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KNOWLEDGE IN THE ENERGY SECTOR: WHAT R&D EXPENDITURES AND PATENTS REVEAL ABOUT INNOVATION

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Overview

Long time series of the IEA and international patent offices offer a huge potential for scientific investigations of the energy innovation process. Insight on the cumulative energy knowledge stock is essential for understanding the energy innovation process, which is also highlighted by Newbery (2014). Thus, this study deals with an analysis of the knowledge induced by public research and development expenditures (R&D) and patents in the energy sector. Moreover, it provides EU knowledge stock scenarios for the next decade and investigates, if there is a significant difference of the knowledge distribution between the EU member states and the European Commission. Thus, I present the findings of three recently published papers. Bointner (2014) describes the relation between renewable energy R&D expenditures and patents in selected IEA countries, Bointner et al. (2014) is dealing with the cumulative energy knowledge stock induced by the European Commission and the EU member states and Bointner and Schubert (2014) shows an application of the cumulative knowledge stock in nuclear reactor safety in Germany.

Methods

Several methods such as ex-post analysis, linear and non-linear regressions as well as statistical test have been applied, which are described in the abovementioned sources. The most important and frequently used methods are as follows: The cumulative knowledge stock *(KS)* of energy technologies in selected countries *i* is broken-down among seven groups *k* defined by IEA (energy efficiency, fossil fuels, renewable energy, nuclear power, hydrogen and fuel cells, energy storage technologies, other cross-cutting technologies). This comprises the depreciated cumulative knowledge stock of the last period $(1 - \delta) \times KS_{(t-1)}$ and the *R&D* expenditures in period *t-x*.

$$KS_{(t)\,i,k} = (1 - \delta) \times KS_{(t-1)\,i,k} + RD_{(t-x)\,i,k} \qquad [EUR]\,(1).$$

See also Klaassen et al. (2005) and Kobos et al. (2006). Exemplary for the scenarios of future R&D expenditures is formula (2). Within the business as usually scenario (BAU) the $R\&D_{BAU}$ forecast in country *i* is based on the *GDP* development and the floating average of the R&D expenditures in technology group *k* of the last five years according to formula (2), whereat *t* denotes time

$$R\&D_{BAU\,(t,i,k)} = \sum_{i=1}^{n}\sum_{k=1}^{7}\overline{\sum_{t-5}^{t-1} R\&D_{t,i,k}} * \frac{GDP_{t,i}}{GDP_{t-1,i}} \quad [EUR](2)$$

For the case study on nuclear reactor safety in Germany the method described by Duffey & Saull (2003) is essential. Along with their theory, the instantaneous rate *IR* shows an exponential decay with growing experience measured in cumulated nuclear electricity generation $TWh_{cum,}$ in year *t*. This means mistakes, measured in reportable events per TWh, are declining with growing experience. *IR* can be approximated over the whole period with formula (3)

$$IR_t = a + b * exp^{\frac{-TWh_{cum,t}}{c}} \qquad (3),$$

in which *a*, *b* and *c* are constants. By applying the cumulative nuclear fission knowledge stock of Germany derived from formula (1), which means substituting the constant *c*, we finally obtain formula (4)

$$IR_t = a + b * exp^{\left[\frac{-TWh_{cum,t}}{KS_{(t,\delta)}\left(d+e*exp^{\frac{-TWh_{cum,t}}{f}}\right)}\right]} \qquad (4).$$

Results

The cumulative energy knowledge stock induced by public R&D expenditures in 14 investigated IEA-countries is 102.3 bn. EUR in 2013. Ranked by their GDP, the sample consists of seven large (Canada, France, Germany, Italy, Japan, United Kingdom and the United States) and seven medium-sized (Austria, Denmark, Finland, the Netherlands, Norway, Sweden and Switzerland) IEA countries. Nuclear energy has the largest share of 43.9 bn. EUR, followed by energy efficiency accounting for 14.9 bn. EUR, fossil fuels with 13.5 bn. EUR, and renewable energy with 12.1 bn. EUR. A regression analysis indicates a linear relation between the GDP and the cumulative knowledge, with each billion EUR of GDP leading to an additional knowledge of 3.1 mil. EUR. However, linearity is not given for single energy technologies. Moreover, the knowledge induced by patent applications has been growing enormously since 1990; by the factor 5.9 in medium sized and the factor 5.6 in large IEA-countries. However, the total number of patents in the countries differs hugely. While the medium-sized sample had around 4400 patents in 2010, large IEA-countries had together more than 52000 patents.

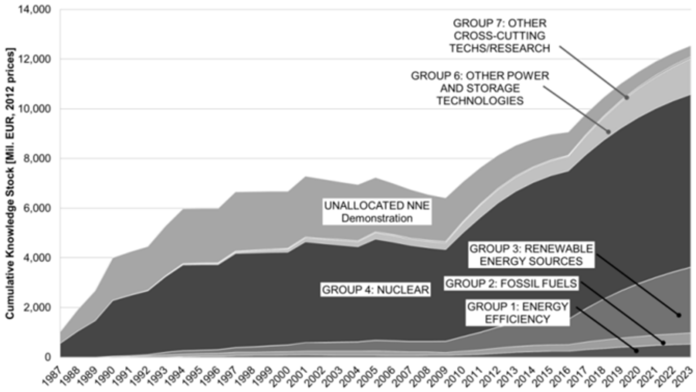

Figure 1 (Exemplary for the study's results): **Cumulative energy knowledge stock induced by public R&D expenditures of the European Commission** [mil. EUR, 2012 prices and exc. rates, knowledge depreciation 10%, time lag 3 years] (Source: Bointner et al., 2014)

With regard to the European Commission (EC) and EU member states, the energy R&D distribution among technologies was similar in the 1980s with a strong focus on nuclear energy. Nowadays energy efficiency and renewable energy technologies are of growing importance and the new programme Horizon2020 is expected to have an equal budget for nuclear and non-nuclear technology. The energy KS induced by public R&D expenditures amounts to 35.8 bn. EUR in 2013, whereupon the EU member states' KS share is more than three times larger than the European Commission's share (see Figure 1). To the author's understanding it is the first time that such comparison has been done. No statistic difference in the knowledge distribution between the EU member states and the European Commission was observed. The energy KS of the EU member states and the EC is expected to increase to a total amount of 48.5-55 bn. EUR in 2023 (with $x=3$) according to the scenarios. For comparison, the energy KS induced by public R&D expenditures in the USA was 34.4 bn. EUR and 35.2 bn. EUR in Japan in 2012.

The cumulative fission knowledge stock of Germany (3.4 bn. EUR in 2014) serves as an input to the case study on reactor safety in German nuclear power plants. Past errors, available as so called reportable events of nuclear power plants, can be approximated with experience measured in cumulated electricity generation by applying the Duffey-Saull method with a high coefficient of determination (R^2=0.84). Today, approximately 0.9 reportable events per generated TWh occur and it is expected to remain at this magnitude in the near future. Moreover, knowledge induced by public R&D expenditures may supplement experience in reducing reportable events. Thus, the cumulative fission knowledge stock of Germany was added to the Duffey-Saull method for the first time. By adjusting the knowledge depreciation rate within this extended method the prediction of reportable events is more accurate (R^2=0.86). Best results were obtained with 10.8% depreciation rate, which is also in line with the literature.

Conclusions

R&D expenditures and patents do not illustrate the whole knowledge stock, as they are facing several limitations. Further research is needed inter alia on private R&D expenditures and the influence of knowledge spillovers. Moreover, we have to keep in mind that there is no true value of knowledge. Knowledge is always related to estimations and indicators. Anyway, the analysis of the 14 IEA countries shows that appropriate public R&D funding for R&D associated with a subsequent promotion of the market diffusion of a niche technology may lead to a breakthrough of the respective technology. An application of the cumulative knowledge stock is shown in case study. For the first time the cumulative fission knowledge stock was added to the Duffey-Saull method and increases the accuracy of the results. Thus, knowing the knowledge is essential for several excises in energy economics such as modelling innovation, creating energy (supply) scenarios, providing policy recommendations and risk analysis.

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