DISCUSSION PAPER

Do Energy Prices Induce Progress in Energy-related Technology? An Empirical Study

Simon Schmitz

HWWA DISCUSSION PAPER

147

Hamburgisches Welt-Wirtschafts-Archiv (HWWA)
Hamburg Institute of International Economics
2001
ISSN 1616-4814

The HWWA is a member of:

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- Arbeitsgemeinschaft deutscher wirtschaftswissenschaftlicher Forschungsinstitute (ARGE)
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Simon Schmitz

The paper was presented at the Summer School Economics, Innovation, Technological Progress, and Environmental Policy, Seeon, August 2001

HWWA DISCUSSION PAPER

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World Economy
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CONTENTS

1 INTRODUCTION 8

2 THEORIES OF TECHNOLOGICAL ADVANCE AND ITS DETERMINANTS 9

3 IMPLICATIONS OF THE INDUCED INNOVATION HYPOTHESIS FOR COSTS AND TIMING OF CLIMATE POLICY 11

3.1 Action and abatement 11

3.2 Dynamic efficiency in abatement 11

3.3 Dynamic efficiency in policy action 12

3.3.1 The Kyoto mechanisms and innovation 12

3.3.2 Uncertainty and technical irreversibility 13

4 DATA DESCRIPTION 15

4.1 Available data 15

4.2 The patent data set 16

4.2.1 Patents as indicators 16

4.2.2 The Derwent World Patents Index (DWPI) 16

4.3 R&D measures 18

4.4 Energy prices and taxes 19

5 AGGREGATION LEVELS AND MODELS 20

5.1 Aggregation across technology groups 20

5.2 Aggregation across countries 21

6 GRAPHICAL PRESENTATION OF DATA 21

6.1 Energy prices 21

6.2 Energy intensity of patenting activity 22

6.3 Government R&D 24

6.4 Proportions of taxes in energy prices 25

7 REGRESSION RESULTS AND INTERPRETATION 25

Model group 1 26

8 REFERENCES 29

APPENDIX 31

I. Government energy R&D categories used by the OECD/IEA 31

Appendix 1 Government energy R&D categories used by the OECD/IEA 31

Appendix 2 R&D correlations with crude oil price 32

Abstract

Research efforts towards new energy sources and towards the efficiency of energy use will be vital to reducing CO_2 abatement costs in the long term. Can such efforts be induced by price instruments? Economists often cite induced technological change as a possible consequence of environmental market-based policies. Unfortunately, however, there is not much empirical evidence about the policy-induced development of environmentally friendly technology.

I use patent data from 1976 to 1997 for the US, Japan and the major European countries in order to estimate the effect of energy prices on energy-efficient innovations. A further supply factor with presumably positive influence in the model is an OECD measure of government R&D expenditures in different energy domains. In order to prevent the model being biased by factors that change the propensity to patent *over time* in one country (such as changes in patenting laws and of course economic growth), I regard the ratio of energy-specific patenting activity to the overall patenting activity of the country as the dependent variable rather than mere patent counts.[1]

I find that energy prices (as a demand-side factor that influences the value of new innovations) have no significant positive effects on innovative activity as measured by patents. At the end of the 1970s, when energy prices were high due to the second OPEC crisis I can observe a little rise in the ratio of energy patenting activity to overall patenting activity across countries and energy-related technologies. This rise is mostly followed by a short decline, which is followed in turn by a very significant rise in the "intensity" of energy-related patenting activity through to 1997. This last rise can obviously not be explained by energy prices that fell significantly during this period. Running additional regressions that include the ratio of energy taxes to the prices of energy yields that this ratio was significantly positively correlated with innovation in both Japan and the EU. A tentative interpretation might be that a rise in this ratio is regarded by economic agents as having the potential to increase the price of energy permanently, whereas mere price fluctuations like those experienced in the oil crises have no real credibility that influences future expectations. Furthermore, the tax ratio, which

[1] To this date, unfortunately we have not been able to obtain adequate data on patent citations to construct a measure of the quality of the existing stock of knowledge (strongly influencing the marginal productivity of research), so that we have to forego the investigation of *technology-push* theories of R&D that emphasise the importance of technological opportunity to innovation. We thus have to postpone the attempt to capture the links between current and future research, another factor which might be considerable in changing the propensity to patent over time.

has consistently risen in Japan and especially the EU, could be seen as an indicator for government and public concern about the scarcity of fossil energy sources and about the urgency of ecological problems such as the greenhouse effect. This would then plausibly feed into the rise of energy-saving-related patenting activity observed. However, this result is weakened by the fact that there have been no taxes at all in the US, which nevertheless exhibits about the same pattern in terms of patenting activity.

Zusammenfassung

Forschung zur Erschließung neuer Energiequellen und Effizienzsteigerung beim Energieverbrauch ist entscheidend, um die CO_2-Vermeidungskosten langfristig zu senken. Kann Forschung durch Preisinstrumente induziert werden? Ökonomen argumentieren häufig mit induziertem technischem Fortschritt als Folge von marktwirtschaftlichen umweltpolitischen Instrumenten. Leider gibt es nicht viele empirische Belege über solche Effekte.

Ich versuche, auf der Basis von Patentdaten des Zeitraums 1976 – 1997 für die USA, Japan und bedeutende europäische Länder die Wirkung der Energiepreise auf Innovationen im Bereich Energieeffizienz zu abzuschätzen. Ein weiterer Angebotsfaktor mit erwartetem positivem Einfluss sind die staatlichen Forschungs- und Entwicklungsausgaben für verschiedene Energieformen. Um eine Verzerrung durch Faktoren zu vermeiden, die die Patentierungsneigung in einem Land im Lauf der Zeit verändern, betrachte ich das Verhältnis zwischen den energiespezifischen Patenten und der Gesamtpatentaktivität.

Ich komme zum Ergebnis, dass Energiepreise keinen signifikanten positiven Effekt auf die Innovation haben. Gegen Ende der 70´er Jahre, als die Energiepreise hoch waren, ist ein leichter Anstieg der relativen Energiepatente zu beobachten. Nach einem kurzen Rückgang kommt es bis zum Ende des Betrachtungszeitraums zu einem sehr deutlichen Anstieg. Dieser lässt sich nicht durch die Energiepreise erklären, die während dieser Periode rückläufig waren. Zusätzliche Regressionen, die den Anteil der Energiesteuern an den Energiepreisen beinhalten, zeigen, dass dieser Anteil in der EU und Japan signifikant positiv mit den Innovationen korreliert war. Dies kann man so interpretieren, dass von den Wirtschaftssubjekten ein Anstieg des Verhältnisses als permanenter Preisanstieg gewertet wird, während Preisschwankungen wie diejenigen der Ölkrisen die Erwartungen nur wenig beeinflussen. Außerdem kann der Anteil der Energiesteuern als Indikator für die öffentliche Beschäftigung mit dem Problem der begrenzten fossilen Brennstoffressourcen und Umweltproblemen wie dem Treibhauseffekt betrachtet werden. Dies könnte einen eindeutigen Einfluss auf die Innovationsaktivitäten haben. Allerdings stieg in den USA die Innovation ebenfalls an, obwohl dort die Steuerlast sehr gering war.

1 Introduction

CO_2 emission reduction policies and their effects on technological change have been much debated recently. A positive relation between high energy prices and energy-related technological advance would corroborate the thesis that the costs of CO_2 emission reduction policies that raise the price of emitting CO_2 could be much lower than expected from calculations with static cost models that do not include induced technological change (ITC).

However, much of recent policy-making and economic modelling was hampered by uncertainties and lack of empirical evidence on the links between environmental policy and innovation. Recent studies that overcome this deficiency include Popp (1999), as well as Jaffe and Stavins (1995) and Newell et al. (1999), who all provide evidence of the positive influence on energy prices and energy-related innovation in the US (examining overall energy-related patenting activity, the adoption of thermal insulation technology and new model offerings in heating and cooling respectively).

In a cross-country analysis including Europe, Japan and the US I follow the approach of Popp (1999), aiming at providing such evidence by testing whether there is a positive relation between domestic energy prices (which could obviously be raised directly via taxes on energy or CO_2 emissions) and energy-related patenting activity.[2] A similar cross-country analysis has been carried out by Gerstenberger (1992), also coming to tentative positive results as regards the induced innovation hypothesis. However, ten years later, a new look at the developments seems justified, especially considering that Gerstenberger (1992) included no measures of public R&D expenditures in the energy domain in his study.

After exploring current theories of innovation and its determinants, such as price signals (Section 2), I will put the issue of technology-inducing policies into a more detailed context of costs and timing of climate policy (Section 3). Section 4 gives an accurate description of the data used and the way it was used in modelling, whereas Section 5 goes into data issues related to the chosen aggregation of data in different models. I then present the data in graphical form (Section 6). Section 7 then presents and interprets results obtained from regression analysis with different combinations of variables.

2 See footnote 1: Popp (1999) constructed a measure of the existing stock of knowledge, which we intended to do in a later study.

2 Theories of technological advance and its determinants

As is well known, there is as yet no adequate theory of endogenous technological advance, and furthermore technological advance has been defined in a number of different ways: Following a definition by Schumpeter, it is all “changes in products, processes of production, raw materials and management methods”. Furthermore, still following Schumpeter, it is acknowledged that there are, in a broad characterisation, 3 stages to be distinguished: Invention as the development of new ideas, innovation, which is the transformation of ideas into products, and diffusion, which is the spread of use and ownership of new technology, the point at which the economy actually obtains benefit.

However, this should be regarded only as an organisational framework, since it has now also been recognised that one can expect a lot of feedback between these three stages: for example, obviously invention supports diffusion, but in some cases the increased diffusion of a technology group will also require improvements (induced by competition, for instance) that, in turn, might trigger new inventions: “Diffusion of innovations is another Schumpeterian concept which has come in for some heavy criticism. Most empirical studies demonstrate that new products and processes are usually changed considerably during the diffusion process.”[3]

Of course a proper definition of technological progress must also incorporate the issue of learning-by-doing, which makes a significant contribution to the picture of the innovative process as autocatalytic, i.e., rather than tamed and easily controllable by governments. Concepts such as economies of scale, informational increasing returns and positive network externalities also play their part in painting this picture: “Beyond a critical point, market forces tend indeed to reinforce the first choice in a self-fulfilling process instead of correcting it.”[4]

This picture might also clarify why there are barriers to market entry for existing technologies that have already passed at least through the first stage of the technological advance process but cannot exploit the possibilities that the technology which is “locked in” can take avail of. It could well be that there is a whole host of new technologies out there just waiting to be marketed. For these, it will be of crucial importance not only to exhibit technological maturity, but also to have a favourable market environment which might have to be supported by government policies, to overcome lock-in effects that impose risks on their commercialisation.

3 Freeman (1994), p.480

4 Ha-Duong et al (1999), p. 9

With these various features of technological advance in mind, the question whether prices have an influence on it thus necessarily becomes a more differentiated one and therefore even trickier to answer, since each different element of the innovation process might be exposed to different driving forces.

It might be argued plausibly, for example, that the successful diffusion or commercialisation process, at least for some technologies that reduce GHG emissions, depends more on the size of the market than the price pressure, since only with increasing size begin the self-enforcing mechanisms to operate. Evidence for this is the far larger diffusion process of wind power technologies in "guaranteed" markets such as Germany and Spain compared to tender procedures (e.g. UK) where markets were limited.

At first, it doesn't seem equally plausible to say that the invention and innovation process (i.e. the early stages of the process of technological change) react in the same way to market size. Rather, by its very nature, the successful deployment of *new* technologies obviously requires the creation of *new* markets, and it is indeed plausible to assume that such creation needs some kind of inducement mechanism that has nothing to do with existing market size.

"Technological opportunity", as emphasised by "technology-push" theories of technical change, in turn, is likely to be an important determinant of inventive activity and research efforts (as confirmed by results from Popp (1999)), but less of product development or diffusion successes.

Let's come to the influence of prices then. The crucial feature of environmental "price policies" is that they make the use of old technology more expensive, setting direct or indirect incentives to develop and introduce new cleaner technologies. This is generally called the demand-pull approach to innovation. In the context of energy policy this means that when higher energy prices prevail there should be more energy R&D projects devoted to making the use of energy cheaper that pass the threshold of profitability, since their expected returns would rise with the demand for potential results, which can indeed be expected to increase.[5]

Finally, what if, as discussed above, diffusion triggers invention? Then the Schumpeterian distinction becomes rather blurred, and the meaning of invention isn't restricted to *new* technologies any more but can also incorporate improvements to existing technologies, which can, in turn, plausibly be influenced by market size. This can considerably extend the scope of "demand-pull" theories of innovation. Obviously, whether it does depends on the measure of

5 For a more detailed account of what R&D projects should fall into this category, see the methodology section 4.

technical change taken. It is important to keep this point in mind for the discussion of patents as indicators for innovation.

Let me now first put the investigation into the context of climate policy and consider some of the consequences of possible results in more detail.

3 Implications of the Induced Innovation Hypothesis for costs and timing of climate policy

3.1 Action and abatement

First of all, it is important to note that any climate policies that aim to induce technological change go under the definition of *action* towards CO_2 emission reduction. Actual *abatement* measures might well take place way after the introduction of, say, a carbon tax. Thus, with the presence of ITC, there is a "conceptual distinction to be made between abatement investments within a given technical endowment and policy action, such as a carbon tax aiming primarily at inducing low cost alternatives in the future."[6]

3.2 Dynamic efficiency in abatement

As regards the timing of climate policies this distinction would seem to suggest to concentrate more abatement efforts in the future when effects of policies have made technologies available with which to achieve emission reductions cheaply. However, this depends crucially on what is regarded to be the driver of technological change. If R&D is what is induced, then the argument holds. In contrast, when LBD is regarded as being the channel for technological change, ITC still makes future abatement less costly but because of learning effects some current abatement based on available technologies will receive an extra value: it will also lower the cost of future abatement. Thus, when LBD is taken into consideration, early emissions reduction measures are preferable. This is confirmed unambiguously by a recent macroeconomic modelling study.[7] Note that in this context, the distinction between action and abatement becomes merely one between current abatement and future abatement.

6 Ha-Duong et al (1999)

7 van der Zwaan et al (1999/2000), as quoted in IPCC (2001b) p. 550 (not referenced there)

3.3 Dynamic efficiency in policy action

3.3.1 The Kyoto mechanisms and innovation

International "mechanisms" (such as Joint Implementation (JI), the Clean Development Mechanism (CDM), and International Emissions Trading (IET) (altogether known as the "Kyoto mechanisms)) provide the opportunity to reduce CO_2 emissions where it is cheapest. This approach implies relying on exploiting differences in the more or less fixed states of technology and thus marginal abatement costs in different countries.

However, the European Union's wish to foster new technologies was the source of the hostility towards the Kyoto mechanisms at the UNFCCC negotiations. The mechanisms should only be used to a limited amount in order to enforce the implementation of domestic policies: CDM and JI projects would be likely to include the building of new "effective" coal and gas plants. IET, on the other hand, has the potential to raise the "price" of CO_2-emisssions and thus provide the demand-pull incentive for new R&D projects described above. However, if the emissions trading regime allows for extensive buying of permits at a cheaper price than the current emission reduction cost (as will most probably be the case judging from the results of the Bonn UNFCCC negotiations), domestic industry has no incentive to reduce CO_2 emissions at its plants even if it is subject to an emissions constraint. In other words, the price of CO_2-emisssions does not effectively rise, and domestic industry won't have an incentive to invest in R&D of new technologies.[8]

It has to be noted, however, that there is a chance of LBD being induced by the Kyoto mechanisms to the extent that they increase the market size for available technologies (at least JI and CDM). So why would we need new cleaner technologies when the Kyoto mechanisms do both, achieve abatement targets at low cost while even fostering LBD?

Put simply, of course, the answer is that fundamentally new technologies such as renewables have stronger emission reduction potential and make CO_2 emission reduction even cheaper in the long run. There are, however, a few more complex considerations to be made that have their own merit.

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8 Furthermore, when faced with an emissions trading regime, private enterprise cannot rely on an expectation of a smooth price rise (because this rise is going to be determined by an unpredictable market mechanism) and thus might not be willing to react immediately. This uncertainty can be avoided by a plausible and credible tax policy.

3.3.2 Uncertainty and technical irreversibility

The proponents of policies aiming at long-term innovation effects emphasise their benefits in case "the climate picture darkens", i.e. in case we must, in the light of more alarming evidence on the adverse effects of climate change, account for a higher risk of having to reduce our emissions more quickly. It could then be extremely valuable to have the technologies needed at our disposal, rather than having to cope with costs of technical irreversibility effects that should be considerable, judging from two major considerations:

- Energy-related capital stock is typically long-lived, which suggests that costly premature retirement would be likely. The same applies to infrastructure of transport systems, for example.

- LBD and increasing informational returns can have caused lock-in conditions that are also costly to break.

In a nutshell, if a rapid reduction of emissions at a later stage is regarded as likely, *and* if furthermore inertia of the capital stock and LBD are taken into consideration, a policy that aims at inducing a technical restructuring of the relevant sectors becomes all the more desirable.

The Kyoto mechanisms would thus be dynamically inefficient, since they would emphasise short-term cost calculations to promote emission reductions (actual *abatement*) where the marginal cost of it is currently lowest ("where-flexibility") while neglecting long-term considerations that would suggest "inducing" (through policy *action*) new technologies with greater reduction potential as soon as possible, also where the cost of *abatement* is currently high.

As Ha-Duong et al. (1999) point out, there is of course also something of a risk that we might "over-protect" the environment, meaning that it might turn out that the impacts of climate change are lower than expected and the concentration "safety ceiling" for CO_2 in the atmosphere can be raised. This would somewhat counter the argument outlined above: on the one hand we might need great flexibility in the worst case scenario and should therefore act as soon as possible, on the other hand there is a cost of achieving that flexibility, and waiting to get more information on how likely the worst case scenario is. Surely, the possibility of over-protecting the environment seems all the more unlikely after the publication of the IPCC Third Assessment Report.[9] However, let us consider the argument more closely in order to

9 IPCC (2001a)

find its weaknesses: It is implicitly based on the consideration that the time between action and abatement will bring costs associated with

- developing the new technologies
- higher and “distorted” prices for the use of the old technologies
- having to break “lock-in” structures in favour of old technologies today, at high costs

First of all it is to be noted that here there will be no costs from premature retirement of existing capital stock. Then, surely developing new technologies comes at a cost, but firstly the risk of a lower concentration target might well justify this (as well as the second cost component), and secondly “new” technologies such as renewables will yield returns, whatever outcome there is from the “climate gamble”: unlike for example carbon storage technologies any energy technologies will be of use even when CO_2 emission reduction becomes less urgent. Thirdly, and it is part of the objective of this paper to show that, the innovation effect of e.g. price policies on available technologies should not be underestimated.

Furthermore, no matter how “locked in” technologies like power generation from fossil fuels such as gas and coal are today, it will be costly if they still are in later stages of the worst case scenario. If new cleaner technologies will be “locked in” there will be no costs in the best case scenario. In any case, it is quite clear that their further LBD potential is not as great as that of future technologies such as wind and solar power.

> „If we want cost-efficient, CO_2-mitigation technologies available during the first decades of the new century, these technologies must be given the opportunity to learn in the current marketplace. Deferring decisions on deployment will risk lock-out of these technologies, i.e., lack of opportunities to learn will foreclose these options making them unavailable to the energy system. From this point of view, the present success of the increasingly efficient combined-cycle technology may significantly reduce CO2 emissions from the electricity sector until 2010, but may prove fatal for new non-fossil electric technology after 2010. Focusing policy measures in the period of 2008-2012 may severely restrict options beyond 2012”.[10]

In conclusion, the consideration of uncertainty in conjunction with technical irreversibility effects arising from LBD and the inertia of the capital stock and the infrastructure gives

10 IEA (2000), Chapter 5

special importance to what kind of technological change we design policies (*actions*) to induce today and urge us to give the "right" technologies the best possible start now.

After we have now considered the reasons why price policies could theoretically be expected to induce the development of new technologies in general (Section 2), the discussion of the Kyoto mechanisms (Section 3.3.1) has shown why these will most probably not provide these price incentives for new technology fields. We have also seen from further theoretical considerations (Section 3.3.2) that the development of such new technologies is highly desirable. About time then to turn to the empirical evidence on how effective price incentives might be.

4 Data description

4.1 Available data

The data at our disposal, for 3 different regions (US, Europe4 (France, Germany, Italy, UK), Japan) respectively (except for crude oil price), include:

<u>Endogenous variable:</u>

- the ratio of energy patenting activity to overall patenting activity, for different technology groups

<u>Exogenous variables:</u>

- Government R&D expenditures in the energy domain, for different technology groups,
- Prices of light fuel oil or electricity for households, for different energy sources, including tax.

For additional regressions, the energy prices including tax are replaced by:

- Taxes on electricity or light fuel oil for households divided by the respective price including tax, and
- The price of the crude oil brand "Arabian light" (not for different countries)

We now turn to describe the data source and the use of each variable in turn.

4.2 The patent data set

4.2.1 Patents as indicators

It should be mentioned that neither R&D data nor patents really cover all of the diffusion component of innovation. This is better done with productivity measures such as energy intensity etc. With my patent approach I shall focus on the invention process, even though we should keep in mind that diffusion can, of course, as discussed above, trigger some new inventions.

Patents are a measure of “R&D output” that is to be used with care in the sense that companies which innovate might even have an incentive to withhold new information in order to avoid other firms “inventing around” the new technology or, secondly, prevent the product from being copied after the exclusive property right expires.

A further difficulty in using patent statistics is that the “propensity to patent” can vary amongst technical fields as well as over time. These variations can be due to different and changing patenting laws, patenting costs or the degree of “scientific opportunity” available in the surrounding scientific network. In times after a significant discovery that subsequent scientists can build their research on there will be more patenting activity than in times when research opportunities in a field of discovery that came up ages ago have been largely exploited. In this context, the analysis of patent citation data can help identifying “scientific breakthroughs”.[11] Unfortunately, this task has proved to be beyond the scope of this paper, however plans for further research in this area have been made in cooperation with the European Patent Office in The Hague.

However, changes in the propensity to patent over time that concern all technologies in one country can be captured by our data since we consider the ratio of patenting in each technology to overall patenting activity in the country as the dependent variable.

Further important issues that concern the changes of the propensities to patent over time and across technologies are considered in the Section on “aggregation levels and models”.

4.2.2 The Derwent World Patents Index (DWPI)

The patent data was obtained in cooperation with the Patent- and Innovation Centre (PIC) in Bielefeld that provided access to the database “Derwent World Patents Index” (DWPI). The DWPI provides information on patent publications from the 40 most important patent issuing

11 For the application of these methods see Popp (1999)

authorities in the world including 38 national patent offices, the European Patent Office (EPO) and the World Intellectual Property Organisation (WIPO). The database covers all patent-relevant areas of science and technology.

The set of technologies chosen for the investigation include:

Energy demand technologies	**Energy supply technologies**
Computers Photocopiers Insulation Illumination Vehicles Heating appliances Telecommunications	Biomass Geothermal Solar Hydro Wind Hydrogen Oil Nuclear Coal Gas

Following Popp (1999), we have decided to divide the data into the two groups of "demand technologies" and "supply technologies". Note that on the supply side we also include more "established" technologies to test their reaction in terms of improvements etc., so that we can test the different reactions of "new" technologies with great emission reduction potential (group "Renewables")[12] and more established energy sources such as fossil fuel and nuclear technology (with arguably smaller emission reduction potential).[13]

The framework for the data search was provided by the International Patent Classification (IPC), which DWPI adopts for all its records. The IPC classifications for the supply technologies were identified by the PIC.

12 It should be noted that we chose this name even though hydrogen-related technology (i.e. fuel cells) is included in the set, which is not strictly speaking a renewable energy source but has great emission reduction potential if used in combination with renewable energy

13 "Arguable" since one might of course regard nuclear energy technology as having great potential for climate change mitigation. A discussion of the ecological risks it bears is not the object of this study. May it suffice to note, then, that including nuclear energy in the second set is a subjective matter.

As regards the demand technologies, obviously only those patents that are related to energy efficiency should be included. This was achieved with a keyword search within the IPC classifications identified for the listed technologies, also identified by the PIC.[14]

The patents are sorted by application year and "country priority code", i.e. country of first application in one patent family (a group of patents, granted by differing institutions but referring to the same invention). This way double counting of different patent family members is avoided. We have used time series from 1976-1997. The reader should be aware of the fact that our search has, in absolute terms, yielded considerably less patent counts in comparable categories than, for example, Gerstenberger (1992) and Popp (1999). This is especially true for earlier years, i.e. the end of the seventies. A possible explanation is that DWPI encompasses all technology areas only since 1974 and might even then have taken some years to speed up to full coverage. In addition, there can, of course, be considerable differences in the specification of IPC classes[15], which is a crucial aspect of the search for patents in such a specific domain as we were trying to identify.

However, we think it is well possible that the structure of the data set is reliable especially since a possible under-representation of patents from earlier years would normally be taken care of by taking the ratio of energy-related patents to overall patenting activity.

4.3 R&D measures

As Pavitt and Patel (1988) point out the data on R&D investment available in most countries exclude especially the efforts of small firms, as well as the efforts undertaken by most companies' engineering departments, which are also an important source of technology. Moreover, the purpose of this study requires that R&D data are grouped according to their contribution to energy efficiency and to developing new energy technologies. To reach this degree of specificity is simply too demanding when dealing with data on private sector R&D.

Fortunately, however, the OECD publishes data on government expenditures on R&D in the energy domain. It should be clear that government expenditures on R&D are not an unambiguous indicator of overall research efforts in a particular technology field. However, as it remains unclear how much substantial these expenditures are in relation to private sector R&D, we will regard them as a proxy for the technology input in each technology field.

14 Lists of the IPC classifications employed and the keywords used are available from the author, as well as a full list of all patent counts.

15 Popp (1999) used the US patent classification, which does not, however, correspond in the slightest to the IPC, which is why comparisons of classifications were imopssible.

Of the three major categories of R&D activities distinguished in the OECD R&D Survey, namely "basic research", "applied research", and "experimental development", this data exclude "basic research" unless it is clearly oriented towards the development of energy-related technologies, in which case it should be included. "Demonstration" projects are included, which encompass those projects that are of large-scale but which are not expected to operate on a commercial basis.

The categories that the OECD employed (see Appendix, Section I) correspond to the ones we chose for the patent measures. This applies to the energy efficiency component only with some reservations, since the set of technologies we chose for the patents is obviously quite specific, whereas the OECD used broader categories such as “Energy Conservation” (with subcategories such as “Residential Commercial” and “Industry”) and “Power and Storage”. Nevertheless, we have matched up the patent data for energy efficiency with the sum of these two categories.

The data is published in nominal local currencies. In order to make the data internationally comparable, we converted them into (nominal, i.e. current) US dollars using the Purchasing Power Parities (PPPs) published by the OECD, and then converted to constant US dollars at the price level of the year 2000. We have used time series from 1974-1997.

4.4 Energy prices and taxes

Local energy prices and taxes were obtained from the publications of the International Energy Agency in Paris, where they are given in nominal local currencies. For international comparability, the same method as for the R&D data was used. We make main use of the price for light fuel oil for households. This price exhibits very similar movements to those of the light fuel oil price for industry, which is mostly lower in absolute terms. The values for 1973 to 1977 were not available from the IEA for this variable and have been extended back to 1973 on the basis of movements in the world oil price, in order to capture the first oil shock as well.

When modelling the intensity of patenting activity in efficiency of energy demand technologies we also run additional regressions with the price of electricity for households (which we employed only back to 1978).

A weighting for the 4 European countries was performed according to EIA[16] measures of Total Net Electricity Consumption and Consumption of Refined Petroleum Products, respectively, in 1997.

The world oil price, which we also make substantial use of (see Section 5.2) is reflected by the spot price at Ras Tanura of the crude oil brand “Arabian light”, provided by OPEC. All price (and tax) variables run through to 1997. Detailed information on taxes is not specified in the IEA publications, and irrelevant for our purpose.

5 Aggregation levels and models

5.1 Aggregation across technology groups

The different dimensions offer several aggregation levels for modelling. As regards the reasons for aggregating in general, first of all there seemed to be a need of aggregating the patent counts across technologies simply because of very low counts in the 70s. However, aggregation is particularly important in connection with the changes of the propensities to patent over time and across technologies.

Consider first changes across technologies. Let’s say solar energy research has a very high research potential all the time, and biomass a very low one, resulting in absolutely less counts for biomass patents. Taken on their own, the effect that the energy price might have on the intensity of patenting activity in the respective technologies wouldn’t be biased, as long as the propensities to patent don’t change over time. Now, if we aggregate and take the ratio of the sum of both patent counts to overall patenting activity, changes in the intensity of biomass patenting would be somewhat underrepresented. This is certainly a problem that we have to recognise and can’t solve at present.

However, apart from the one just mentioned, in our view there is no other reason to interpret reactions of patenting on a more disaggregated level, since measures of the quality of the existing stock of knowledge in each field are, for known reasons, not available. And there is one important advantage of aggregation: It is also possible (if the problem described above is not all that serious) that the average propensity to patent (over time) is at least similar for all technologies and that propensities to patent are fluctuating significantly over time. If that is the case, some of the effects of differing “technological opportunity” in individual technology groups might cancel out when aggregating across technologies, as well as other factors causing the propensity to patent to change over time.

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16 The Energy Information Administration in the US

It is hard to say which of the effects of aggregation dominates. Thus, simplicity decided, and even though the R&D data could theoretically provide more individual explanations for each individual technology, we will apply the more macro-level approach and also aggregate the R&D data to the same level of technology groups as the patent data.

5.2 Aggregation across countries

In models using patent and R&D data summed up across countries, only very aggregated movements can be expected. In these models we use the crude oil price “Arabian light” rather than averages of local prices.

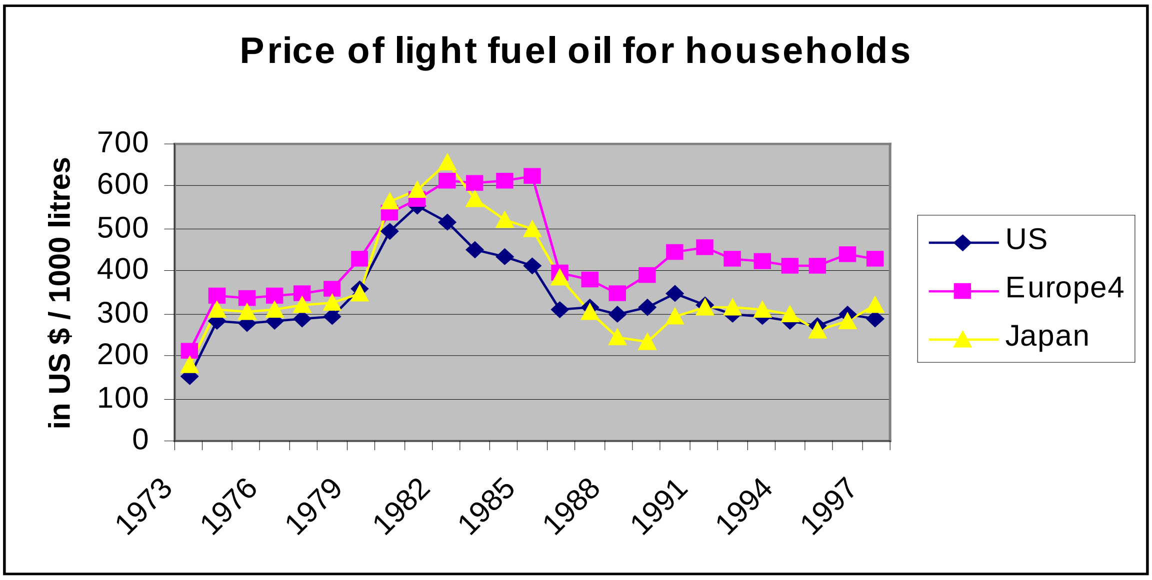
We’d like to note here that it is possible that high government energy R&D expenditures are somewhat induced by high energy prices. Investigating scatter plots for individual countries yielded that there is no significant correlation in any of the regions, neither for the whole energy budget nor the different technology groups. This after all, can be expected, since there will be all sorts of different political influences in the different countries. It is however, interesting, to note the “world-wide” correlation between the crude oil price “Arabian light” and the sum of government expenditures on energy R&D in the three regions (Figure 5, in the Appendix), where differing political influences seem to cancel out. The correlation seems to be even stronger for the energy supply technology group, whereas it is not unambiguous for the demand group. Thus, in models that aggregate the countries and explain the intensity of energy supply patenting activity, we have taken out government R&D in order to avoid problems with multicollinearity.

6 Graphical presentation of data

6.1 Energy prices

The most important features to be seen from the graphs in Figure 1 are of course the two price hikes in 1973/1974 and 1979/1980. Europe exhibits the highest oil and electricity prices, largely due to high tax levels (see Figure 1). For the oil prices, the difference to Japan and the US are especially pronounced during the 90s. In all regions the price declined significantly after the second oil crisis, reaching a more or less stable path by 1990.

In electricity prices, the oil price rises of the 70s are greatly extenuated, and in all countries the price exhibits quite a constant pattern.



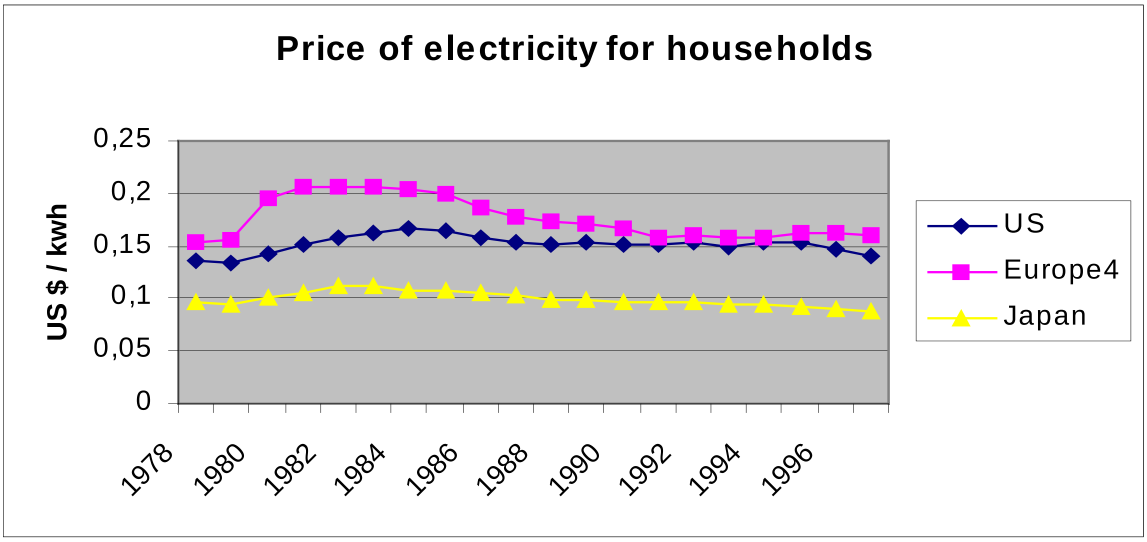
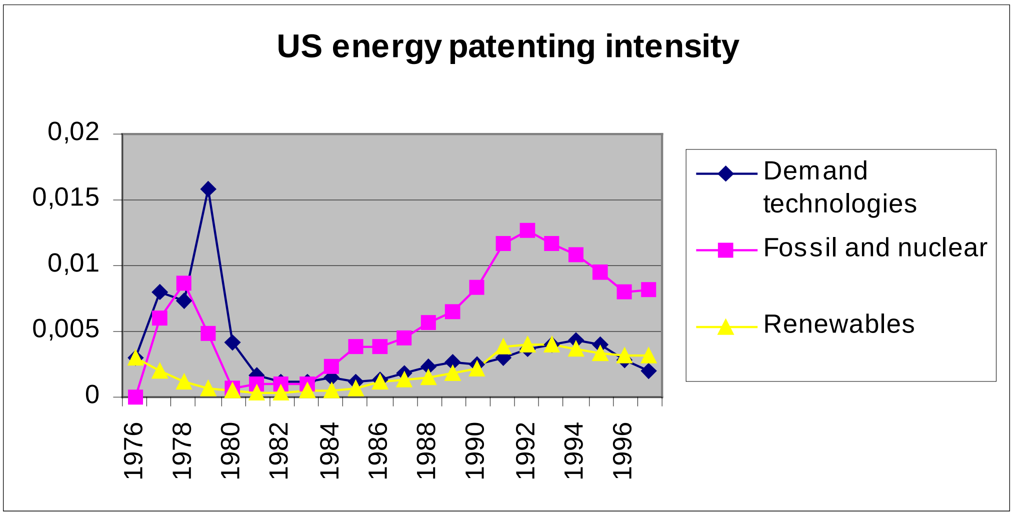


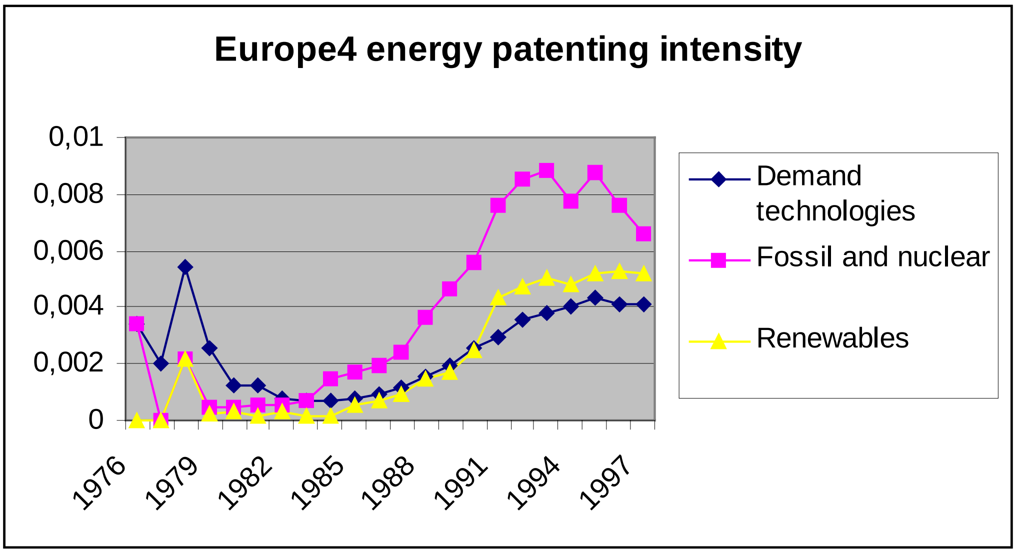
Figure 1

6.2 Energy intensity of patenting activity

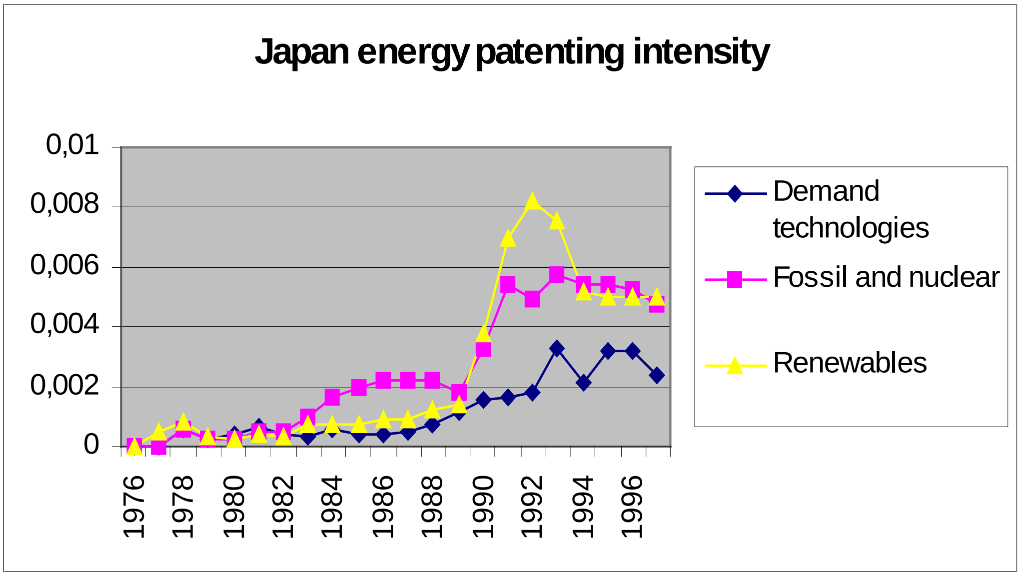
As shown in Figure 2, in the US and Europe we can see a distinct rise in this measure during the end of the 70s. This does indeed look like a reaction to the first oil shock, but then it is puzzling why there has been apparently no reaction in Japan, as well as why a second reaction is nowhere to be seen (it would have to be a very long-winded reaction, for all technologies, in all countries!). Further notable is the consistent rise in the proportion of energy patenting until the beginning of the 90s in all regions and technologies, followed by a significant slowdown towards 1997. This is definitely a first sign for a relationship with the price of energy that is not strictly positive. The proportion of renewables seems to be especially high in Japan.



US energy patenting intensity
0,02
0,015
0,01
0,005
0
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Demand technologies
Fossil and nuclear
Renewables



Europe4 energy patenting intensity
0,01
0,008
0,006
0,004
0,002
0
1976
1979
1982
1985
1988
1991
1994
1997
Demand technologies
Fossil and nuclear
Renewables



Japan energy patenting intensity
0,01
0,008
0,006
0,004
0,002
0
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Demand technologies
Fossil and nuclear
Renewables

Figure 2

6.3 Government R&D

First of all, it should be as expected that R&D for fossil fuel-related and nuclear energy technology always was significantly higher than that for renewables or energy efficiency. Other important information that Figure 3 exhibits is that the US had amazingly high levels of government energy R&D around 1980. The difference is still significant when we consider that US GDP is about 30% bigger than the sum of GDP of the 4 countries of Europe considered and about twice as big as that of Japan[17]. However, one can only conjecture whether this might have something to do with the generally high energy consumption and the US government being worried about this not being guaranteed in the future.

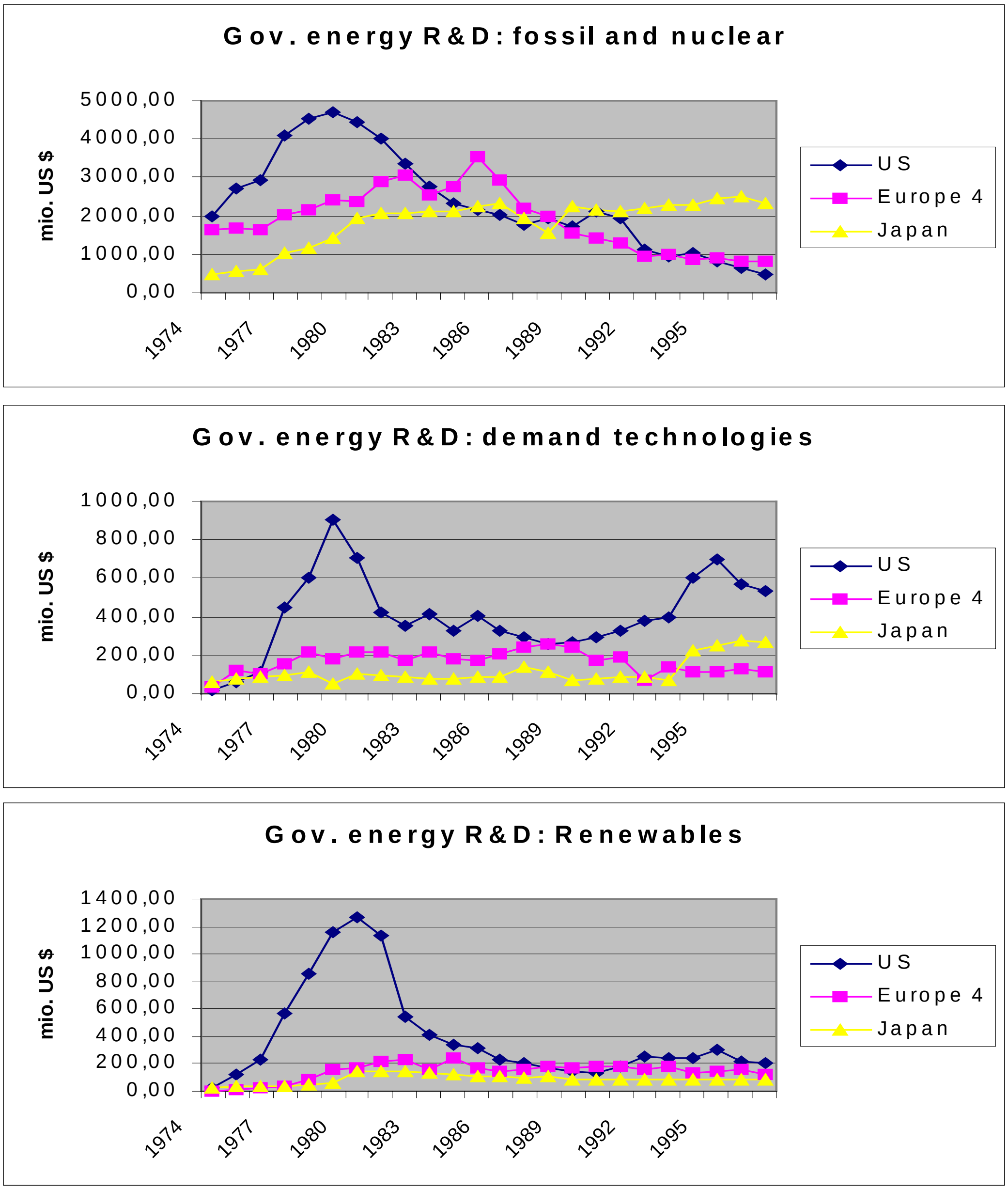


Figure 3

17 Source: OECD economic indicators, downloadable with the R&D data

6.4 Proportions of taxes in energy prices

As there have been no taxes imposed on either light fuel oil or electricity in the US, Figure 4 only contains data from Europe and Japan. Clearly enough, the proportion of tax on energy prices is much higher in Europe than in Japan, and it exhibits a strongly rising trend for both sources, whereas the proportion in Japan rises only slightly in the case of light fuel oil and is quite constant over time in the case of electricity.

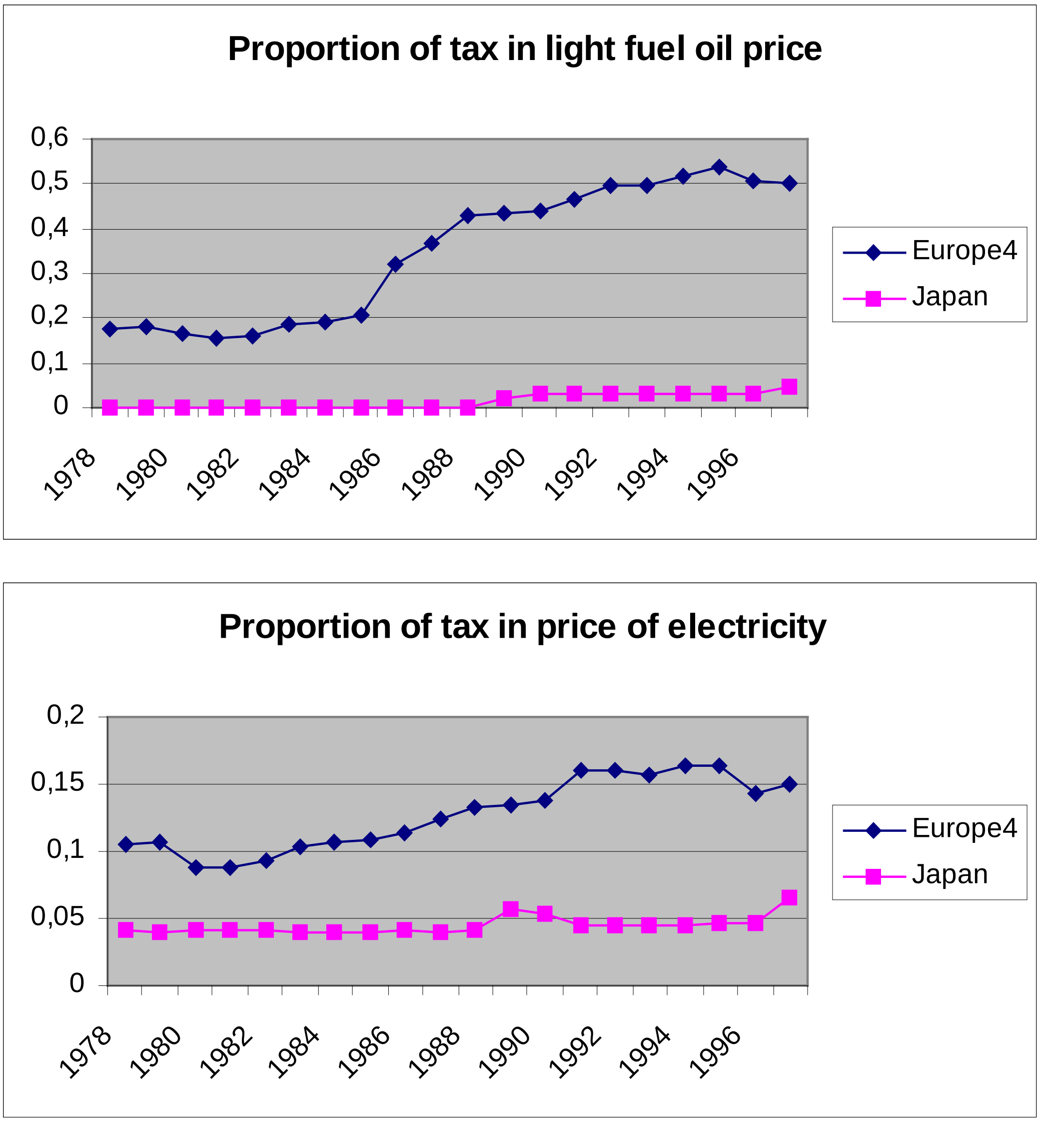


Figure 4

7 Regression results and interpretation

For testing the influences of the various variables on the energy intensity of patenting activity in regression analysis, we ran all the models written out in the following tables separately (each model represents one box in the tables), for the time series available, estimating parameters by the OLS (Ordinary Least Squares) method. Logarithms of all variables are used in order to view all coefficients as elasticities. Reported in the tables are the signs of the coefficients B to C (or D in model group 2), as well as the lag combination (lags for each variable in brackets after the sign) that yielded the highest coefficient of determination (R2), which is also reported for each model. Lags longer than 3 years were not tested simply because we regard it as quite implausible that a research process induced by high energy prices should take longer than that to yield a patent application. Statistical significance in terms of the t-test for each coefficient are reported in terms of stars, ranking from the 1% level (***) to a level higher than 10% (no stars).

Model group 1

$$\ln (EPAT_{ij}/TOTPAT_j) = A_{ij} + B_{ij} \ln(PRI_{kj}) + C_{ij} \ln(RD_{ij})$$

i= technology group; j= region; k= energy price

Patents/R&D category	**Statistic results: influence on energy patent ratio**	**USA**	**Japan**	**EU-4**	**All3**[18]
	Sign electricity price	- (3) ***	- (2) ***	- (1) *	Not appl.
Energy demand/ efficiency	Sign Gov R&D	- (3) ***	+ (1) *	- (1) ***	Not appl.
	R^2	0.86	0.63	0.43	Not appl.
	Sign oil price	- (3) ***	- (2) ***	- (2) ***	- (2) ***
	Sign Gov R&D	- (3) ***	+ (1)	- (1) ***	+ (1)
	R^2	0.74	0.5	0.65	0.67
Coal, oil, gas, nuclear	Sign oil price	- (2) **	- (2) ***	+ (2) **	- (1) ***
	Sign Gov R&D	- 1) ***	(1) ***	- (1) ***	
	R^2	0.56	0.69	0.59	0.56
Renewables	Sign oil price	- (2) ***	- (1) ***	- (1) **	- (1) ***
	Sign Gov R&D	- (1) ***	- (1)	- (1)	
	R^2	0.82	0.5	0.33	0.64

Table 1

The first model includes local energy prices including tax (the world oil price when data is aggregated across countries) and government R&D. To put the matter straight, it is clearly visible from Table 2 that we find no significant positive relationship between energy intensity of patenting activity and energy prices. Rather, the "relationship" found is negative in all but one case and often even significant at a high level. It should be noted that we have found positive signs for the coefficient here but only when increasing the length of lag to more than 6 years. Such lags would firstly reflect implausible assumptions, and secondly statistical

[18] oil price: Arabian light

significance for these results (in terms of both R^2 and the t-test) was much lower than for the ones reported.

Furthermore, government R&D expenditures seem to have, in this model, a quite insignificant effect, which is mostly negative as well. To sum up, this model yields results quite contrary to those that a price inducement mechanism would suggest. Of course there is no reason to believe that the significance reported for the negative relationships is in any way meaningful. It is precisely this which made us turn to different models.

Model group 2

$$\ln(EPAT_{ij}/TOTPAT_j) = A_{ij} + B_{ij}\ln(ARA) + C_{ij}\ln(TAX_{kj}/PRI_{kj}) + D_{ij}\ln(RD_{ij})$$

i= technology group; j= region; k= electricity or light fuel oil

Patents/R&D category	Statistic results: influence on patent ratio	Japan	EU-4
Energy demand/ efficiency	Sign Arabian light	- (2) ***	- (1)
	Sign tax ratio electr.	+ (2) *	+ (2) ***
	Sign Gov R&D	+ (1)	+ (1)
	R^2	0.76	0.87
	Sign Arabian light	- (2) ***	- (2)
	Sign tax ratio LFO	+ (1) ***	+ (2) ***
	Sign Gov R&D	+ (1)	+ (1)
	R^2	0.88	0.95
Coal, oil, gas, nuclear	Sign Arabian light	- (1) ***	+ (2)
	Sign tax ratio LFO	+ (1)	+ (2) ***
	Sign Gov R&D	+ (1) ***	+ (1)
	R^2	0.86	0.89
Renewables	Sign Arabian light	- (2) ***	- (2)
	Sign tax ratio LFO	+ (2) ***	+ (2) ***
	Sign Gov R&D	+ (1) ***	+ (1)
	R^2	0.89	0.93

Table 2

Model group 2, results for which are reported in Table 2, begins to place the emphasis on the proportion of taxes in energy prices, but also includes government R&D as well as the crude oil price "Arabian light", which replaces the local energy prices mainly because otherwise the local prices including taxes would have been an influencing factor in two different guises, and the local prices excluding taxes should mostly be unknown to economic actors without perfect information. However, the crude oil price should act as a proxy for the world oil price level, influencing expectations of researchers more generally.

Yet again, the oil price exhibits negative coefficients in all but one case, where it is insignificant. However, this model yields all positive significant coefficients for government R&D. These coefficients are especially significant for Japan in the case of energy supply technologies. The relatively poor results for the demand technologies could be due to a mismatch between the technologies covered in R&D and the patent data respectively (see Section 4).

The most striking element of the results from model group 2 is that the tax ratio is strongly significant and positive in all models. In Europe, where the ratio is absolutely higher than in Japan and also exhibits a much stronger rising trend, the coefficients are always positive and significant at the highest level (recall the rise in the energy intensity of patenting activity throughout the eighties). Moreover, the significance of the other two variables included in the models for Europe seems to pale in comparison with that for the tax ratio. It thus seemed plausible to run one extra set of models that disposes of the oil price which certainly didn't add much explanatory power this time either.

Model group 3

$$\ln(EPAT_{ij}/TOTPAT_j) = A_{ij} + B_{ij}\ln(TAX_{kj}/PRI_{kj}) + C_{ij}\ln(RD_{ij})$$

i= technology group; j= region; k= electricity or light fuel oil

Patents/R&D category	**Statistic results: influence on patent ratio**	**Japan**	**EU-4**
Energy demand/ efficiency	Sign tax ratio electr.	+ (2) ***	+ (2) ***
	Sign Gov R&D	+ (1) **	+ (1)
	R^2	0.55	0.94
	Sign tax ratio LFO	+ (2) ***	+ (2) ***
	Sign Gov R&D	+ (1)	- (1) *
	R^2	0.79	0.95
Coal, oil, gas, nuclear	Sign tax ratio LFO	+ (1) ***	+ (2) ***
	Sign Gov R&D	+ (1) ***	+ (1)
	R^2	0.78	0.89
Renewables	Sign tax ratio LFO	+ (2) ***	+ (2) ***
	Sign Gov R&D	- (1)	+ (1)
	R^2	0.74	0.94

Table 3

Table 3 summarises the results from the model group that only includes the tax ratios and government R&D as explanatory variables. First of all, the tax ratio has the "right" sign and is highly significant in all cases. Government R&D has positive signs as well, and the overall significance levels are quite high, much higher than for model group 1, and not much lower than for model group 2, which confirms the rationale for leaving out the oil price. The result that in Japan the influence of the tax indicator seems to be less significant (from model group 2) seems to be only vaguely confirmed by lower values of R^2, but not of the t-statistics.

This result obviously points towards the importance of taxes in price signals. One might regard the tax ratio also as a general indicator of public concern about, or awareness of ecological problems related to energy consumption. This interpretation of the results would not give much credit to the theory of price signals. However, another interpretation would be that it is a better indicator of real expectations than mere prices since price movements might be regarded as temporary, whereas taxes on energy can normally be expected to be of a more permanent nature (or is that a specifically European perspective??). Maybe, then, the most important result of this study is that, if any price rises in energy, then only long-term predictable ones have a significant impact on innovation, which supports a credible tax policy such as the "eco-tax" in Germany. Note here that the effect is equal for all technologies, which means that there should be potential even for the established technologies to develop under price pressure, which would reduce the cost of any price policy.

This leaves the rise of the energy intensity of patenting activity in the US to be explained. There could of course be a patent spillover from Europe and Japan, even though we don't want to attach too high significance to this interpretation. It seems more likely that the model is, for some reason, incomplete in its US coverage. The most likely candidates of omitted variables are, in our view, "technological opportunity" measures as well as the size of the market for technologies. Including this second measure would, of course, put more emphasis on the thesis that diffusion induces patent application than we have done, stressing the weakness of the Schumpeterian distinction between invention, innovation and diffusion.

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APPENDIX

I. Government energy R&D categories used by the OECD/IEA

1.1 Industry

1.2 Residential Commercial

1.3 Transportation

1.4 Other Conservation

TOTAL CONSERVATION

2.1 Enhanced Oil & Gas

2.2 Refining Transp. & Stor.

2.3 Oil Shale & Tar Sands

2.4 Other Oil & Gas

Total Oil & Gas

3.1 Coal Prod. Prep. & Trans.

3.2 Coal Combustion

3.3 Coal Conversion

3.4 Other Coal

Total Coal

TOTAL FOSSIL FUELS

4.1 Solar Heating & Cooling

4.2 Solar Photo-Electric

4.3 Solar Thermal-Electric

Total Solar

5. Wind

6. Ocean

7. Biomass

8. Geothermal

9.1 Large Hydro (>10 MW)

9.2 Small Hydro (<10 MW)

Total Hydro

TOTAL RENEWABLE ENERGY

10.1 Nuclear LWR

10.2 Other Converter Reactors

10.3 Nuclear Fuel Cycle

10.4 Nuclear Supporting Tech.

10.5 Nuclear Breeder

Total Nuclear Fission

11. Nuclear Fusion

TOTAL NUCLEAR FISSION/FUSION

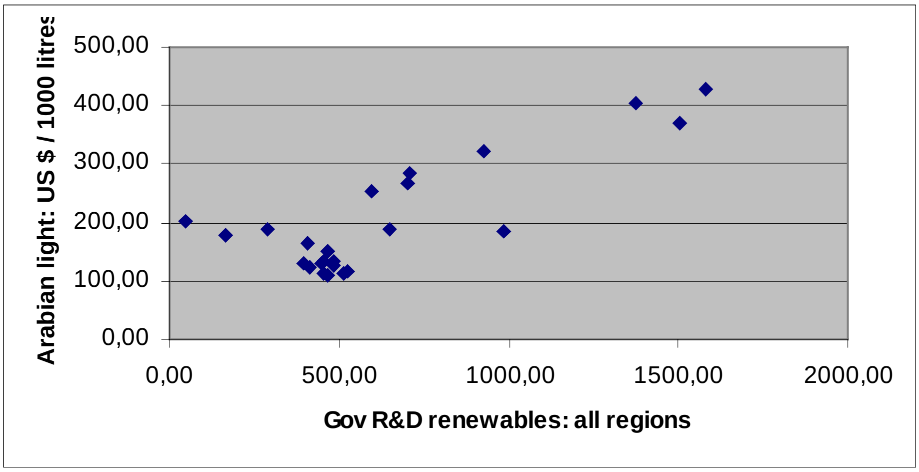
12.1 Electric Power Conversion

12.2 Electricity Transm. & Distr.

12.3 Energy Storage

TOTAL POWER & STORAGE TECH.

II. R&D correlations with crude oil price



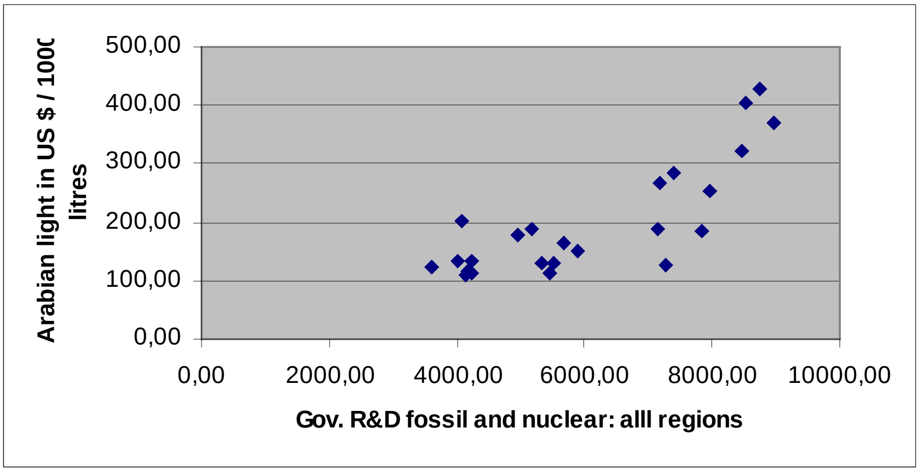


Figure 5