that Scherer used a broader dataset and included several types of industries. Firms with market power are able to use their strategic advantage to increase market shares. In contestable markets market power can encourage firms to innovate and to create demand endogenously. This makes the simple demand story more complicated. The significance of the results is further depending on technological opportunities of the underlying industries. Kleinknecht and Verspagen (1990) have shown that Schmookler's dataset contains reverse causality problems. There is the important implicit result that even though it is true that at a given point in time t the size of the market S has an impact on the probability to innovate P ($P_t : S_t \rightarrow P_t(S_t)$), there is the endogenous effect that innovation is able to increase the size of the market by itself ($S_t : P_t \rightarrow S_t(P_t)$). Demand and supply both have to be relevant (Pavitt 1984).

However, beside the fact that the underlying relationship is more difficult than initially intended, the intuition of Schmooklers reasoning, that demand positively effects innovations, is not falsified (Fontana and Guerzoni 2008, p. 930). There are further empirical studies on the sectoral level that support Schmookler's argument. For instance Lichtenberg and Waldfogel (2003)

[2]For a simple formal description compare Fontana and Guerzoni (2008).

[3]For a survey about the discussion on demand-pull and supply-push see Freeman (1994) among others.

[4]Rosenberg (1974), p. 105, states that: "[..] technical problems and their relative complexity stand independently of demand considerations as an explanation of the timing and direction of inventive activity. Therefore any analytical or empirical study which does not explicitly focus upon both demand and supply side variables is seriously deficient".

study the problem of a lack of innovation incentives in pharmaceuticals when the disease predominantly occurs in countries with relatively low average incomes per capita (so called neglected diseases). A similar study about innovation incentives in pharmaceuticals comes from Glennerster et al. (2006). Popp (2002) is able to show that energy prices have an impact on innovations in energy saving technologies. Further studies are based on the demand side approach but are more sophisticated in their research question as they distinguish between product and process innovations and do also cope with the dynamics of the economic system (Cohen and Klepper 1992, 1996a,b, Klepper 1996, Klepper and Thompson 2006).[5]

The lesson that can be drawn from the previous discussion is that there is a problem of generalization. The underlying relationship only lasts under the special circumstances that (*i*) market shares and/or total market expenditures are unaffected by innovations and (*ii*) fixed costs of innovations have to be spread uniformly among innovating firms. The previous arguments build the background to formulate the first hypothesis which is the so called Schmookler hypothesis.

Hypothesis 1: Increase in market size (S) positively affects firms within a GT industry j to be engaged in innovative activities.

Technological lock-in and the energy system?

As stated at the beginning of this section in markets characterized through self-selection and creative destruction, a direct link between innovations and growth can be drawn (Schumpeter 1934, 1942). However, self-selection processes of markets can be accompanied by suboptimal results (market failure). Especially in markets characterized through learning curves and/or economies of scale[6] there is the possibility that the economic system locks-in into a technology that can be considered to be suboptimal *ex ante*. This problem was high-

[5] It is one of the shortcomings of our study that we are not able to distinguish process from product innovations. However, as we are convinced that both types of innovations are important, we think that our study is still interesting.

[6] Adaptive expectations and network externalities are additional reasons able to create a technological lock-in (Arthur 1994).

lighted by David (1985) and further developed analytically by Arthur (1989, 1994).[7] Technological lock-in is often used as an argument for state intervention. However, there are situations in which, even though there is a temporary lock-in to a suboptimal technology, lock-out can evolve spontaneously (Witt 1989, 1997).

Arthur (1989) distinguishes in his first example between two technologies (A and B) competing on the market for adoption. The early market entrance of a certain technology (A) can make it difficult or even impossible for a competing technology (B) to "get started", as there is technological lock-in (Arthur 1989, p. 119).[8] We propose to treat A as a vector with conventional non-renewable energy technologies (e. g. NUCLEAR power plants or COAL power plants regime) and B as a vector of GTs (e. g. SOLAR, WIND, WATER, GEO and BIO).[9]

The energy system differs from the lock-in described above with respect to its market structure. As the energy sector is highly regulated, development of A and B strongly depend on political decisions. A and B can be treated to be policy induced technological systems that were not exposed to the self-selection process of the market (compare Unruh (2000), p. 826). Following the logic of technological lock-in, it seems plausible that if A is the dominant technological regime, B is very limited with respect to innovations and diffusion (Unruh 2000).[10]

One could argue that in case of the energy system, future changes in factor prices may allow B to evolve spontaneously at a certain point in time t the invention pays off (compare also Popp (2002)). If technological lock-out would

[7] Well known is the example of QWERTY. QWERTY is the current standard used in type-writing. Because a superior system has been developed able to substitute QWERTY from a pure technical perspective, the lock-in to the QWERTY system has to be explained by high switching costs and cannot be considered as optimal from an ex-post perspective.

[8] Examples for the suboptimal selection process of markets are given by the US television system, the example about the U.S. programming language FORTAN or the example of QWERTY (Arthur 1984, David 1985, Hartwick 1985).

[9] This distinction would be misleading for the case that those technologies incorporated in B are not able to substitute conventional energy in the long run. In this case A and B cannot be treated as substitutes ex post. This would make it difficult to find rational arguments in favor of the support for GTs.

[10] Note, this does not mean that inventions do not take place. For instance the invention for electricity production with solar as technology goes back to an invention by Becquerel in 1839 (Sørensen 1991, p. 9), nevertheless due to the high production costs commercialization of solar cells was not able before 1954.

result due to a change in relative prices, all resources (labor and capital) going into B would be directly connected to economic growth and development as the process of creative destruction would be at force.

In contrast to this, if there is a managed transition from A to B, there is still the problem that governments can make wrong decisions about the transfer of resources channeled to different GTs j. Successful transition management is highly sensitive to the institutional setting and its capability to allow for dynamic adjustments. Further problems can occur if B is implemented on a non-optimal point in time t (Nordhaus et al. 1973). Additional problems occur if there is discrimination with respect to monetary resources channeled to the different technologies incorporated in B. The result will be distortion in competition within B.

However, in case of high uncertainty or risky externalities related to A, investment into B is important in order to reduce distortions in competition. Further, there is the positive impact that the knowledge stock related to GTs increases. The creation of a niche for different GT industries j (implementation of diversity) can be seen to be a starting point in order to allow transition towards B in the long run (Rotmans et al. 2001). Technological lock-in to a non-sustainable energy system is a further argument for certain investments going into GTs (Rennings 2000, Unruh 2002, Nill and Kemp 2009).[11]

In case of lock-in to non-renewable energy technologies, the development of electricity prices should only play a minor role for innovation in GTs. Because there is no real consensus about the theoretical argument of lock-in (Witt 1989, 1997) an alternative interpretation has to be mentioned. The possible case that there is no reaction on changes in electricity prices may simply indicate the superiority of conventional energy technologies. The interpretation, however, is non-trivial as it is highly sensitive to the institutional setting and there is the problem of externalities related to A. Hypothesis 2 is formulated to test the impact electricity prices have on innovative activity.

Hypothesis 2: Increasing electricity prices have no impact on innovative ac-

[11] The theoretical aseeesment in section 4 resumes the argument of non-sustainability of the energy system.

tivity in GT industry *j*.

In contrast to hypothesis 2, one could also ague that due to the creation of a niche for GTs under the SEG and EEG, electricity prices could have an impact as some partial lock-out from *A* already took place.[12] A short overview on institutional change in the German energy sector is presented at the end of this section.

Eco-innovations and the double externality problem

Because this study is dealing with innovations in GTs (so called "eco-innovations"[13]) we have to take into account the "double externality problem" (Rennings 2000). Like other innovations eco-innovations are able to create positive externalities (Arrow 1962) and additionally their diffusion is connected to environmental specific positive externalities (Rennings 2000, p. 325).

This double externality problem (problems related to cost-internalization) reduces incentives for firms to invest into environmental friendly R&D. Suboptimal market allocations can occur, as under certain conditions "technology push and market pull alone [...] [are not] strong enough [for self-enforcement of eco-innovations]" (Rennings 2000, p. 326). Public R&D expenditures may help to push for eco-innovations. In order to test the technology push factor we formulate our next hypothesis.

Hypothesis 3: Public R&D plays a significant role for innovations within GTs.

Transition policy in the GT sector (from the SEG to the EEG)

Pull factors for GTs have been implemented through the SEG and EEG. The switch in the energy regime from conventional energy production *A* to an energy regime that mainly builds on energy produced with green technolo-

[12] An increase in electricity prices for GT producers can indicate a higher market potential for GTs. However, regulation in the energy sector towards an increase of GTs may also drive electricity prices affecting the electricity price endogenously.

[13] "Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households) which; (i) develop new ideas, behavior, products and processes, apply or introduce them and (ii) which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets."(Rennings 2000, p. 322)

gies B is therefore dependent on its institutional setting. We distinguish three different institutional stages that roughly describe institutional change in the German energy system.

The first stage is characterized by a monopolistic electricity market with almost no competition. A is considered to be the main source of electricity supply. Due to the cost argument as well as the problem that no institutional setting exists to feed-in electricity produced with B into the network of electricity, diffusion of B is very limited.[14] The first stage shall characterize the German energy market until 1991 (Toke and Lauber 2007, p. 683).

First change in the energy system was implemented with the "Stromeinspeisegesetz" (SEG). The SEG entered into law in January 1991 (Toke and Lauber 2007, p. 683). The SEG was important because it allowed small and medium electricity producing companies to feed-in their electricity into the grid. The remuneration was based on 75 percent (for WATER and BIO), and 90 percent (for SOLAR and WIND) on the average market price for electricity. The SEG allowed for some first competition in the energy market and first decentralization. Nevertheless, diffusion of B was limited because remuneration was lower than the average market price for electricity produced with A (compare (SEG 1990)). The institutional arrangement under the SEG held from 1991-1999. The SEG can be seen as a necessary requirement for the contestability of conventional energy markets.

At the end of the 1990's it came to liberalization of the energy market and additionally the so-called "Erneuerbare Energieengesetz" (EEG) entered into law in April 2000. It has elements best described as "command and control", because only some selected technologies get a defined remuneration for the electricity feeded-in. The EEG is designed in a way that discrimination between different technologies takes place through different remuneration rates. Degression rates for the feed-in tariffs also differ. Discrimination was a necessary condition in order to implement diversity. Under the EEG, until 2003, the range of remuneration was from $6.5ct/KWh$ for electricity produced by the use of WATER and BIOGAS and went up to $51.62ct/KWh$ for SOLAR. The highest

[14] Note that in some geographical areas WATER (which is considered to belong to B) is very cost-efficient and therefore was traditionally one main source of electricity supply.

feed-in tariff except SOLAR was given for BIO (biomass) with $10ct/KWh$.[15] The German government so far modified the EEG two times (for details on the differences compare EEG (2000, 2004, 2009)).

The institutional arrangements described above implemented a policy-induced demand for GTs (compare also figure 1). The following hypothesis is defined to test whether a structural break can be observed by comparing the SEG (1990-1999) with the EEG (from 2000 on).

Hypothesis 4: Demand driven innovation under the EEG is significantly higher compared to the SEG.

Figure 1 connects the institutional change with diffusion of GTs. The expected structural break between the SEG and the EEG is characterized through different slope parameters related to the dotted arrows representing diffusion of GTs under the SEG and diffusion of GTs under the EEG. Figure 2, tries to take the underlying dynamics of technological diffusion over time into account (Rotmans et al. 2001, p. 17). The inverted s-shaped curve represents three system dimensions of diffusion. They are characterized by (a) speed of change, (b) size of change and (c) time period of change (Rotmans et al. 2001, p. 4). For the speed of diffusion three phases can be distinguished: (1) take-off phase, (2) acceleration phase and (3) stabilization phase. It can be seen that changes in slopes within phase (1) and (3) are rather low. It might be that the expected structural break will not be significant if diffusion is still within its take-off phase.

3 Empirical Strategy

3.1 Data and Descriptive Statistics

We constructed a panel going from 1990 until 2005. The sectors of interest are wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO)

[15]For more details about the remuneration until 2003 compare table 12 (page 40). One also has to mention that current reforms of the EEG were accompanied by changes in remuneration rates.

Figure 1: Technical Change under the SEG and the EEG

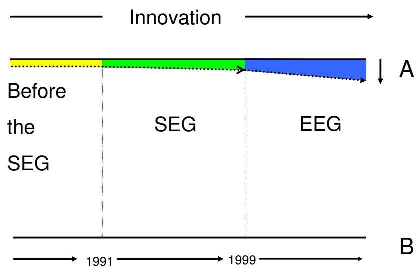
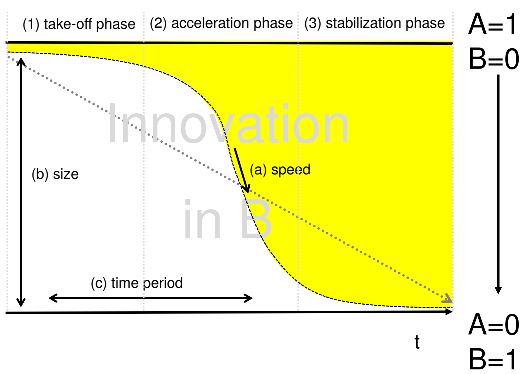


Figure 2: Innovation and Technological Change



Own presentation, oriented on Rotmans et al. (2001), p. 17.

and biomass (BIO).[16] Our panel therefore contains 16 observations over time and 5 sector specific observations.

Innovations will be measured by patent counts PAT, $APAT$.[17] The variable PAT describes the sector specific patent counts and $APAT$ are all patents applied in Germany in all IPC classes (the database for PAT is DEPATIS net). We use the application date for all patents that have been granted (inventions) within the IPC classes reported in table 11 (page 39). The data contains only those patent counts with priority in Germany (double counting excluded). We also have information about sector specific public expenditures on research and development RuD and the installed capacity of the different technologies (measured in MW/h) $INCAP$. Prices are measured by $CPIE$ (consumer price index for electricity). Electricity consumption is measured by the consumption of KW/h per capita ELC. The variables PAT, RuD and $INCAP$ contain sector specific information. The variables $CPIE$ and ELC are aggregated observations with country specific information. The variables are summarized by table 1.

Table 1: Summary of the Data

	Obs	Mean	Std. Dev.	Min	Max	Measure
PAT	80	76.5125	85.67025	3	297	Counts
$APAT$	80	50281.13	7286.154	37252	59685	Counts
RuD	80	17.47135	22.97052	0	91.178	Mio. Euro
$INCAP$	80	2213.532	3695.865	0.01	18428	MWh
$CPIE$	80	109.3919	15.03489	85.18	134.04	2004 indexed to 100
ELC	80	6601.992	257.3511	6246.21	7111.05	KWh per capita

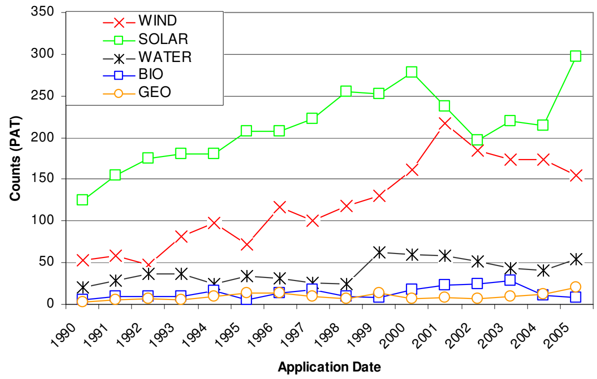
Patent counts (PAT) as a proxy for innovations

Figure 3 shows a time trend of granted patents (patents counts at application date). It is interesting to see that granted patents for SOLAR started to decrease under the EEG before they increased again after 2002. For WIND, a decline of the patenting intensity can also be observed after 2001. Parts of the decline

[16] The five sources of the data are the German Patent Office (GPO), the International Energy Agency (IEA), Eurostat (ES), The German Statistical Office (GSO) and the German Ministry of the Environment (BMU). For a detailed description of the data compare page 37.

[17] There is the critique that "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in 'quality', in the magnitude of inventive output associated with them" (Griliches 1990a, p. 1669). However, using patents as a proxy for innovation is very common and seems appropriate as there are only a few economically significant inventions which have not been patented (Dernis et al. 2000, 2004).

Figure 3: Patent Counts (*PAT*)



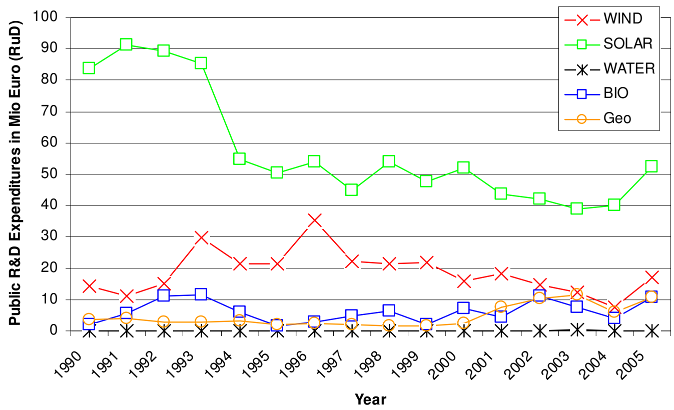
could be explained with a time lag between the application date and the date of patent granting. In order to avoid this problem, we restricted our panel to the year 2005 even though our database on patent counts goes until 2007. We make the implicit assumption that applied patents will be granted within a time frame of two/three years. If one takes into account that patenting activity can also be interpreted as a stock of knowledge, even though the patent counts decrease, the stock of knowledge does still increase. It is also notable that SOLAR has the highest patenting activity, followed by WIND. In contrast to this, GEO and BIO generate relatively low knowledge stocks.

Public *R&D* expenditures (*RuD*)

Figure 4 reports the industry specific *R&D* fundings imposed by the federal government. It can be seen that there was a decrease in public *R&D* funding for SOLAR after 1993. Compared to this, there is a relatively low level of reported public *R&D* expenditures for technologies like WIND, WATER, BIO or GEO. It can be seen that most *R&D* expenditures went into SOLAR, followed by WIND. BIO and GEO received relatively low public *R&D* transfers. There is no reported *R&D* support going into WATER.[18]

[18]It might be that *RuD* does not display all direct payments going to GTs. One first hint is that expenditures of the local government are not measured by *RuD*. Nevertheless, *RuD* incorporates all *R&D* expenditures of the federal government reported to the IEA.

Figure 4: Public Expenditures for Research and Development (RuD)



Installed capacity of GTs ($INCAP$) and change of installed capacity ($\Delta INCAP$), measured in MW/h to proxy the change in size of the market (S)

Figure 5 shows the increase of installed capacity of renewable energies under the SEG and EEG. It can be seen that until 1999, WATER was the most important renewable energy source. After 1999, the share of WIND increased with high growth rates and its installed capacity exceeded the one of WATER. Until 2005 the installed capacity of SOLAR was still on a lower level than for BIO. The installed capacity of GEO is almost zero. Figure 6 represents corresponding growth rates to the installed capacity.

Consumer price index electricity ($CPIE$), a marked based indicator for the incentives to innovate

Figure 7 gives insights about electricity prices which decreased until the year 2000 and increased again after the year 2000.[19]

[19]Having the liberalization of the market for electricity in mind, the decrease in electricity prices may report the welfare gains due to liberalization. It might be the case that regulation related to the EEG had some impact on this development.

Figure 5: Installed Capacity of Green Technologies ($INCAP$)

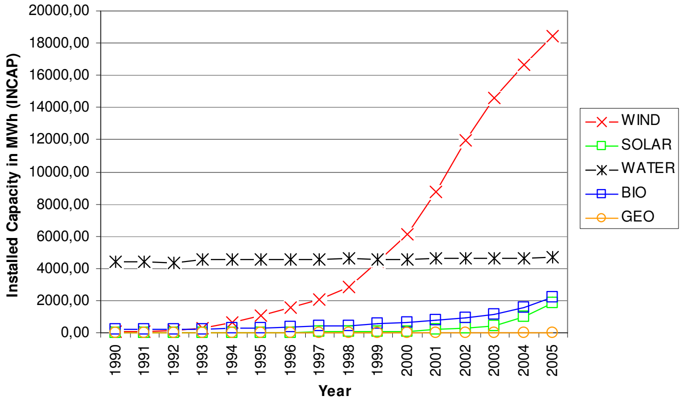


Figure 6: Change of Installed Capacity of Green Technologies ($\Delta INCAP$)

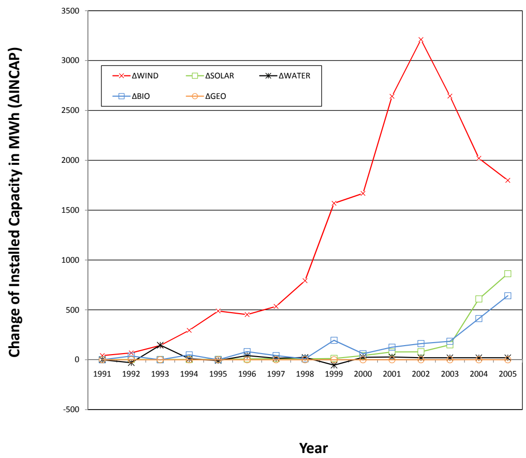
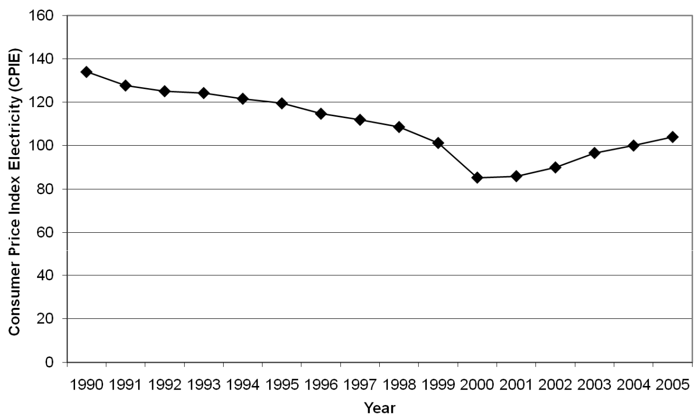


Figure 7: Consumer Price Electricity ($CPIE$)



3.2 Econometric Model

The model is aimed to test the following relationship:

$$PAT = f\left(\underset{+}{\Delta INCAP}, \underset{0}{CPIE}, \underset{+}{RuD}\right).$$

For our dataset we assume that $T \to \infty$ and our independent variable consists of a vector with count data. Two major problems therefore are related to our data. On the one hand observations over time may not be independent from each other and on the other hand (as we are dealing with count data) standard errors may not be normally distributed.

If we estimate a linear model with OLS we can formalize the econometrics as follows (Wooldridge 2002a, pp. 247):

$$y_{it} = \beta^T x_{it} + c_i + u_{it}, \tag{1}$$

where $i = 1, \ldots, n$ indexes the technologies listed within the different patent classes (compare table 11 (page 39)) and $t = 1, \ldots, T$ indicates time. The error term u_{it} is idiosyncratic and c_i allows to control for group specific heterogeneity (fixed effects model). Calculating first differences for the observations over time can already help to correct first order serial correlation (Wooldridge 2002b, p. 365). Non linear AR(1) estimation methods offer additional opportunities to handle non stationarity of the error component (Wooldridge 2002b, p. 350).

As mentioned above, the underlying assumption of the normal distribution does not seem to be most efficient because of the count data characteristic of patents. Suggested estimation models for event counts[20] are negative binomial models or Poisson models (Maddala 1983, Cameron and Trivedi 1998, Wooldridge 2002a). The negative binomial model is based on a Poisson distribution with an unobserved error parameter ν, implementing heterogeneity in the variance. The intensity parameter φ is explained by a vector of all explanatory variables X.

Formally:

$$PAT_{i,t} \rightarrow NegBin(\varphi;\sigma),$$

equals

$$PAT_{i,t} \rightarrow Poisson(\varphi) \quad if \begin{cases} \varphi = \widetilde{\varphi}\nu = exp(\beta X) \\ \nu \rightarrow \Gamma(\frac{1}{\sigma};\frac{1}{\sigma}). \end{cases}$$

The standard deviation for the expected value $E(PAT_{i,t}) = \varphi$ is given by $V(PAT_{i,t}) = \varphi(1+\sigma^2\varphi)$. Thus, with $\sigma \rightarrow 0$ the intensity is φ and the model converges towards a Poisson distribution. It can be seen that the negative binomial model is superior compared to the Poisson model.

One striking feature of the linear model or some standard non linear estimation methods like AR(1) is that one can easily correct for serial correlation. However, applying such models may cause a bias in our estimates because of the wrong assumption about the functional form. We propose to solve this problem by the following estimation strategy: The basic model is estimated with a first differences linear fixed effects model. We than compare this model with the fixed effects negative binomial regression (where we do not control

[20] An event count "is the realization of a nonnegative integer-valued random variable" (Cameron and Trivedi 1998, p. 1).

for first order serial correlation). If the estimated coefficients in both cases show comparable results, we can conclude that first order serial correlation is not inflating the significance of our estimates. Endogenous effects are additionally controlled for by the use of time dummies. The robustness of our results is further demonstrated by estimating the AR(1) model (combined with first differences).

In table 2, 4 and 5 we start the estimation with only a few variables and proceed by integrating additional variables in further steps. In the last column of table 2, 3, 4 and 5 we report the estimation result for the negative binomial regression. In table 3 and 6 we report estimation results from different additional models. We try to test hypothesis 1 with the variable $\Delta INCAP$, hypothesis 2 with $CPIE$ and hypothesis 3 with RuD. We use period dummies to test for the structural break (hypothesis 4). Model specifications for the standard model are given for

$$\begin{aligned} PAT_{i(t-1)} &= \gamma_t + \beta_1 z_{i(t-2)} + \beta_3(\Delta INCAP_{it}) \\ &\quad +(RuD_{i(t-1)}) + \beta_4(CPIE_{i(t-2)}) + c_i + u_{it}, \end{aligned} \tag{2}$$

and for hypothesis 4 we have

$$\begin{aligned} PAT_{i(t-1)} &= \beta_0 + \beta_1 z_{i(t-2)} + \beta_2^{SEG}(\Delta INCAP_{it}) + \beta_3^{EEG}(\Delta INCAP_{it}) \\ &\quad +\beta_4(RuD_{i(t-1)})\beta_5(CPIE_{i(t-2)}) + c_i + u_{it}. \end{aligned} \tag{3}$$

In the model, t indexes time and i indexes different industries operating within the GT sector,[21] SEG stands for the period from 1990-1999 and EEG represents the period from 2000-2005. If the variables are indicated with $(t-1)$, a one year time lag is used in order to incorporate dynamic effects into the model, $(t-2)$ and $(t-3)$ are two year and three year time lags. Δ is used as a symbol for first differences. $z_{i(t-2)}$ describes two observable characteristics integrated as control variables, namely ELC_{t-2} and $APAT_{t-2}$. ELC_{t-2} is integrated into the model because electricity prices may also react to electricity consumption. $APAT_{t-2}$ allows to control for endogenous institutional

[21] Table 9 (page 38) shows the correlation matrix for the variables integrated into the model.

changes in the German patent system.[22] The variable β_0 denotes the intercept. The error component c_i is group specific (individual heterogeneity) whereas u_{it} represents the idiosyncratic error term (dependent on i and t). With respect to the lag structures, strong assumptions are implemented into the econometric model. However, the time lags assumed are oriented on earlier contributions from the literature (Brunnermeier and Cohen 2003, Griliches 1990b, 1998, Hall et al. 1986). It can be criticized that private R&D expenditures are not integrated as explanatory variable into the econometric model. As we do not have information on private R&D, we have to stick to the model presented above. From a theoretical point of view it has to be taken into account that firms operating within an industry compete with each other. There is the implicit assumption that firms have to innovate (with process or product innovations) to be able to compete on the market. Hence, $INCAP$ should also capture at least parts of successful private $R\&D$.[23]

With respect to the construction of the panel we got some inspiration from Johnstone et al. (2008). They run a panel on the international level combining patent counts with data from the IEA.[24] Johnstone et al. (2008) run the regression with a negative binomial model. As we compare the estimation results from the first differences linear fixed effects model with the estimation results from the negative Binomial regression we are able to control for first order serial correlation.

3.3 Estimation Results

The results of the Hausman test show that random effects would also be an appropriate estimation method. Nevertheless, we stick to the fixed effects model as fixed effects is more robust and with the assumption of normally distributed standard errors it is difficult to interprete the coefficients anyway. In order

[22]It might be possible that overall patents have increased (e. g. due to institutional changes) and therefore most of the variance in patenting activity would follow a trend which is observable in overall patent counts.

[23]However, as can be seen from the estimation results of our OLS regression, less than fifty percent of the variance are captured by our model. Having information on private $R\&D$ may further increase the explanatory power of our model.

[24]There are additional important differences. $\Delta INCAP$ was not part of the sample and WATER was not integrated. We run the regression excluding WASTE due to the fact that this variable does not contribute much to sustainable electricity supply. For more details have a look at table 11 (page 39).

to control for serial correlation we use the Baltagi-Wu LBI-Test (which has to be estimated with random effects). The test statistic is published in table 3, column 4. The Baltagi-Wu test statistic is bigger than two (Baltagi-Wu LBI = 2.113425) indicating that there is no significant autocorrelation for the AR(1) model. Because the significance of our estimates does only change slightly if we switch among the AR(1) model, the first differences OLS model and the negative binomial model, we are able to state that first order autocorrelation is not the major problem within our data.

It can also be seen that the main variables of interest do not change significantly if we compare the linear first differences fixed effects model with the negative binomial regression. Only our *control* $APAT$ changes its sign and gets significant in most of the cases. Our control ELC becomes insignificant under the negative binomial regression reported in table 3. The estimation results give support for hypothesis 1, hypothesis 2 and hypothesis 3. Increase in market size positively affects the probability that firms operating within different GT industries are engaged in innovative activities. According to hypothesis 2 we come to the result that electricity prices only play a minor role for innovative activity in the different GT industries. The estimation outcomes reported in table 4 column 3 and 4 indicate that prices may have an impact within a two year time lag. However, the result vanishes if we include our controls. Integrating the controls is important as leaving them out may generate an omitted variable bias. The significant result for RuD indicates the positive impact policy induced supply push can have on innovative activity. One may criticize that in the model with $CPIE_{i(t-3)}$ (compare table 4) there is obviously a problem of multicollinearity (compare table 10 (p. 39)). $CPIE$ is highly correlated with ELC and $APAT$. This problem is not that severe if one keeps in mind that multicollinearity does not cause a bias in the estimated slope coefficients (as long as the correlation is not perfect) and OLS remains BLUE (Berry 1993).

The strong evidence for the negative and significant result of the coefficient related to ELC_{t-2} (compare table 2, table 3 and table 5) is not very intuitive but is in line with the findings of Johnstone et al. (2008). One possible explanation for the negative sign is that investment in GTs was accompanied by policy measures for energy efficiency (Johnstone et al. 2008, p. 14) and therefore electricity consumption may have decreased while patenting activity increased.

Table 2: PAT: Estimation result 1a (First Differences Model (FD) and negative Binomial regression (neg. Bin))

estimation method	**OLS FD** (fixed effects)	**OLS FD** (fixed effects)	**OLS FD** (fixed effects)	**OLS FD** (fixed effects)	**neg.Bin.** (fixed effects)
PAT_{t-1}					
$\Delta INCAP$	0.031518** (0.0088205)	−−	−−	0.0302018** (0.0083791)	0.0001959** (0.0000445)
RuD_{t-2}	−−	1.039079** (0.3292184)	−−	1.018854** (0.314086)	0.0061104* (0.0024728)
$CPIE_{t-2}$	−−	−−	−0.4966235 (0.3961358)	−0.4149241 (0.3640293)	−0.0062943 (0.0055762)
ELC_{t-2}	−−	−−	−−	−0.0380029* (0.0165895)	−0.0004479** (0.000168)
$APAT_{t-2}$	−−	−−	−−	−0.0008328 (0.0011242)	0.000021+ (0.0000114)
β_0	1.936991	4.100494*	1.583963	3.154136	6.642954
time dummies	*No*	*No*	*No*	*No*	*No*
R-sq	0.1844	0.1044	0.0249	0.3501	
Wald chi2(5)					133.82
Nr. of Observations:	70	70	65	65	70
Nr. of groups:	5	5	5	5	5

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

The structural break (hypothesis 4) is tested by the use of period dummies for $INCAP$ (compare table 5). The Chow-test was calculated for the regression reported in the fourth and fifth column. The test statistic did not show any significant difference between the two coefficients.[25] We thus have to reject hypothesis 4. One possible explanation might be given by figure 2 (page 12). Due to the fact that most GT industries (except $WIND$) are still operating on rather low scales (compare figure 5), one can argue that GTs on average are still in the take-off phase. This may explain the relatively low difference in the slope coefficient. Having the theory of industrial dynamics in mind, it is plausible to assume that coming to the acceleration phase the linear relationship will disappear.

Our main findings can be summarized as follows: We find good evidence for hypothesis 1, there is support for hypothesis 2 and hypothesis 3. Hypoth-

[25]Under OLS the p-value for the Chow-test (HA significant difference in coefficients) was reported to be 35.16 percent. If the Chow-test was calculated for the negative binomial regression the p-value increased to 73.25 percent. In 35.16 (73.25) percent of the cases we cannot reject HO indicating that there is not significant difference in the coefficients.

Table 3: *PAT*: Estimation result 1b, different Estimation Models with time dummies included

estimation method	OLS FD (fixed effects)	GLS FD (random effects)	AR(1) FD (fixed effects)	AR(1) FD (random effects)	neg.Bin. (fixed effects)
PAT_{t-1}					
$\Delta INCAP$	0.0291369**	0.03143**	0.0291153**	0.0318369**	0.0001903**
	(0.0090864)	(0.0087421)	(0.0093004)	(0.3595341)	(0.000044)
RuD_{t-1}	1.211616**	1.056867**	1.309931**	1.098368**	0.0065433*
	(0.3825941)	(0.3599975)	(0.386108)	(0.3595341)	(0.0026027)
$CPIE_{t-2}$	−0.5227731	−0.5053394	−0.5248703	−0.5035705	−0.0082038
	(0.4096686)	(0.4051253)	(0.4079489)	(0.4023662)	(0.0068756)
ELC_{t-2}	−0.073431**	−0.0687862**	−0.0761015**	−0.0698056**	−0.0002328
	(0.0267883)	(0.0263069)	(0.0269798)	(0.026377)	(0.0002038)
$APAT_{t-2}$	−0.0026993	−0.0025231	−0.0027616	−0.002535	0.0000184
	(0.0017919)	(0.0017695)	(0.0017907)	(0.0017628)	(0.0000181)
β_0	7.848957	6.789275	8.434545	7.006506	5.735006**
time dummies	*YES*	*YES*	*YES*	*YES*	*YES*
R-sq	0.4144	0.4174	0.4173	0.4433	
Wald chi2				36.47	150.68
Baltagi-Wu LBI				2.113425	
Nr. of observations:	65	65	60	65	70
Nr. of groups:	5	5	5	5	5

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

Table 4: *PAT*: Estimation result 1c, model with two years time difference between PAT and CPIE

estimation method	OLS FD (fixed effects)	OLS FD (fixed effects)	OLS FD (fixed effects)	OLS FD (fixed effects)	OLS FD (fixed effects)	neg.Bin. (fixed effects)
PAT_{t-1}						
$\Delta INCAP$	−−	0.0310202**	−−	0.0300739**	0.0299035**	0.0002053**
		(0.009274)		(0.0084534)	(0.0085125)	(0.0000473)
RuD_{t-1}	−−	−−	1.157342**	1.119732**	1.170648**	0.0069161*
			(0.3589887)	(0.3251934)	(0.3298149)	(0.0029355)
$CPIE_{t-3}$	0.6090625	0.4691462	0.8728286+	0.7286088+	0.8491981	0.001469
	(0.4737662)	(0.4365525)	(0.4448474)	(0.4047913)	(0.5653796)	(0.0070755)
ELC_{t-3}	−−	−−	−−	−−	−0.0101108	−0.0002682
					(0.0204088)	(0.0002671)
$APAT_{t-2}$	−−	−−	−−	−−	0.0011585	0.0000314*
					(0.0013187)	(0.0000145)
β_0	5.157509+	3.075181*	7.302342**	5.213833*	4.04667	3.932665
time dummies	*No*	*No*	*No*	*No*	*No*	*No*
R-sq	0.0281	0.2198	0.1596	0.3473	0.3632	
Wald chi2(5)						97.24
Nr. of Observations:	60	60	60	60	60	65
Nr. of groups:	5	5	5	5	5	5

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

Table 5: PAT: Estimation result 2 (model with period dummies)

estimation method	OLS FD (fixed effects)	OLS FD (fixed effects)	OLS FD (fixed effects)	OLS FD (fixed effects)	neg.Bin. (fixed effects)
PAT_{t-1}					
$\Delta INCAP^{SEG}$	0.032095**	0.0320388**	0.031452**	0.0307259**	0.0001859**
	(0.008878)	(0.0082015)	(0.0091931)	(0.0084065)	(0.0000533)
$\Delta INCAP^{EEG}$	0.0333466**	0.0330009**	0.0328012**	0.0321356**	0.0001943**
	(0.0091505)	(0.0084539)	(0.0094563)	(0.0086367)	(0.0000448)
RuD_{t-1}	−−	1.031156**	−−	1.001563**	0.0060137*
		(0.2999175)		(0.3149585)	(0.0024934)
$CPIE_{t-2}$	−−	−−	−0.3049563	−0.4460741	−0.0067637
			(0.3718595)	(0.3659216)	(0.0057518)
ELC_{t-2}	−−	−−	−−	−0.0395008*	−0.0004512**
				(0.0166834)	(0.0001686)
$APAT_{t-2}$	−−	−−	−−	−0.0009091	0.0000199+
				(0.0011284)	(0.0000118)
β_0	1.850512	2.547872	0.4977128	3.09456	6.768015**
time dummies	*No*	*No*	*No*	*No*	*No*
R-sq	0.1931	0.2975	0.2144	0.3618	
Wald chi2					133.64
Nr. of Observations:	70	70	65	65	70
Nr. of groups:	5	5	5	5	5

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

Table 6: PAT: Reverse causality

estimation method	OLS FD (fixed effects)	GLS FD (random effects)	AR(1) FD (fixed effects)
$\Delta INCAP$			
PAT_{t-1}	6.326775**	6.592951**	5.69906**
	(1.755278)	(1.652705)	(1.641692)
$CPIE_{t-1}$	−3.844091	−3.647414	−3.876413
	(5.305394)	(5.179065)	(5.375029)
RuD_{t-1}	−6.793616	−6.801143	−7.104368
	(4.876487)	(4.526577)	(4.440642)
ELC_{t-1}	0.161962	0.1715023	0.0317271
	(0.250351)	(0.2436037)	(0.2552254)
$APAT_{t-1}$	−0.0030656	−0.0027472	−0.0015684
	(0.0163475)	(0.0159701)	(0.0145496)
β_0	15.43433	14.53108	21.80976
time dummies	*No*	*No*	*No*
R-sq	0.2384	0.2385	0.2444
Number of observations:	65	65	60
Number of groups:	5	5	5

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

esis 4 has to be rejected. In general, the estimation results can be interpreted in the direction that demand is one important factor that firms operating in different GT industries are engaged in innovative activities. As reported in table 6, reverse causality issues also play an important role. This has to be taken into account by interpreting the result for hypothesis 1. There is clear evidence that innovations in GTs increase the size of the marked endogenously. This is in line with the literature. Even though the model is quite robust under unchanged time lags, it has to be mentioned that a change in the model dynamics also changes some of the estimation results. Therefore, we tried to motivate the assumed time lags theoretically.

In the following section we try to assess the observed structural change in the German energy system. We distinguish among two major arguments that are used in order to justify investments in GTs. One argument is based on the externality problem and the other argument is based on non-sustainability in the energy system.

4 Environmental Impact of Structural Change in the Energy System and the Schmookler Hypothesis

Recent energy production in Germany is still highly dependent on conventional energy technologies. They have the major characteristic that *non-renewable/ exhaustible* energy sources[26] they use as an input. The system hence lacks long-term *sustainability*. Non-renewable energy sources have the shortcoming that they are either responsible for externalities in form of CO_2 emissions[27] (like in the case of COAL or GAS) or that there are unsolved externality problems (like in the case of NUCLEAR energy). In comparison to this renewable energies have the major advantage that they are able to produce energy without imposing remarkable harm to the environment. However, energy production with non-renewable energy sources is more cost intensive and substitution of

[26] A definition for exhaustibility is given by Dasgupta and Heal (1979), p. 153:"an exhaustible resource is [...] used up when used as an input in production and at the same time its undisturbed rate of growth is nil".

[27] CO_2 emissions represent one big part of total greenhouse gas (GHG) emissions which are seen to be highly responsible for global warming (IPCC 2007, p. 5).

conventional energy is still far from reality.

Two distinct problems are often combined when the discussion is about structural change in the energy system and diffusion of GTs. The first problem is related to *externalities* and the second to transition from a non-renewable energy system to a system mainly based on renewable energies in order to implement long-term sustainability.

If the discussion is about the externality problem one can argue that a substitution of conventional energy technologies by GTs has to reduce externalities and consequently its diffusion contributes positively to the environment. Another option would be to apply instruments that allow to enforce the internalization of the externality directly by the non-renewable energy technologies. Theoretically such an approach has some advantages as GTs cannot be treated to be adequate substitutes to conventional energy technologies so far.

Economic theory offers different instruments that can be applied to the environmental externality problem. Some instruments worth mentioned are quotas (Baumol et al. 1988, pp. 57), taxes (Pigou 1924), property rights (Coase 1960), negative rules (Hayek 1978/1993), tradable certificates (Dales 1968) and trial and error processes implemented via regulation (Baumol and Oates 1971). In the case of CO_2 emissions and the related problem of global warming, tradable certificates have many desirable features and are highly recommended (Olmstead and Stavins 2006). Diffusion of GTs according to this reasoning cannot be treated to be a first best solution. If diffusion of GTs is combined with tradable certificates (like in the case of Germany), the positive environmental impacts vanish (Traber and Kemfert 2009).

Apart from the externality problem there is an additional argument why diffusion of GTs may have positive impacts. This argument is related to the problem of non-sustainability in the energy system. Sustainability requires transition from non-renewable energy sources to a system that mainly builds on GTs ("backstop technologies"). The point in time of transition can be influenced by policymakers ("transition management"). The European Union for instance has implemented a directive that in 2020 the percentage of total energy that shall be produced with renewable energies has to be at least 20 percent (COM 2008). The aim of sustainable energy supply is also used as an argument for diffusion of GTs under the EEG.[28]

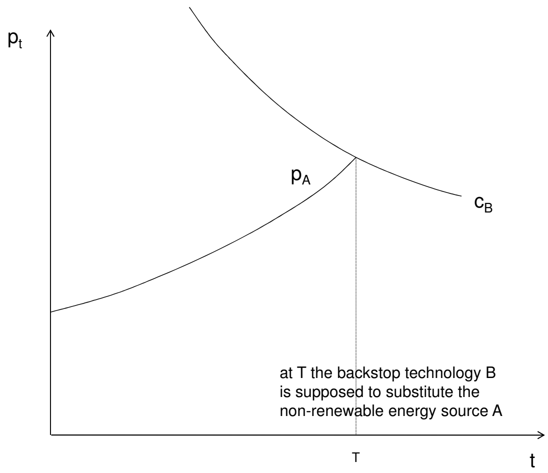
The lack of sustainability is one major concern in many studies that cope with environmental problems (Kemp 1997, Norgaard 1994, van den Bergh and Gowdy 2000, van den Bergh 2003, van den Bergh et al. 2007, Nill and Kemp 2009). If non-sustainability is treated to be a major problem in the energy sector, than successful transition management towards sustainability needs regulation, unlocking policy to preserve diversity and fostering of innovations (van den Bergh et al. 2007).

Even though the argument of sustainability seems to be convincing at first glance, there are concerns to apply sustainability as the adequate normative argument for transition management in the energy sector. One important aspect comes from environmental and resource economics. There is the argument that extraction of a non-renewable energy source is a decision among expected profits to be earned in the future by leaving the resource in the ground and profits that can be earned by extraction of the resource. One of the shortcommings is that from an international perspective investments into GTs may not lead to an increase in sustainability (Sinn 2008). This counterintuitive result can be explained by the "Hotelling" model (Hotelling 1931) about extraction of non-renewable energy sources (compare also Gray (1914)). An equilibrium requires that $p_{A1} = p_{A0}(1 + r)$ where p_{A0} is the competitive market price for the exhaustible resource today, p_{A1} the competitive market price for the following period and r is the real interest rate (Wacker and Blank 1999, p. 16). Figure 8 and figure 9 are aimed to visualize the impact GTs may have on the speed of extraction for non-renewable energy sources.

In figure 8 and 9 c_B stands for the marginal production costs of renewable energy technologies modeled as "backstop technologies" (Nordhaus et al. 1973), t indicates time and p_A represents the world market price for a non-renewable energy source (e. g. COAL). It can be seen (compare figure 8) that there has to be a switch to energy produced with backstop technologies once

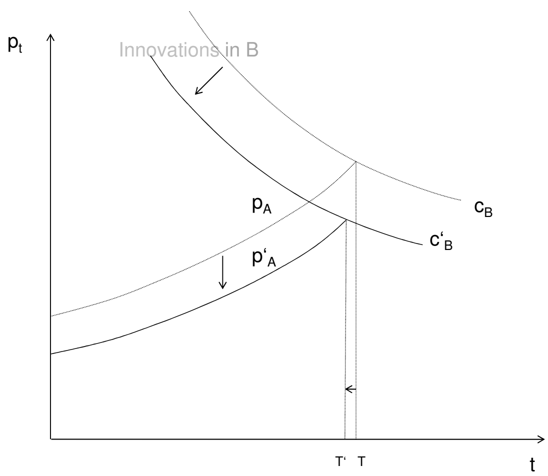
[28] Article 1(1) EEG: "facilitate a *sustainable* development of energy supply, particularly for the sake of protecting our climate and the environment, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to conserve fossil fuels and to promote the further development of technologies for the generation of electricity from renewable energy sources" (EEG 2009).

Figure 8: Transition from A to B without managed transition



Own presentation, oriented on Wacker and Blank (1999), p. 43.

Figure 9: Transition from A to B with managed transition (open economy perspective)



Own presentation, oriented on Wacker and Blank (1999), p. 43.

the price for the extracted resource equals marginal production costs of a certain GT j (compare also Wacker and Blank (1999), pp. 43). In figure 9, the values indicated with an apostrophe represent the change in relative prices due to a managed transition to GTs. It can be seen that the change in relative prices has an impact on the speed of extraction with the possible result that investment into GTs does not conserve non-renewable energy sources rather than to increase their consumption.

The underlying relationship can be explained as follows: The decrease in expected revenues related to the extraction of non-renewable energy sources (because of the possible substitution through backstop technologies) leads to the result that resource owners increase the rate of extraction. The backstop technologies change the equilibrium condition from $p_{A1} = p_{A0}(1+r)$ to $p'_{A1} = p'_{A0}(1+r)$ with $p'_{A1}, p'_{A0} < p_{A1}, p_{A0}$. The decrease in world market prices will be accompanied by an increase in current consumption of non-renewable energy sources (compare also Baumol et al. (1988), pp. 138). This model builds on the assumption that renewable energies are adequate substitutes to conventional energy technologies. So far this does not seem to be the case for most GTs available. However, if innovations indicate growth and the possibility to substitute conventional energy technologies in the near future, price reactions become more likely. The investment into backstop-technologies thus may accelerate consumption of non-renewable energy sources.

It can be seen that theoretically there is a lack of straightforward arguments for a managed transition towards an energy system that mainly builds on renewable energies. It therefore seems to be a better strategy to focus on internalization of the externality and to adapt the institutional setting in order to allow for an endogenous transition from non-renewable energy sources towards sustainability in the energy system. If there would be complete internalization of the externality, the increase in production costs for conventional energy technologies may have the side effect that some GTs become competitive. Following this line of arguments, transition from a niche to a new economic system has to evolve endogenously once a change in relative prices makes investments into transition technologies profitable (Nordhaus et al. 1973). This was also the argument that has become known as the "Schmookler hypothesis”. An implicit requirement is the open market access for GTs. Theoretically the dissemination of a sufficiently superior technology is possible under these special circumstances (Witt 1997). Nevertheless, there remains an important role for energy related public R&D (Popp and Newell 2009) in order to foster energy related innovations and/or inventions to overcome the double externality problem (Rennings 2000).

Two policy-reforms thus can be considered to be in line with the requirements for an efficient transition towards change in the energy system. The SEG as necessary requirement for a market access of GTs (compare also section 2) and the liberalization of the energy market at the end of the 1990’s as a necessary requirement for an increase in competition at the energy market. The SEG already allowed for a first diffusion of some GTs j (Wangler 2009). The problem that occurs is that non-renewable energy sources still produce externalities leading to distortions in competition. However, as mentioned above, a first best solution would be the internalization of the externality. This aim could be achieved by a stricter application of the emission trading scheme combined with open market access for GTs.

That supply is able to react in a very short time period to a changes in relative prices (the same is true for innovations), is one of the results demonstrated by the econometric model. However, as diffusion of GTs has been implemented artificially, diffusion of GTs may increase the speed of extraction of non-renewable energy sources. Diffusion of GTs therefore is accompanied by inefficiencies without significant positive impact on the environment. What remains is the positive effect of a reduction in uncertainty and the increase in knowledge stocks related to the production of green technologies.

5 Concluding Remarks

This study was aimed to test if policy induced structural change in the energy sector in Germany is accompanied by innovative activity. The empirical findings support the hypothesis that an increase in the size of the market has an impact on firms to be innovative. The empirical findings also show that public R&D expenditures are important. We test for reverse causality and find that innovative activities have a significant impact on the increase in market shares by themselves. Innovations in GTs are a necessary condition to substitute conventional energy technologies in the future. However, investment into GTs may not help to preserve non-renewable energy sources. There is also little hope for positive environmental impacts as feed-in tariffs are applied simultaneously with tradable certificates. Additional concerns are related to the institutional setting of the EEG as it bears the potential threat to create new lock-ins. Efficiency related to the diffusion of GTs would require a mechanism that allows for more self-selection by the market about future potential of different GTs j.

References

Arrow, K. J.: 1962, Economic Welfare and the Allocation of Resources for Invention, *in* R. R. Nelson (ed.), *The Rate of Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton, pp. 609–625.

Arthur, W.: 1984, Competing technologies and economic prediction, *IIASA Options*, **Vol. 2**, pp. 10–13.

Arthur, W.: 1989, Competing technologies, increasing returns, and lock-in by historical events, *The Economic Journal*, **Vol. 99(394)**, pp. 116–131.

Arthur, W.: 1994, *Increasing returns and path dependence in the economy*, University of Michigan Press, Ann Arbor.

Baumol, W. J. and Oates, W. E.: 1971, The use of standards and prices for protection of the environment, *The Swedish Journal of Economics*, **Vol. 73(1)**, pp. 42–54.

Baumol, W., Oates, W., Bawa, V. and Bradford, D.: 1988, *The theory of environmental policy*, Cambridge University Press, Cambridge.

Berry, W.: 1993, *Understanding regression assumptions*, Sage Publications.

BMU: 2007, *Erneuerbare Energien in Zahlen: Nationale und Internationale Entwicklung*, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. <http://www.erneuerbare -energien.de/files/erneuerbare_energien/-downloads/application/pdf/broschuere_ee_zahlen.pdf.

BMU: 2008, *Erneuerbare Energien in Zahlen: Nationale und Internationale Entwicklung*, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit. <http://www.erneuerbare-energien.de/files/erneuerbare_energien/-downloads/application/pdf/broschuere_ee_zahlen.pdf>.

Brunnermeier, S. and Cohen, M.: 2003, Determinants of environmental innovation in US manufacturing industries, *Journal of Environmental Economics and Management*, **Vol. 45(2)**, pp. 278–293.

Cameron, A. and Trivedi, P.: 1998, *Regression Analysis of Count Data*, Cambridge University Press.

Coase, R.: 1960, The problem of social cost, *The Journal of Law and Economics*, **Vol. 3(1)**, pp. 1–44.

Cohen, W. and Klepper, S.: 1992, The Tradeoff between Firm Size and Diversity in the Pursuit of Technological Progress, *Small Business Economics*, **Vol. 4(1)**, pp. 1–14.

Cohen, W. and Klepper, S.: 1996a, A reprise of size and R&D, *The Economic Journal*, **Vol. 106(437)**, pp. 925–951.

Cohen, W. and Klepper, S.: 1996b, Firm size and the nature of innovation within industries: the case of process and product R&D, *The Review of Economics and Statistics*, **Vol. 78(2)**, pp. 232–243.

COM: 2008, *Europe's climate change opportunity*, COM(2008) 30 final: COMMISSION OF THE EUROPEAN COMMUNITIES. <http://unfccc.int/-resource/docs/convkp/kpeng.pdf>.

Dales, J. H.: 1968, *Pollution, Property and Prices*, University of Toronto Press, Toronto.

Dasgupta, P. and Heal, G. M.: 1979, *Economic theory and exhaustible resources*, Cambridge Economic Handbooks.

David, P.: 1985, Clio and the economics of QWERTY, *The American Economic Review,* **Vol. 74(2)**, pp. 332–337.

Dernis, H., Guellec, D. and van Pottelsberghe, B.: 2000, Using patent counts for cross-country comparisons of technology output, *STI-Science Technology Industry Review,* pp. 129–146.

Dernis, H., Khan, M., for Economic Co-operation, O. and Development: 2004, *Triadic patent families methodology*, Paris: OECD.

EEG: 2000, *BGBl: Gesetz für den Vorrang Erneuerbarer Energien*, (BGBl. I S. 305). <http://www.bmu.de/gesetze/verordnungen/doc/2676.php>.

EEG: 2004, *Act on granting priority to renewable energy sources (Renewable Energy Sources Act)*, Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. <http://www.erneuerbare-energien.de/files/-pdfs/allgemein/application/pdf/eeg_en.pdf>.

EEG: 2009, *Act Revising the Legislation on Renewable Energy Sourcesin the Electricity Sector and Amending Related Provisions*, FederalMinistry for the Environment, Nature Conservation and NuclearSafety. <http://www.bmu.de/files/pdfs/allgemein/application/pdf/-eeg_2009-_en.pdf>.

Fontana, R. and Guerzoni, M.: 2008, Incentives and uncertainty: an empirical analysis of the impact of demand on innovation, *Cambridge Journal of Economics,* **Vol. 32**, pp. 927–946.

Freeman, C.: 1994, The economics of technical change, *Cambridge Journal of Economics,* **Vol. 18(5)**, pp. 463–514.

Glennerster, R., Kremer, M. and Williams, H.: 2006, Creating markets for vaccines, *Innovations: Technology, Governance, Globalization,* **Vol. 1(1)**, pp. 67–79.

Gray, L. C.: 1914, Rent under assumption of exhaustability, *Quarterly Journal of Economics,* **Vol. 28**, pp. 466–489.

Griliches, Z.: 1957, Hybrid corn: an exploration in the economics of technological change, *Econometrica,* **Vol. 132(3422)**, pp. 501–522.

Griliches, Z.: 1990a, Patent statistics as economic indicators: a survey, *Journal of Economic Literature,* **Vol. XXVIII**, pp. 1661–1707.

Griliches, Z.: 1990b, Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature,* **Vol. 28(4)**, pp. 1661–1707.

Griliches, Z.: 1998, *R&D and Productivity: The Econometric Evidence*, University Of Chicago Press.

Hall, B., Griliches, Z. and Hausman, J.: 1986, Patents and R&D: Is There a Lag?, *International Economic Review,* **Vol. 27(2)**, pp. 265–283.

Hartwick, J.: 1985, *The persistence of QWERTY and analogous seemingly suboptimal technologies*, Mimeo, Queen's University, Kingston, Ontario.

Hayek, F. A.: 1978/1993, *Law, legislation and liberty, Volume 2: The Mirage of Social Justice*, Routledge, Chicago-London.

Hicks, J. R.: 1932, *The theory of wages*, MacMillan, London.

Hotelling, M.: 1931, The economics of exhaustible resources, *Journal of Political Economy,* **Vol. 39(2)**, pp. 137–75.

IEA: 2007, *Energy Policies of IEA Countries: Germany 2007 Review*, International Energy Agency. <http://www.iea.org/textbase/nppdf/free/2007/-germany2007.pdf>.

IPCC: 2007, *International Panel on Climate Change, 30 April-4 May 2007: Mitigation of Climate Change – Summary for Policymakers*. <http://www.ipcc.ch/SPM040507.pdf>.

Johnstone, N., Hascic, I. and Popp, D.: 2008, Renewable energy policies and technological innovation evidence based on patent counts, *Working Paper, 13760*, NBER, Cambridge.

Kemp, R.: 1997, *Environmental policies and technical change. A comparison of the technological impact of policy instruments*, Edwar Elgar, Cheltenham.

Kleinknecht, A. and Verspagen, B.: 1990, Demand and innovation: Schmookler re-examined, *Research Policy,* **Vol. 19(4)**, pp. 387–94.

Klepper, S.: 1996, Entry, exit, growth, and innovation over the product life cycle, *The American Economic Review,* **Vol. 86(3)**, pp. 562–583.

Klepper, S. and Thompson, P.: 2006, Submarkets and the evolution of market structure, *RAND Journal of Economics,* **Vol. 34(4)**, pp. 861–886.

Lichtenberg, F. and Waldfogel, J.: 2003, Does misery love company? Evidence from pharmaceutical markets before and after the orphan drug act, *Working Paper, W9750*, NBER, Cambridge.

Maddala, G. S.: 1983, *Limited-Dependent and Qualitative Variables in Econometrics*, Cambridge University Press, Cambridge.

Mowery, D. and Rosenberg, N.: 1979, The influence of market demand upon innovation: a critical review of some recent empirical studies, *Research Policy,* **Vol. 8(2)**, pp. 102–153.

Nill, J. and Kemp, R.: 2009, Evolutionary approaches for sustainable innovation policies: From niche to paradigm?, *Research Policy,* **Vol. 38(4)**, pp. 668–680.

Nordhaus, W., Houthakker, H. and Solow, R.: 1973, The Allocation of Energy Resources, *Brookings Papers on Economic Activity,* **Vol. 3**, pp. 529–570.

Norgaard, R.: 1994, *Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future*, Routledge, London and New York.

Olmstead, S. and Stavins, R.: 2006, An international policy architecture for the post-Kyoto era, *American Economic Review,* **Vol. 96(2)**, pp. 35–38.

Pavitt, K.: 1984, Sectoral patterns of technical change: towards a taxonomy and a theory, *Research policy,* **Vol. 13(6)**, pp. 343–373.

Pigou, A. C.: 1924, *The economics of welfare*, MacMillan, London.

Popp, D.: 2002, Induced innovation and energy prices, *American Economic Review,* **Vol. 92(1)**, pp. 160–180.

Popp, D.: 2005, Using the Triadic Patent Family Database to study environmental innovation, *Environment Directorate Working Paper, ENV/EPOC/WPNEP/RD (2005) 2*, OECD, France, Paris.

Popp, D. and Newell, R. G.: 2009, Where Does Energy R&D Come From? Examining Crowding Out from Environmentally-Friendly R&D, *Working Paper , 15423*, NBER.

Rennings, K.: 2000, Redefining innovation-eco-innovation research and the contribution from ecological economics, *Ecological Economics,* **Vol. 32(2)**, pp. 319–332.

Rosenberg, N.: 1974, Science, invention and economic growth, *The Economic Journal,* **Vol. 84(333)**, pp. 90–108.

Rotmans, J., Kemp, R. and van Asselt, M.: 2001, More evolution than revolution, *Transition Management in Public Policy, Foresight,* **Vol. 3(1)**, pp. 15–31.

Salter, W.: 1960, *Productivity and technical change*, Cambridge University Press, Cambridge.

Scherer, F.: 1982, Demand pull and technological invention: Schmookler revisited, *Journal of Industrial Economics,* **Vol. 30(3)**, pp. 225–237.

Schmookler, J.: 1962, Determinants of industrial invention, *in* R. R. Nelson (ed.), *The Rate of Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton.

Schmookler, J.: 1963, *Invention and economic growth*, Harvard University Press, Camebridge, MA.

Schumpeter, A. J.: 1934, *The theory of economic development*, Harvard University Press.

Schumpeter, A. J.: 1942, *Capitalism, socialism and democracy*, Harper.

SEG: 1990, *BGBl: Gesetz über die Einspeisung von Strom aus erneuerbaren Energien in das öffentliche Netz (Stromeinspeisungsgesetz),* (BGBl I S. 2633). <http://www.gesetzesweb.de/Strom.html>.

Sinn, H.: 2008, Das grüne Paradoxon: Warum man das Angebot bei der Klimapolitik nicht vergessen darf, *Working Paper , No.54*, Ifo, München.

Sørensen, B.: 1991, A history of renewable energy technology, *Energy Policy,* **Vol. 19(1)**, pp. 8–12.

Toke, D. and Lauber, V.: 2007, Anglo-Saxon and German approaches to neoliberalism and environmental policy: the case of financing renewable energy, *Geoforum,* **Vol. 38**, pp. 677–687.

Traber, T. and Kemfert, C.: 2009, Impacts of the German Support for Renewable Energy on Electricity Prices, Emissions, and Firms, *The Energy Journal,* **Vol. 30(3)**, pp. 155–178.

Unruh, G.: 2000, Understanding carbon lock-in, *Energy Policy,* **Vol. 28(12)**, pp. 817–830.

Unruh, G.: 2002, Escaping carbon lock-in, *Energy Policy,* **Vol. 30(4)**, pp. 317–325.

van den Bergh, J.: 2003, Evolutionary thinking in environmental economics: retrospect and prospect, *in* J. Foster and W. Holzl (eds), *Evolutionary Thinking in Environmental Economics: Retrospect and Prospect. Applied Evolutionary Economics and Complex Systems*, Edwar Elgar, Cheltenham.

van den Bergh, J., Faber, A., Idenburg, A. and Oosterhuis, S.: 2007, *Evolutionary Economics and Environmental Policy: Survival of the Greenest*, Edward Elgar Publishing.

van den Bergh, J. and Gowdy, J.: 2000, Evolutionary theories in environmental and resource economics: approaches and applications, *Environmental and Resource Economics,* **Vol. 17(1)**, pp. 37–57.

Wacker, H. and Blank, J. E.: 1999, *Ressourcenökonomik (Bd.2, Einführung in die Theorie erschöpfbarer natürlicher Ressourcen)*, R. Oldenburg Verlag, München and Wien.

Wangler, L.: 2009, The Political Economy of the Green Technology Sector, *Working Paper, No. 2009-024*, JERP.

Witt, U.: 1989, The evolution of economic institutions as a propagation process, *Public Choice,* **Vol. 62(2)**, pp. 155–172.

Witt, U.: 1997, "Lock-in" vs. "critical masses" – industrial change under network externalities, *International Journal of Industrial Organization,* **Vol. 15(6)**, pp. 753–773.

Wooldridge, J. M.: 2002a, *Econometric analysis of cross section and panel data*, MIT Press.

Wooldridge, J. M.: 2002b, *Introductory Econometrics: A Modern Approach*, Thomson, South-Western.

Appendix

The empirical data

Patents (*PAT*) and all patents Germany (*APAT*), source DEPATIS net
Table 11 contains the list of patent classes from which the patent counts are extracted. The "renewable energy sector specific technologies" of interest are electricity production with wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO) and biomass (BIO). The original table on patent classes has been developed by Johnstone et al. (2008).[29] The patent data comes from the German Patent office.[30] The vector contains patents that have been granted in Germany (including the "Neue Bundesländer") using the *date of application*.[31] The data does not contain double counting and only those patents with priority for Germany are taking into account in order to exclude foreign inventors. Information captured with *PAT* are on national level and sector specific (WIND, SOLAR, WATER, GEO, BIO).
Information captured with *APAT* are also on national level but are not sector specific. *APAT* stands for the count of alls patents applied for in Germany.

German R&D expenditures(*RuD*), source IEA
The data on sector specific public expenditures on *R&D* in the different GT industries comes from the international energy agency.[32] R&D refers to expenditures of the federal government. The resources can be given to private as well as public entities. The data is in million Euro on exchange rates from 2006.[33] Information captured with *RuD* are on national level and sector specific (WIND, SOLAR, WATER, GEO, BIO).

German installed capacity of sector specific technology INCAP, source BUND
INCAP is used as a proxy for the size of the market for different GTs. The data contains information about the installed capacity measured in megawatt hours (MWh). It measures the overall installed capacity of the sector specific technology per year. The data comes from the Ministry for the Environment in Germany.[34] Information captured with *INCAP* are on national level and sector specific (WIND, SOLAR, WATER, GEO, BIO)).

[29] Note that the list is extended with patent classes for WATER as the law for renewable energy which is analyzed for Germany also changed the institutional framework for energy produced with water. On the other hand WASTE is excluded from the list because it is difficult to separate non-renewable waste from renewable waste.

[30] For further information see http://depatisnet.dpma.de/DepatisNet/depatisnet?-window=1&space=menu&content=index&action=recherche&session=c23b66f230d535e054a-0e96346f598d6b4b3c0c1ada0&stamp=34353.

[31] Even though information about patents until 2007 are available, the analysis is restricted to 2005. The information about the last two years is dropped to get rid of the problem that there is a long time lag between the application for a patent and patent granting. Once the patent is granted, the patent protection goes back to the application date. Therefore, it is plausible to assume that the data from 2006 and 2007 contains a lack of information (Popp 2005, p. 5).

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

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

[34] Compare BMU (2007).

Electricity price index ($CPIE$), electricity consumption (ELC), source GSO and IEA
The electricity price index comes from the German Statistical Office. $CPIE$ is inflation corrected and the year 2004 is set to 100. Consumption taxes are not taken into account. Information about ELC comes from the International Energy Agency. ELC is measured in kilowatt hours per capita. Information captured with $CPIE$ and ELC are on the national level and are not sector specific.

Table 7: Correlation matrix 1

	PAT	$INCAP$	$CPIE$	ELC	$APAT$	RuD
PAT	1.0000					
$INCAP$	0.1745	1.0000				
$CPIE$	-0.2146	-0.2630	1.0000			
ELC	0.1380	0.3558	-0.5783	1.0000		
$APAT$	0.2214	0.2927	-0.9467	0.5699	1.0000	
RuD	0.7675	-0.2187	0.1156	-0.0693	-0.1271	1.0000

Table 8: Correlation matrix 2

	PAT_{t-1}	$INCAP$	$CPIE_{t-2}$	ELC_{t-2}	$APAT_{t-2}$	RuD_{t-1}
PAT_{t-1}	1.0000					
$INCAP$	0.4076	1.0000				
$CPIE_{t-2}$	-0.1822	-0.3500	1.0000			
ELC_{t-2}	0.0755	0.2465	-0.6393	1.0000		
$APAT_{t-2}$	0.1873	0.3401	-0.9555	0.5095	1.0000	
RuD_{t-1}	0.7854	0.0180	0.1230	-0.0429	-0.1434	1.0000

Table 9: Correlation matrix 3

	ΔPAT	$\Delta(\Delta INCAP)$	$\Delta CPIE_{t-2}$	ΔELC_{t-2}	$\Delta APAT_{t-2}$	ΔRuD_{t-1}
ΔPAT_{t-1}	1.0000					
$\Delta(\Delta INCAP)$	0.4434	1.0000				
$\Delta CPIE_{t-2}$	-0.1578	-0.1618	1.0000			
ΔELC_{t-2}	-0.1726	0.0016	-0.1941	1.0000		
$\Delta APAT_{t-2}$	-0.0140	-0.0202	-0.2537	-0.1957	1.0000	
ΔRuD_{t-1}	0.3028	-0.0121	-0.0913	0.1176	-0.0155	1.0000

Table 10: Correlation matrix 4

	ΔPAT	$\Delta(\Delta INCAP)$	$\Delta CPIE_{t-3}$	ΔELC_{t-3}	$\Delta APAT_{t-2}$	ΔRuD_{t-1}
ΔPAT_{t-1}	1.0000					
$\Delta(\Delta INCAP)$	0.4517	1.0000				
$\Delta CPIE_{t-3}$	0.1676	0.0931	1.0000			
ΔELC_{t-3}	-0.1230	-0.0198	-0.4736	1.0000		
$\Delta APAT_{t-2}$	-0.0133	-0.0208	-0.5101	0.0009	1.0000	
ΔRuD_{t-1}	0.3274	-0.0095	-0.1775	0.1464	-0.0110	1.0000

Table 11: 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. (2008)

Feed-in tariffs under the EEG

Table 12: Remuneration (FIT) for different GTs

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%