Impact of climate policy and external shocks on innovation in renewable energy technologies

Pia Weiss & Dirk Rübbelke

Abstract

Environmental regulations enforced after 1997 in signatory states of the Kyoto Protocol were partly designed to meet the emission reduction targets to which the countries committed to. One of the pillars of climate change policy is to boost development and use of renewable energy technologies (RET). A number of empirical studies investigated the impact of environmental regulations on innovative activities in RET. Since they rely an traditional empirical methods, they present an incomplete picture. We complement this view by applying innovative methods frequently employed in social network analysis.

We show that the first oil price shock and the signing of the Kyoto Protocol had a profound effect on the patenting activities in RET. Both shocks resulted in research that looked beyond the known traditional knowledge fields to find better solutions in RET. Above all, we find that both shocks led researchers to exploit synergies in apparently distinct technology fields.

1 Introduction

Today, innovations are perhaps the most important ally in battling climate change. Researchers are developing cleaner technologies, e.g. cars that are capable of emitting less greenhouse gases than earlier models. As all economic activity, research and development (R&D) responds to incentives which may be policy induced or external. Therefore, external and policy induced shocks may alter the direction of R&D. For instance, automobile producers developed more fuel efficient engines after governments imposed emission standards. This leads us to believe that one of the most important factors in battling climate change is to set incentives for eco-friendly innovations. However, to adequately set incentives, we need an accurate picture of how R&D and innovations responded to external shocks and policy shocks in the past.

After the first oil price shock and again with the negotiations to the Kyoto Protocol, countries initiated a variety of programs to make domestic energy supply more independent of oil imports and thereby less polluting. Today, every industrialised country has a number of government financed programs to support R&D as well as the deployment of renewable energy technologies. To evaluate and potentially re-focus these government programs, we need to establish the success of similar programs in the past. In recent years, a number of studies examined whether environmental regulations had a positive impact on patenting activities in e.g. renewable energy technologies. These studies exclusively relied on traditional econometric techniques [1, 2, 3, 4, 5, 6]. We believe that these methods uncover only part of how R&D responded to altered incentives because they neglect important interrelations between patents. We therefore used graph theory, a technique widely used in studying social networks, to reveal new facts about the impact of shocks on innovations in renewable energy technology [7, 8].

We chose families of worldwide patent applications to measure innovation (see supplement, patent applications and innovations). We included all families of patent applications classified as one of seven electricity generating technologies using renewable energy sources. According to the European Patent Classification System (ECLA) they are: geothermal energy, hydro energy, energy from the sea, solar thermal energy, photovoltaic, thermal-photovoltaic hybrid technology or wind energy (see methods, data collection). Our renewable energy sample consists of 131,371 worldwide patent applications filed between 1882 and 2010. In order to distinguish the effects of shocks on patenting activities from general trends in all patent classes, we used a control group for which we randomly selected 131,371 worldwide patent applications.

For each of the patent families, we collected the application year and all IPC classes. We use the fact that most patent applications are assigned to a number of IPC classes to construct a IPC-network (see methods, construction of networks). For instance, the EPO received a patent application (EPO 200909380102.5) in 2009 which it classified as relevant for generating electricity from wind energy according to the ECLA system (Y02E10:70). The patent was assigned to the F03D 11/04, E04H 12/12 and E04H 12/16 according to the IPC. In our IPC-network, this patent application would translate into three edges connecting the three IPCs. The edges retain the information on renewable technologies as an edge attribute. To aid graphical representation, we assigned different colors to the renewable energy technologies and merged multiple edges between the same IPCs given they belong to the same renewable energy technology. Consequently, we will have pairs of IPC classes that are still connected by more than one edge as e.g. classes F03G 7/04 and F25B 30/02 in Figure 1(b).

For the control group, we cannot assign patent applications to distinct technologies with precision. We are therefore not able to color-code the edges of the resulting IPC-network and to identify IPC classes that may serve as hub for knowledge spillovers. However, we can compare the properties of the renewable energy network with the properties of the control group's network.

General trends

Our focus is on the impact of external and policy shocks on patent activity. Therefore, we need to introduce time as a dimension. We create seven subgraphs, each covering the first five years of a decade, beginning with 1940. In addition, we created a graph covering 1978 to 1982 to capture the post oil-price-shock period. Figure 1 shows the subgraphs for the renewable energy sample as well as for the control group for worldwide patent applications filed between 1940 and 1944.

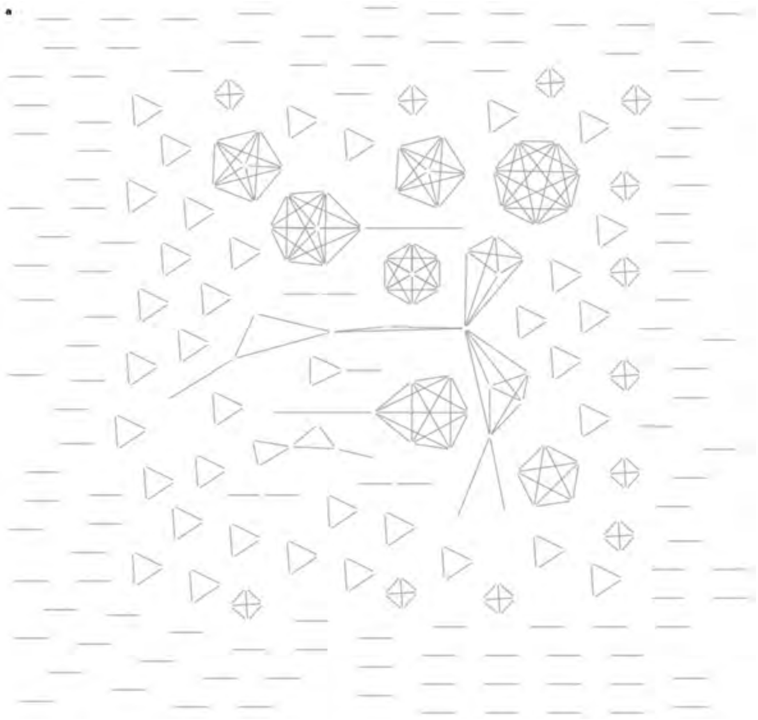
Our renewable energy sample and the control group both consist of distinct technologies so that we would expect the resulting graphs to be somewhat alike. In fact they are not. The control group has a much higher number of connected components than the renewable energy sample and vertices appear to be less well connected. By comparing the properties of the control group's graph to those of the renewable energy graph, we are therefore able to separate the general trend affecting all patent activities from the ones specific to renewable energy technologies. We summarise the properties for important time intervals in Table 6 (see supplement, Table 3 for the properties for all time intervals).

Table 1: Renewable energy technologies and control group

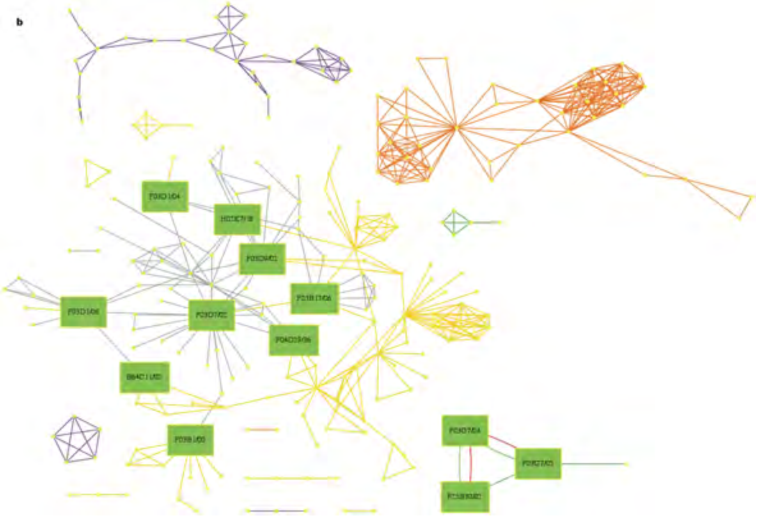
	1940-44	1970-74	1978-82	1990-94	2000-04
Control group					
IPCs	456	9728	11854	15750	19737
Av Degree	1.99	7.15	8.00	12.34	20.87
Density	0.0044	0.0007	0.0007	0.0008	0.0011
Components	171	1114	1032	707	524
Av Size	3	9	11	22	37
Renewable energy technologies					
IPCs	226	943	2997	2182	5708
Av Degree	4.29	7.89	12.99	11.90	26.07
Density	0.0191	0.0083	0.0043	0.0055	0.0046
Components	14	29	23	30	24
Av Size	16	33	130	73	238
Sinks	12	99	482	348	1244

In the first row, we recorded the number of vertices, i.e. IPC classes that form the basis of the respective subgraph (see methods, construction of networks and supplement, comparing graphs). A patent application is only assigned to a patent class if the invention makes a contribution to the technology field associated with the IPC. Consequently, the number of IPCs illustrates how diverse patentable research has been over the selected period of time. The first row for the control group shows us that patenting activities have rapidly spread into a large number of technology fields between 1940 and 1970. Over the succeeding 30 years, i.e. between 1970 and 2000, R&D ventured into relatively fewer "new" technology fields. This slower pace of discovering new technology fields is to be expected since new IPCs are created sparingly. Although patent applications for nanotechnology have been filed since at least 1984 (patent application number US19840626177 19840629), a separate IPC class for nanotechnology (B82) was only created with version 8 in 2006.

The second row contains the average degree of a vertex, i.e. the average number of edges connected to an IPC class. For the control group, we observe a



(a) Control group



(b) Renewable energy sample

Geothermal
SolarThermal
Wind
Hydro
Photovoltaic
Sea
Thermal/PV-Hybrid

Figure 1: IPC network for patent applications between 1940 and 1944

steady increase in the average degree over time. We can therefore conclude that inventions tend to draw upon a larger variety of knowledge over time. Again, the effect is more pronounced between 1940 and 1970 than between 1970 and 2000. The average degree is rather intuitive, but it is not normalised, i.e. a graph consisting of 3 vertices cannot have an average degree of 7 unless we allow multiple edges between the same pair of vertices. Therefore, we also present the normalised version of the average degree — the density (see supplement, comparing graphs). The density is 0 if the graph has no edges, i.e. if it is totally disconnected; and it will be 1 if every vertex is connected to every other vertex in the graph. In general, we find that the control group's subgraphs are extremely loosely connected; a notion that is confirmed by Figure 1(a) for the 1940s. Interestingly, the density was sharply dropped after the 1940s to remain fairly stable at about 0.0008 afterwards.

We also present the number of connected components (third row) and the average size of the components (fourth row) in Table 6. Both measures give a much better picture of the overall connectedness of the graph than the average degree. Figure 1(a) illustrates the point for the control group. We find a relatively large number of small components in the 1940s — the average size is just three. Although the number of connected components rapidly increase over the 30 years between 1940 and 1970, the average size of a component increases slightly. From the tremendous increase in the number of both IPCs and connected components we conclude that although research expanded into a vast number of new technologies fields, knowledge remained fairly isolated to specific areas. Over the subsequent 30 years (1970-2000) we observe a steady increase in the average size of connected components suggesting that modern inventions are based on a wider knowledge base.

To summarise, the number of technology fields in which R&D has made significant advances has exploded since 1940 for our randomly selected control group. As to be expected for a random sample, the graphs are rather disconnected. The level of connectedness stays fairly constant from 1970 onwards although each vertex is on average connected to more technology fields.

Trends in renewable energy technologies

The size of the renewable energy technologies subgraphs are smaller than the subgraphs for the control group. Even though we consider photovoltaic to be distinct from e.g. wind energy technology, the knowledge base is much more concentrated than the one for the control group. Between 1940 and 1970, the network expands by about 320% whereas the control group expanded by more than 2000%. Different from the control group however, the renewable energy technologies extended much faster into new technology fields than the control group between 1970 and 2000. We found this discrepancy especially pronounced following the oil price shocks (1970-74 compared to 1978-82) and to a lesser degree following the signing of the Kyoto Protocol in 1997 (1990-94 compared to 2000-04).

The data on the average degree re-enforce the findings. Technology fields tend to be more interconnected in our renewable energy sample than in the control group. This suggests that technology spillovers are more pronounced in the renewable energy sample than in a random sample. Again, we observe a particular increase in the use of diverse knowledge around the Kyoto Protocol.

As in the control group, the density of the graphs decrease over time. We also find that the graphs in our renewable energy sample are rather loosely connected. This fact confirms our notion that the renewable energy technologies are distinct technologies even though they occasionally contribute to the same technology fields (IPCs). However, we also find that the renewable energy technology sample is more than four times more dense then the control group suggesting that renewable energy technologies have more in common than a random selection of patent applications.

As discussed before, the number and average size of connected components gives a much better idea about how homogeneous the interrelatedness of technology fields is. As expected, we found that a random sample of inventions is only loosely connected with a large number of rather small connected components. We find a completely different picture in our renewable energy sample as a comparison between Figure 1(a) and 1(b) shows. We generally observe a much smaller number of connected components that are also on average larger in the renewable energy sample. The average size of the connected components increases dramatically after the oil price shocks (1978-82 compared to 1970-74). After the oil price returned to its pre-oil-price-shock level, and the various government funded programs established in the wake of the oil price shocks tapered off, the average size of the connected components returned to the 1970s level. However, after the signing of the Kyoto Protocol, the average connected component size was almost eight times the pre-Kyoto level (see also Figure 2 and 3). Again, we believe that the sharp increase in the size of the connected components is a sign that renewable energy technologies rely on and contribute to a larger knowledge base. We believe that this cannot be explained by a general trend but that it is the caused by the oil price shocks in the 1970s and the impact of the Kyoto Protocol in the 1990s.

Evidence on knowledge spillovers

A patent application is assigned to an IPC class if it makes a contribution to the technical progress in the field. Figures 1(b), 2 and 3 show clearly that the renewable energy technologies are build on a large number of IPCs. It can also be seen that certain IPCs are central for more than one renewable energy technology. These technology fields may therefore allow spillovers from e.g. wind energy technology to hydro electricity technology and vice versa (F03 D1/04 in Figure 1(b) is for "wind rotors"). We call such IPCs sinks. In Figures 1(b), 2 and 3, we marked the sinks as boxes with different colors indicating how many different renewable energy technologies are contributing to the IPC.

We find that the number of sinks as well as the number of renewable energy

(a) 1970-1974

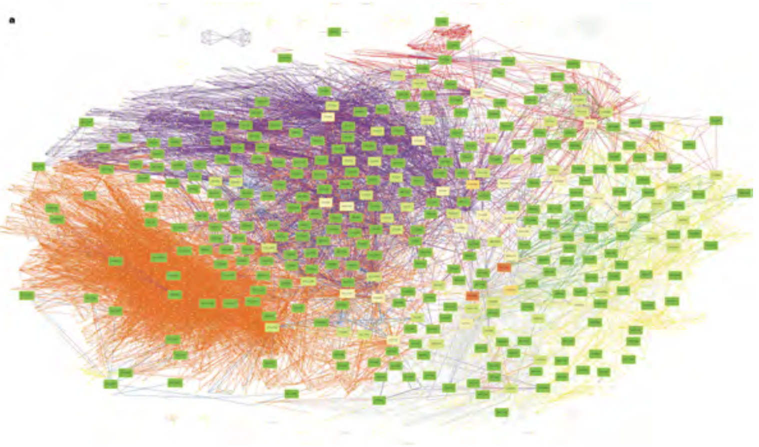
(b) 1978-1982

Geothermal
SolarThermal
Wind

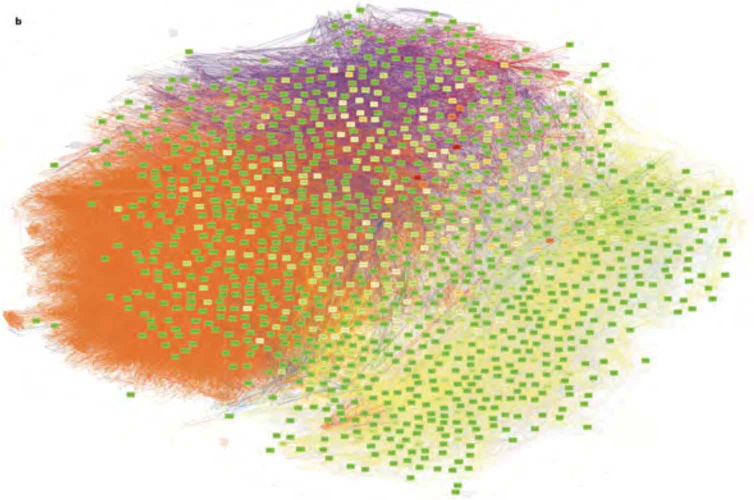
Hydro
Photovoltaic
2 3 4 5 6 7

Sea
Thermal/PV-Hybrid

Figure 2: IPC network for renewable energy technologies before and after the oil price shocks



(a) 1990-1994



(b) 2000-2004

Figure 3: IPC network for renewable energy technologies before and after the singing of the Kyoto Protocol

technologies contributing to the IPC class rises sharply around the oil price shocks and again around the Kyoto Protocol. This development is consistent with the notion that the different renewable energy technologies "move towards" each other, i.e. become more intertwined.

In Figure 1(b) both solar technologies (photovoltaic and solar thermal energy technology) have apparently nothing in common with each other nor with other renewable energy technologies in the 1940s. Patent applications for geothermal energy and energy from the sea, however, share three IPCs in the 1940s. The largest connected component with the largest number of sinks is formed by patent applications for wind and hydro energy technologies. We also notice that none of the sinks are vital for three or more renewable energy technologies in the 1940s.

Shortly before the oil price shocks the picture has changed. We can see that the largest connected component is now formed from all renewable energy technologies, i.e. now there are some synergies between photovoltaic and solar thermal energy as well as with all the other renewable energy technologies. In the 1970s, both the number of sinks and the number of renewable energy technologies for which the sinks are important have increased since the 1940s. We therefore conclude that the search for synergies and the exploitation of spillovers is a natural process in R&D. It is therefore natural to expect a further increase of the number of sinks between 1970-74 and 1978-82. In fact however, we observe an average yearly increase of 48% around the oil price shocks, twice as much as in the 30 years before 1970. In our opinion, this indicates that the oil price shocks not only triggered an explosive search for solutions for renewable energy technologies in unfamiliar technology fields, but more importantly to an exploitation of knowledge spillovers.

Remarkably, the number of sinks slightly decreased until the pre-Kyoto period in 1990-94. In the period of 2000-04, i.e. after the singing of the Kyoto Protocol, we again observe an increase in the number of sinks and the number of renewable technologies which contribute to the sinks. For the first time, we find IPC classes that are used in all seven renewable energy technologies. We believe that the magnitude of the increase in sinks cannot be explained by an underlying common trend, but is largely driven by the negotiations to the Kyoto Protocol (see supplements, an empirical test).

Conclusions

The role of innovation in the battle against climate change has been well recognised in the economics literature. A number of papers have studied the driving forces behind climate change mitigating innovations [5] or renewable energy technologies [3]. These studies rely on (weighted) patent counts as a proxy for innovation and control for external shocks as e.g. the oil price shocks in the 1970s. However, we feel that traditional econometric methods for studying external and policy induced shocks on innovations in renewable energy technologies miss important details since they neglect technological interrelations between patent applications. We therefore used graph theory to uncover new facts about the effects of external and policy induced shocks on the interrelatedness between the renewable energy technologies.

We find that the exploitation of technology fields that have not been used in connection to renewable energy technologies is especially pronounced after the oil price shock and — although to a lesser degree — after the signing of the Kyoto Protocol. Although we observe a similar trend in the control group, the increase for the renewable energy sample is too large to be explained by a common trend.

Even more remarkably, the oil price shock and the negotiations for the Kyoto Protocol seem to have induced researchers to exploit synergies between the renewable energy technologies. We believe that these two events fundamentally altered R&D in renewable energy technologies which is corroborated by an econometric test (see supplements, an econometric test).

Methods

Data collection

The renewable energy sample

We use the 2010 edition of the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office (EPO) to construct both the renewable energy data set and the control group. PATSTAT provides a wealth of information on patent applications including details on inventors, applicants, technology classes, relation to other (successful) patent applications and more.

We extracted 131,371 patent applications assigned to group "Y02E10" of the European Patent Classification system (ECLA) (see supplement, patent applications and technology classes). This group "Y02E10" contains applications that contribute to the technology field of "Energy generation through renewable energy sources" and is further divided into Geothermal energy ("Y02E10:10", henceforth class 10), Hydro energy (20), Energy from sea (30), Solar thermal energy (40), Photovoltaic (50), Thermal-photovoltaic hybrid technologies (60) and Wind (70). For each patent application, we recorded the first application year, the patent family and the classes according to the International Patent Classification System (IPC). Since applicants may seek to protect a single invention in several countries, we used information on patent families to remove all multiple entries of the same invention (see supplement, patent applications and innovations).

Construction of the control group

In constructing the control group, we randomly selected the same number of patent applications (131,371) from PATSTAT. We recorded the first application year, the patent family and the IPC classes and removed multiple entries using the patent family information.

Construction of networks

Most patent applications are assigned to more than one IPC class on the lowest level. For instance, a recent patent application for “Integrated Circuits Based on Aligned Nanotubes” (application number: US201213447105 20120413) is assigned to classes H01L29/76 and B82Y99/00 thereby establishing a connection between unipolar semiconductor devices (H01L29/76) and specific uses or applications of nano-structures (B82Y99/00). We use the IPC classes for each invention to construct a network where the vertices are IPC classes on the lowest level and edges between the networks represent inventions. A single invention adds more than one edge to the network if the invention is classified in more than two IPC classes. To draw a clearer picture, we merged multiple edges between the same IPC classes.

Analysis

We constructed a network of IPC classes for the renewable energy technologies and the control group for the first five years of each decade from 1940 onwards. In addition, we created a network for the time interval between 1978-1982 to study whether the oil price shocks had any effect on patenting activities in renewable energy technologies. We used NetworkX to create the networks and Graphviz to render the graphs on the High Performance Cluster of the University of Nottingham.

A number of measures have been developed to characterise and compare graphs [9, 10] (see supplements, comparing graphs).

Sinks

Each edge connecting two IPC classes represents the number of inventions belonging to the same renewable energy technology. We retain this information as an edge attribute and assign different colors to the renewable energy technologies. We call an IPC that is connected by edges representing different renewable energy technologies as “sinks”. Therefore, “sinks” are patent classes, where knowledge spillovers are likely to occur.

Unfortunately, we cannot construct sinks for the control group since the ECLA “Y” group is reserved for a very limited amount of technologies and no alternative is available.

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Supplements

Patent applications and innovations

Unfortunately, we lack a good and consistent measure for innovation for several reasons. Firstly, researchers have failed to define what is exactly meant by an innovation. Traditionally, we distinguished product innovations and process innovations. More recently, researchers have acknowledged that changes in the organisational structure may also be innovative. Secondly, even if we had a precise definition of innovation, firms are often reluctant to disclose any information about the subject to protect their intellectual property rights and more importantly their position in the product market.

These problems have lead researchers to regard the process of research and development (R&D) as a special form of technology which transforms inputs into outputs where the outputs of the "R&D technology" are "innovations". The one property that sets R&D apart from any other technology is the fact that the transformation process is highly uncertain, i.e. more inputs do not guarantee "more innovation" or indeed any innovation. Nevertheless, this notion allows us to measure "innovations" indirectly, by either measuring the either inputs, i.e. research expenditures, number of researchers etc., or by finding a proxy for innovations itself. Both approaches have advantages and disadvantages [11]. We decided to use patent applications as a proxy for innovations because they offer a wealth of standardised information about inventors, applicants, technology fields and more. Although patent applications are often a first step to an innovation, not every application is granted a patent and not every patent is turned into an innovation. However we believe that patent applications are the best proxy for our study.

Patents give the owner the exclusive right to use the invention in the country that granted the patent. Consequently, applicants tend to apply for a patent in the country in which they intend to use the invention. In countries in which the owner did not apply for a patent, the invention could be legally copied. All patent applications for the same invention are called a patent family. We use patent families as a proxy for innovations.

Patent applications and technology classes

Each patent application is assigned to one or more patent classes of a national and international patent classification system. For our purpose, two systems are particularly useful: the International Patent Classification System (IPC) developed by the World Intellectual Property Organisation (WIPO) and the European Patent Classification System (ECLA) used by the European Patent Office (EPO). Using the IPC ensures that our data will be consistent, i.e. all patent applications assigned to e.g. “F03D 7/00” will all make contributions to “Controlling wind motors” [12] independent of when and where they were filed. Although the IPC guarantees consistency, the patent classes and technology fields are not usually the same. The ECLA system allows us to identify all patent applications relevant for seven “energy generating technologies using renewable energy sources”, i.e. ECLA classification “Y02E10”.

Comparing graphs

We can use a number of measures to characterise and compare graphs [9]. The simplest and most obvious one is the number of vertices (IPC classes). We call a graph larger when the number of vertices is higher.

However, we are not only interested in the size of the graphs but also on how well the vertices are connected. A simple measure of connectedness is the “average degree” (ADegree), i.e. the ratio between the total number of edges in a graph and the total number of vertices

$$\text{ADegree} = \frac{E}{V},$$

where E is the number of edges and V is the number of vertices in a graph. Although the average degree is a very intuitive measure, it is not normalised. This makes it more difficult to compare graphs of different size. We therefore also provide the density of a graph [10]:

$$\text{Density} = \frac{2 * \text{ADegree}}{V - 1}.$$

The density of a graph is 0 if it only consists of unconnected vertices; and it will be 1 if every vertex is connected to all other vertices. Naturally, larger graphs tend to be less dense than smaller ones.

Neither ADegree nor Density give us any information about well vertices are globally connected in the graph. We use the number of connected components and the average size of the components to capture global connectedness.

An empirical test

We want to further pursue the question whether the oil price shocks and the negotiations for the Kyoto Protocol had an impact on the number of sinks in our renewable energy sample. We employ standard empirical methods to quantify the effects of the oil price shocks and the Kyoto Protocol. In particular we use the number of sinks as the dependent variable.

Estimation method and variable construction

The number of sinks is a count variable so that employing a Poisson regression instead of an ordinary least square estimation produces better results. In particular, we use the following estimation model to estimate the impact of the oil price shocks and the Kyoto Protocol on the number of sinks y:

$$\log E(y_t|X_t) = a + b'X_t,$$

where y_t is the number of sinks in year t, X_t represent the independent variables in year t, a the constant intercept, and b the coefficients.

In order to construct the number of sinks (y), we create a network for our renewable energy sample for every year between 1940 and 2008. The number of stinks each year is recorded in y_t.

As independent variables, we use the nominal oil prices (retrieved from http://inflationdata.com/inflation/Inflation_Rate/Historical_Oil_prices.asp) and dummy variables for the first oil price shock and the negotiation and coming into effect of the Kyoto Protocol. The variable for the first oil price shock takes the value 1 from 1973 onward and 0 otherwise. We therefore test whether the relationship between the oil price and the number of sinks fundamentally altered with the occurrence of the first oil price shock. The dummy variable KyotoN takes the value 1 from 1997 onward, the year when negotiations were successfully brought to an end. The variable KyotoR takes the value 1 from 2005, i.e. when the Kyoto protocol came into force.

Results

We present the estimation results in the first column of Table 2. We found the nominal oil prices, the first oil price shock and the signing of the Kyoto Protocol to have a highly significant and positive on the number of sinks. We reported the standard error (SE) on the second column. The interpretation of the coefficients is difficult for the Poisson model. Therefore, we also calculated the marginal effects dy/dx which are given in the third column of Table 2.

Table 2: Estimation results

Sinks	Coeff	(SE)	Marg Effect	(SE)
OilP	0.021^{***}	(0.003)	1.759^{***}	(0.248)
OilPShock	3.007^{***}	(0.148)	250.876^{***}	(20.451)
KyotoN	0.867^{***}	(0.127)	72.333^{***}	(13.148)
R^2	0.91			

$p < 0.1\% : ***; p < 1\% : **; p < 5\% : *$

According to the marginal effects, an increase in the nominal oil price by $1 will increase the number of sinks by 1.75. The first oil price shock fundamentally altered the this relationship between the nominal oil price and the number of sinks. After 1973, the number of sinks is has increased 251 even without a further increase in the oil price. The successful negotiations of the Kyoto Protocol lead to another increase in the sinks by 72. We do not report the effect of the ratification of the Kyoto Protocol because it was insignificant. Figure 4 illustrates the estimation.

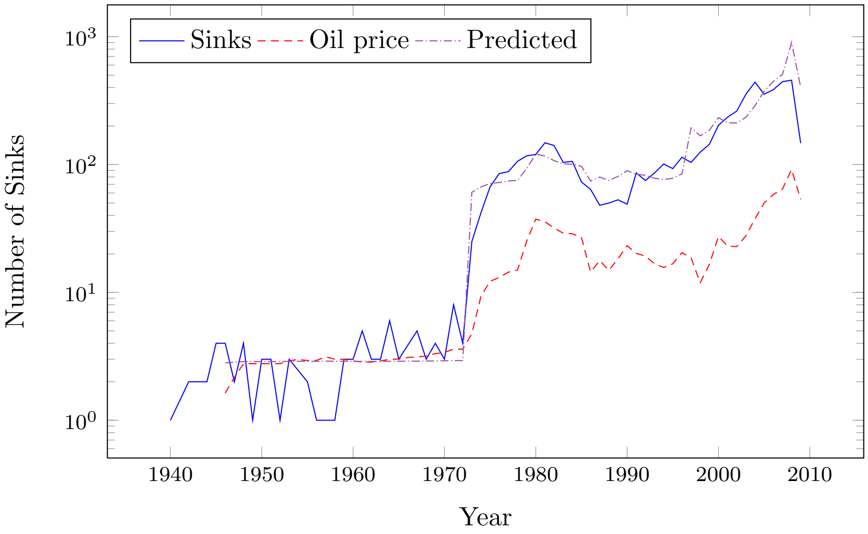

Figure 4: Number of sinks, oil price and predicted number of sinks

We find that before 1973, the nominal oil price (dashed line) was a good indicator for the number of sinks in our renewable energy sample. However after 1973, the number of sinks reached a much higher level. The effect of the successful negotiations of the Kyoto Protocol have a much smaller effect than the first oil price shock. Overall, our model fits reasonably well as a comparison between the number of sinks and the predicted number of sinks (dashdotted line) shows.

Table 3: Created sinks for country

	1	2	3	4	5	Sum(1-3)
70s	US	FR	DE	JP	GB	
	51.31	14.10	13.44	4.10	3.77	78.85
80s	US	JP	DE	FR	GB	
	32.48	30.77	19.80	6.55	2.14	83.05
90s	DE	US	JP	GB	FR	
	31.39	29.91	14.56	3.13	3.03	75.86
00s	US	DE	JP	GB	FR	
	31.57	20.13	12.69	5.60	3.99	60.39
70s-00s	US	DE	JP	FR	GB	
	33.46	21.40	14.33	5.22	4.53	69.23

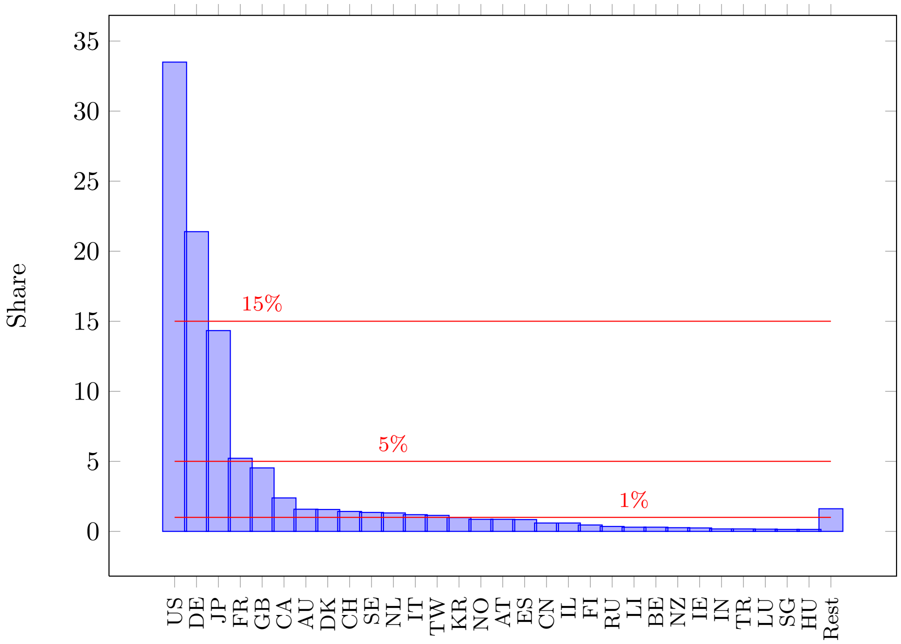

Figure 5: Number of created sinks by country 1970-2009

	10	20	30	40	50	60	70	Sinks
Anvar 70s			3.70	81.48	11.11		3.70	0
Schatta, M. 70s		23.08	15.38	23.08			38.46	4
Siemens 70s		17.86		21.43	60.71			0
Kogyo 80s	1.86		2.48	20.50	74.53		0.62	3
Hitachi 80s	1.10	50.0	0.37	16.97	26.38	0.37	4.80	18
Matsushita 80s	0.33			69.02	30.43	0.11	0.11	8
Canon 90s				0.82	97.25	1.65	.28	18
SMU 90s						100		0
Texas Instruments 90s				4.0	80.0	16.0		1
Labrador, G. 90s			25.0				75.0	12
GE 00s	0.17	12.62	0.17	0.17	13.04	0.17	73.22	85
Motech 00s					100			0
Wobben, A. 00s		2.80					97.1	10
Siemens 00s	0.68	2.05		4.11	19.86		73.29	4
Konarka 00s					87.5	12.5		6

Table 4: firms

	1	2	3	4	5	Sum(1-3)
10	US	DE	JP	FR	GB	
	28.73	20.45	13.07	7.61	4.43	62.25
20	US	DE	FR	CH	JP	
	35.11	22.47	7.1	3.55	3.23	59.59
30	US	GB	FR	DE	NO	
	26.66	14.40	9.46	9.29	4.82	50.52
40	US	DE	FR	JP	CH	
	31.33	25.69	11.70	3.24	3.08	68.72
50	US	JP	DE	KR	FR	
	31.25	25.87	16.80	5.46	4.08	73.92
60	US	DE	JP	FR	GB	
	29.89	28.84	10.32	3.37	3.16	69.05
70	DE	US	FR	DK	GB	
	28.37	22.20	7.37	5.86	5.15	57.94

Table 5: Patent application by first applicant (1940-2009)

Table 6: Percent of overall created sinks by firm

	1	2	3	Sum(1-3)
70s	Anvar (FR)	Schatta, Martin (DE)	Siemens (DE)	
	1.56	1.43	1.29	4.28
80s	Kogyo Gijutsuin (JP)	Hitachi Ltd (JP)	Matsushita Electric Industries Co Ltd	
	2.49	2.37	2.13	6.99
90s	Canon (JP)	Southern Methodist University (US)	Labrador, Gaudencio A. (US) Texas Instruments (US)	
	3.02	2.05	0.98	6.05
00s	GE (US) Motech (US)	Wobben, Aloys (DE)	Siemens (DE) Konarka Technologies Inc (US)	
	6.78	1.84	1.664	10.26
70-00s	GE (US)	Wobben, Aloys (DE)	Siemens (DE) Konarka Technologies Inc (US)	
	4.16	1.19	1.17	6.52

Table 7: Renewable energy technologies and control group

	¡1940	1940-44	1950-54	1960-64	1970-74	1978-82	1980-84	1990-94	2000-04
Control group									
IPCs	1582	456	867	2659	9728	11854	12271	15750	19737
ADegree	2.08	1.99	2.11	3.25	7.15	8.00	9.00	12.34	20.87
Density	0.0013	0.0044	0.0024	0.0012	0.0007	0.0007	0.0007	0.0008	0.0011
Components	557	171	307	710	1114	1032	1017	707	524
Av Size	3	3	3	4	9	11	12	22	37
Renewable energy technologies									
IPCs	380	226	352	401	943	2997	3056	2182	5708
ADegree	4.41	4.29	5.07	5.41	7.89	12.99	12.34	11.90	26.07
Density	0.0116	0.0191	0.0145	0.0135	0.0083	0.0043	0.0040	0.0055	0.0046
Components	8	14	14	14	29	23	19	30	24
Av Size	48	16	25	29	33	130	161	73	238
Sinks	25	12	18	20	99	482	476	348	1244