Energy research and R&D indicators:

An LMDI decomposition analysis for the IEA Big 5 in energy research

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Highlights

• Two main factors in the improvement of the research output: GDP & R&D Expenditures.

• The Big Five examined here are Australia, Canada, Germany, UK & US using LMDI.

• Four factors examined: GDP, R&D intensity, energy R&D rate of return & R&D priority.

• Energy R&D intensity is a negative factor while all others positive.

• The results are different at periods of low GDP.

Abstract

The literature has always shown that there are two important factors in the improvement of a country's research output: Gross Domestic Product (GDP) and R&D Expenditures. Taking the discussion a step further, and in an effort to provide policy recommendations on what is needed to boost research capacity, this paper aims at decomposing the change in energy research papers of five countries (Australia, Canada, Germany, UK and US) into four factors: GDP, R&D intensity (ratio of total R&D to GDP), energy R&D rate of return or productivity (number of energy-related papers per unit of energy R&D expenditure), and energy R&D priority (share of energy R&D to total R&D expenditure).

The findings show a general trend in the sign of the four effects on research for all five countries: energy R&D productivity, energy R&D priority, and GDP are mostly found to be positive contributors, while the R&D intensity a negative one. This pattern has exceptions that are more prominent during periods where economic growth is constrained, for example during 2008/09. The results have policy implications not only for these five countries but also for developing countries (low GDP) that aim at contributing more to the energy-related research output globally.

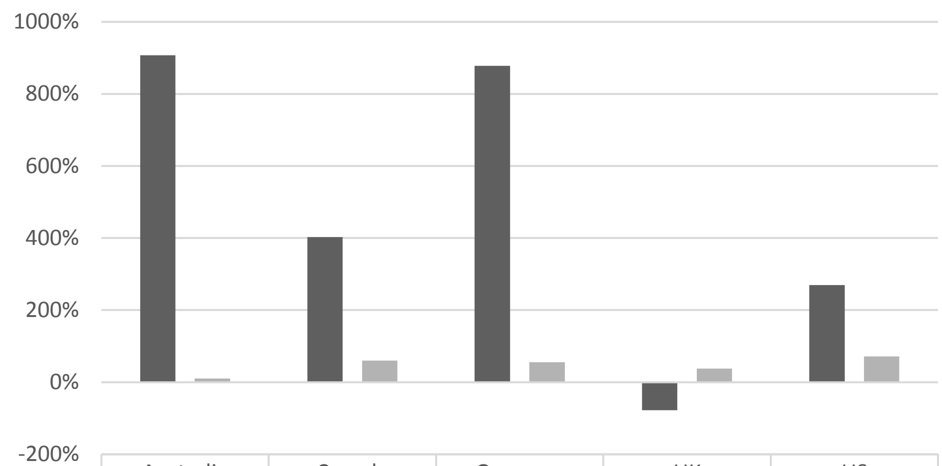
Keywords: energy research; R&D intensity; R&D return; top research producers

Introduction

In a recent commentary by the International Energy Agency (IEA), Bennet and Gigoux (2017) have expressed their deep concerns on the declining energy research budgets and the possible devastating effects on the sustainable, accessible and affordable global energy system. Internationally, voices are calling for specifically directed Research & Development (R&D) for clean energy applications from both the public and private sectors, and on the productivity and return of the monetary investments.

In the literature, the R&D expenditures are considered as input indicators while research publications and patents output indicators of the research process. Although the availability of funds surely enables the research productivity of the community, the policy makers would like more information when it comes to the impact of the monetary investment in the production of innovation. Additionally, de Corninck et al. (2008) discuss that long-term technology R&D is not panacea into tackling climate change and its environmental consequences through energy usage for example. Appropriate allocation of R&D and return on investment are as crucial as the implementation of the suggested solutions (invention to innovation).

In addition, more developed countries with higher levels of Gross Domestic Product (GDP) tend to spend more on R&D activities. The structure of the R&D expenditures and contribution to various sectors is not homogenous among them. Wang et al. (2013), however, explain that increases in energy R&D will not necessarily have positive contributions to the economic growth of a country: increases in energy R&D result in improved production processes and hence higher productivity. On the other side, however, dedicating more financial resources on energy R&D might mean substitution from other production factors with negative results to economic growth. Hence, the share of energy R&D to total R&D demonstrates the prioritisation of energy in the R&D agenda of a country.



	Australia	Canada	Germany	UK	US
Change in energy research	908%	403%	878%	-78%	270%
Change in energy R&D	10%	60%	56%	38%	72%

Figure 1: *Energy R&D and energy-related research output (in published papers) percentage change: 1990 – 2017 for Top 5 IEA countries in Energy-related Research. Note: Energy-related research fields = Ecology, Energy & Fuels, Environmental Studies, Water resource.*
Sources: Thomson Reuters (2017) and IEA (2018)

Observing their R&D expenditure in the energy field, they have all generally increased for the period from 1990 to 2017, with the exception of UK that has shown a decrease in the number of energy-related papers. It can be observed in Figure 1, that the energy R&D expenditures have increased in the period 1990 to 2017, with US having the highest increase (72%) while Australia the lowest (10%); while at the same time, Australia showed the highest increase in energy-related papers in the period (908%). Also, although energy R&D increased by 38% the energy-related research showed a decrease by 78% in this period. All in all, the question here is whether energy R&D expenditures in monetary units is the factor that determines energy research in a country or other R&D indicators are better determinants of research. This paper aims at decomposing the changes in energy-related research for the top 5 IEA countries in energy-related research for the period 1981 to 2017 into four factors: energy R&D productivity, energy R&D priority, R&D intensity, and GDP.

Brief literature review: Energy R&D

International literature stresses through the years the importance of R&D expenditure in the growth and development of the economies, through promoting innovation. The literature discusses extensively the connection between research and economic growth. Studies such as Grilliches (1994), and Jones and Williams (1998) concluded the positive effects of R&D on productivity growth, both in levels but also presented as intensities to the total GDP of the various countries. Clearly, there are barriers in entering the market to invest in R&D, even though the positive effects are well documented. One of those is the size of firms in the economy (Costa-Campi, Duch-Brown, & Garcia-Quevedo, 2014) while many studies have looked for explanation in the liberalisation process of the energy industry (Dooley, (1998); Jamasb and Pollit, (2008); Kim et al. (2012); Markard and Truffer, (2006); Sanyal and Ghosh, (2013); Sterlacchini, (2012)).

The importance of R&D in the energy sector and its role in facing current energy and environmental challenges with the promotion and development of new knowledge is stressed in many studies recently (Anadon, (2012), Anadon et al. (2011); IEA (2012); Nakicenovic and Nordhaus (2011); OECD (2011); Costa-Campi et al. (2014)). More specifically, the energy sector is in need of investment in R&D, taking into consideration the much-desired benefits from new ideas and technologies to future sustainability, security, efficiency and supply of energy (Inglesi-Lotz, 2017). Recent literature (Cohen, (2010); Griffith et al. (2006); Savignac (2008)) has discussed the effects of liberalised and open electricity markets on innovation: competitive structures have positively affected the innovative urge of the competitors although the specific determinants vary among countries.

To decouple the topic of R&D, studies such as Grilliches (1994), Jones and Williams (1998), Corderi and Lin (2011), and Inglesi-Lotz (2017) have made use of not the volume of R&D expenditures, but the R&D intensity as a percentage to GDP, to tone down differences among countries, and amplify the importance of energy R&D for the economies. In addition, Inglesi-Lotz (2017) looked further in disaggregating the energy R&D into different technologies and not dealing of it as a single expenditure item. Her results showed investing in R&D to promote energy efficiency and nuclear technologies yield positive return for the society.

The reason why the role of R&D expenditure to energy knowledge and technologies as well as its return in investment is not extensively estimated and quantified in the literature primarily due to lack of data (Costa- Campi et al. (2014), Inglesi-Lotz, (2017)), especially in developing countries (example Gyekye et al. (2012) that looked at R&D and its contribution to economic growth in Sub-Saharan Africa in a quantitative manner). The case of developed countries attracted in the literature more attention not only due to data availability but also because most of energy R&D is invested there and most energy knowledge is produced there: almost 85-90% of global energy R&D is conducted in high-income countries (Breyer et al. (2010)).

The usual link of the impact of R&D to the economy is through changes in productivity and innovation and stock of knowledge. The literature identifies the challenge of defining innovation or stock of knowledge. R&D is classified as an input indicator while indicators such as patents and academic publications are output indicators in the production of knowledge. Drawing from the scientometric discipline (De Moya-Anegon and Herrero-Solana (1999); King (2004); Vinkler (2008); Lee et al. (2011); Inglesi-Lotz and Pouris (2013); Inglesi-Lotz et al. (2015)), various indicators were used to measure a country's research performance and through that its innovative capacity: quantity of research output in papers or patents, share of papers to the rest of the world, or impact in the number of citations of papers. Pouris and Pouris (2009) have concluded that the number of published papers is one of the most objective and straightforward ways to measure a country's capacity for innovation, through production and stock of knowledge.

Methods and data

Decomposition techniques have been used extensively in the energy literature to decouple the effects of various factors on the evolution of emissions or energy consumption for example (Inglesi-Lotz & Blignaut, 2011) (Inglesi-Lotz & Pouris, 2012) (Shao, et al., 2016) (Sumabat, et al., 2016) (Xu, et al., 2016). According to Ma and Stern (2006), there are two broad categories of decomposition analysis: input-output techniques – structural decomposition analysis (SDA) – and disaggregation techniques – index decomposition analysis (IDA).

The SDA can differentiate between direct and indirect energy demands while the IDA is incapable of doing so. The advantage, however, of the IDA technique is that it can easily be applied to any available data at any level of aggregation and to data available in time series format. In this paper, we employ the IDA model owing to a lack of energy data in an input-output format; therefore, the changes are only direct without considering indirect spillovers.

Within the IDA approach, there are various methods to employ but there is no consensus as to which one is the best. We decided to follow the method proposed by Ang and Liu (2001) and Ang (2004) who argue that the logarithmic mean divisia index (LMDI) should be preferred to other methods for the following four main reasons:

- Perfect decomposition: the method does not allow for the existence of unexplained residuals.
- Path independency: the method presents symmetry between decomposition of changes in terms of ratios or differences.
- The ability of the method to handle zero values.
- Consistency in aggregation: decomposition exercises are usually conducted in a disaggregated level and consistency allows the results to be summed at an aggregated level.

Using the equation below, the assumption is that the drivers of energy research (measured by the number of academic papers) do not interact with each other; but their relative contributions in both sign and magnitude can be detected and compared over time.

In the LMDI method used here, changes in energy academic publications (Research) are decomposed into four factors (equation 1):

1) Gross Domestic Product (GDP),
2) Energy R&D productivity: the number of research papers per monetary unit of R&D invested,
3) Energy R&D priority: the share of energy R&D to total R&D expenditure,
4) R&D intensity: the ratio of total R&D to the country's GDP.

$$Research_i = \sum GDP_i \frac{energy\_research_i}{energyR\&D_i} \frac{energyR\&D_i}{R\&D_i} \frac{R\&D_i}{GDP_i} \rightarrow$$

$$Research_i = \sum GDP_i * energyR\&Dproductivity_i * energyR\&Dpriority_i * R\&Dintensity_i \quad (1)$$

Hence, changes in research output are equal to the sum in changes of each of all the drivers. The logarithmic scheme (weight) used here is adopted from Zhao, Ma and Hong (2010) where w_{it}= ln ($Research_{it}/Research_{i0}$)=($Research_{it}$-$Research_{i0}$)/ln($Research_{it}/Research_{i0}$).

The data are derived from the IEA RDD Budgets database (IEA, 2018), and the Thomson Reuters databases (Thomson Reuters, 2017) for the period 1981- 2017 (See Appendix for graphical representation of all data). Combining the number of papers in energy – related fields (Ecology, Energy & Fuels, Environmental Studies, Water resources) as measured in the Web of Science database for the period 1981-2018, the five most research producing countries that are members of the International Energy Agency (IEA) are: US (28.52%), UK (7.27%), Canada (5.95%), Germany (5.28%), and Australia (5.26%). The study has chosen particularly these five countries for their consistent research performance in energy – related research.

Empirical results

Looking at the results for the countries group in its entirety for the full period from 1981 to 2017, Figure 2 suggests that the only negative contributor in the changes of energy research was the R&D intensity of the countries, while all the other factors pushed upwards the number of energy-related papers. Energy R&D productivity was the dominant positive contributor.

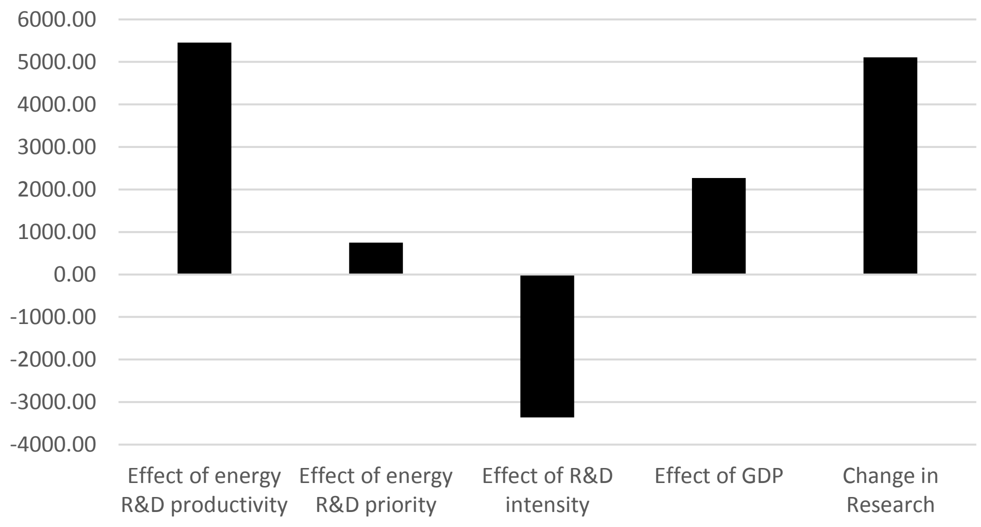


***Figure 2**: Total Decomposition results 1981-2017 (average of the five countries)*

Figure 3 illustrates the decomposition results for the period 1981 to 2017 for each of the countries individually. The signs of the determinants follow the overall pattern with the total decomposition exercise, even though the magnitudes differ. The only exception is UK where the R&D intensity was the dominant positive contributor for the period with GDP playing a negative role.

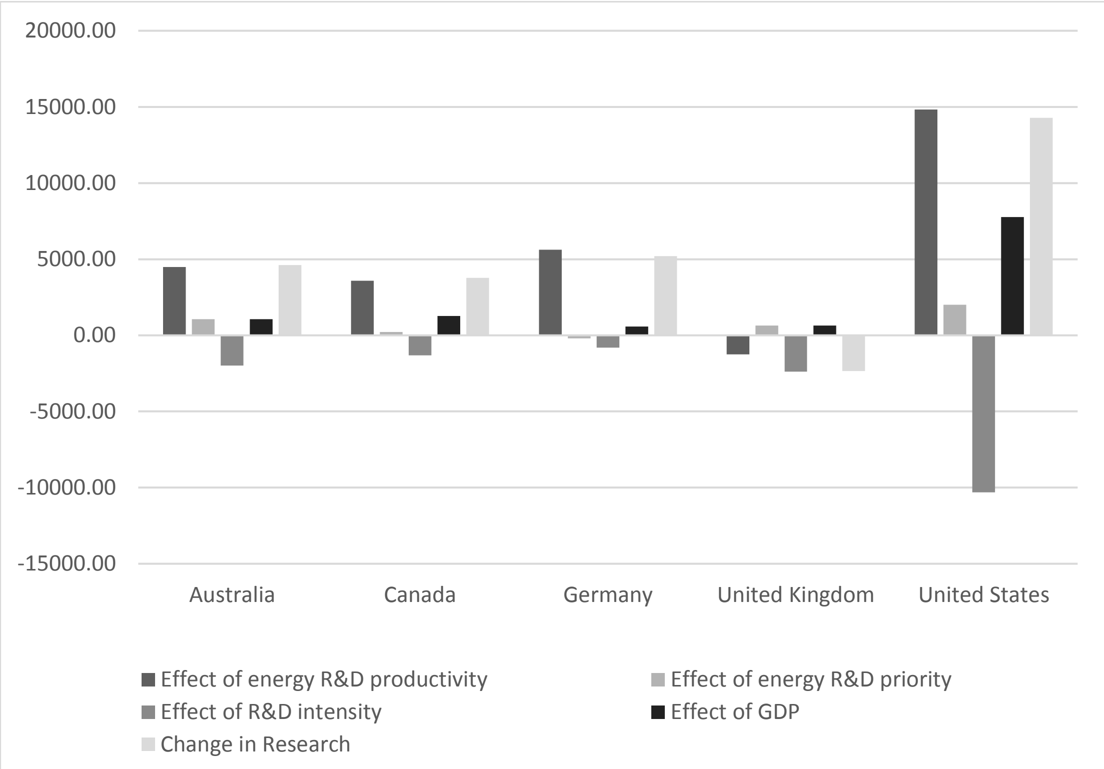


***Figure 3**: Top 5 energy-related research IEA countries decomposition 1981-2017*
Note: The sum of the four effects equals the changes in research output.

The period from 1981 to 2017 was characterized by drastic changes in economic growth and in the interest of the literature in energy-related fields. Especially after the 2000s, the consequences of climate change as well as issues in energy security have attracted attention by researchers. As per Margolis and Kammen (1999), energy technology R&D expenditures showed decreases from the early 1980s until the beginning of 2000s in US, but Costa-Campi et al. (2014) and GEA (2012) also confirm that R&D expenditure in the energy field is relatively low, compared to other fields. Based on this, the study proceeds with a separate decomposition exercise for four periods/decades: 1981-1990, 1991-2000, 2001-2010 and 2011-2017 (Figure 4).

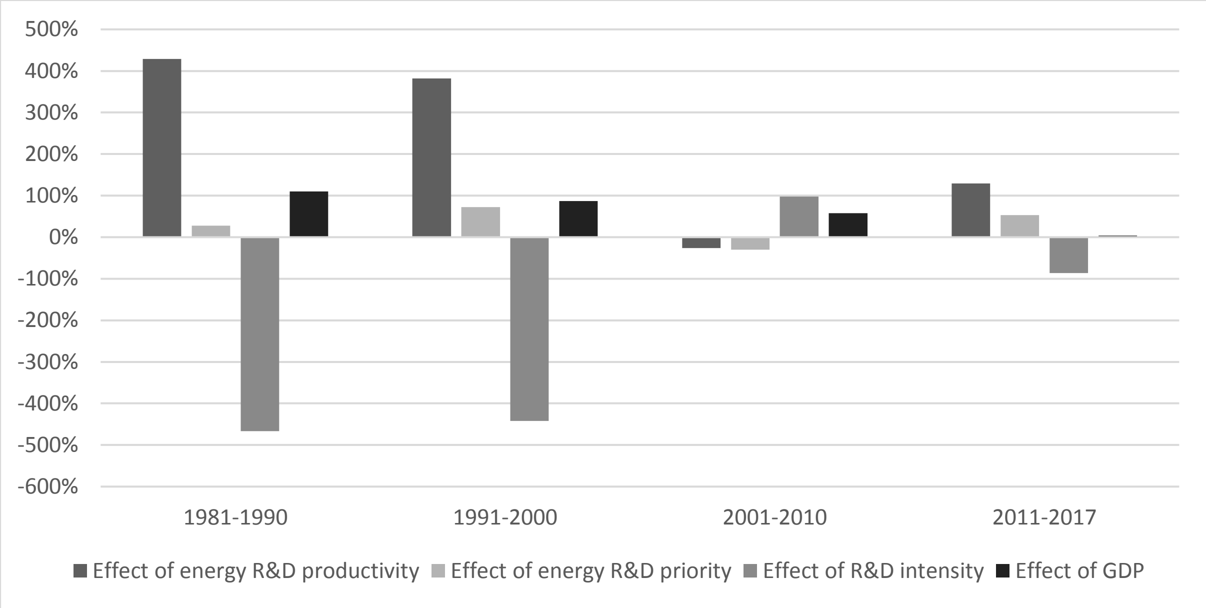


***Figure 4**: Decomposition exercise (average) per decade*

The first two periods follow the same signs in factors as the overall decomposition results. However, for 2001-2010 and 2011-2017, the direction and magnitude of the effects change: the dominant positive factor during 2001-2010 is the R&D intensity with energy R&D productivity becoming a negative contributor. When the countries start recovering from the global financial crisis of 2008/09, what boosts again the increase of energy-related papers is the energy R&D productivity while the GDP and R&D intensity are a marginal positive and negative contributors respectively.

Conclusion and Policy Implications

Recent data for the IEA countries show that their public sectors have spent $16.6 billions for R&D, showing a decline for fourth year in a row. The private sector R&D shows a similar trend. Bennet and Gigoux (2017) observed two shifts in spending among various technological applications: in the 1980s and 1990s, the funding contribution for nuclear applications gave space to coal technologies, while from the 2000s, energy efficiency, and renewable energy technologies take the lead with shares of 21% and 19% respectively in 2016. Two are the country leaders in energy R&D expenditures recently: Japan and US, with EU countries being a competitor only when presented in aggregation. Bennet and Gigoux (2017) summarise the situation in the sector: “Accelerating energy innovation is a complex task that requires coordination between public and private sectors and regular adjustment to new developments, especially at a time of rapid change in digital technologies… In addition to trying to maintain and raise research budgets, governments can use existing funds to target key research gaps. They can also build capacity to ensure that the outputs of innovation policies, as well as the investments, are being tracked for better policy making".

The decomposition exercise of this paper sheds light into the contribution of R&D expenditures indicators towards changes in energy research output through the years and provide future policy recommendations. The total decomposition exercise findings show that the only negative contributor in the changes of energy research was the R&D intensity of the countries, while all the other factors increased the number of energy-related papers, with energy R&D productivity being the dominant one. What these results demonstrate is that the importance of countries shown to R&D in relation with their economic production affected negatively the energy-related research, due to its low and decreasing levels over the years – as can be seen in Figure 5 only in recent years, the R&D intensity in the five countries have shown a slight upward trend without however reaching the levels of the 1980s yet.

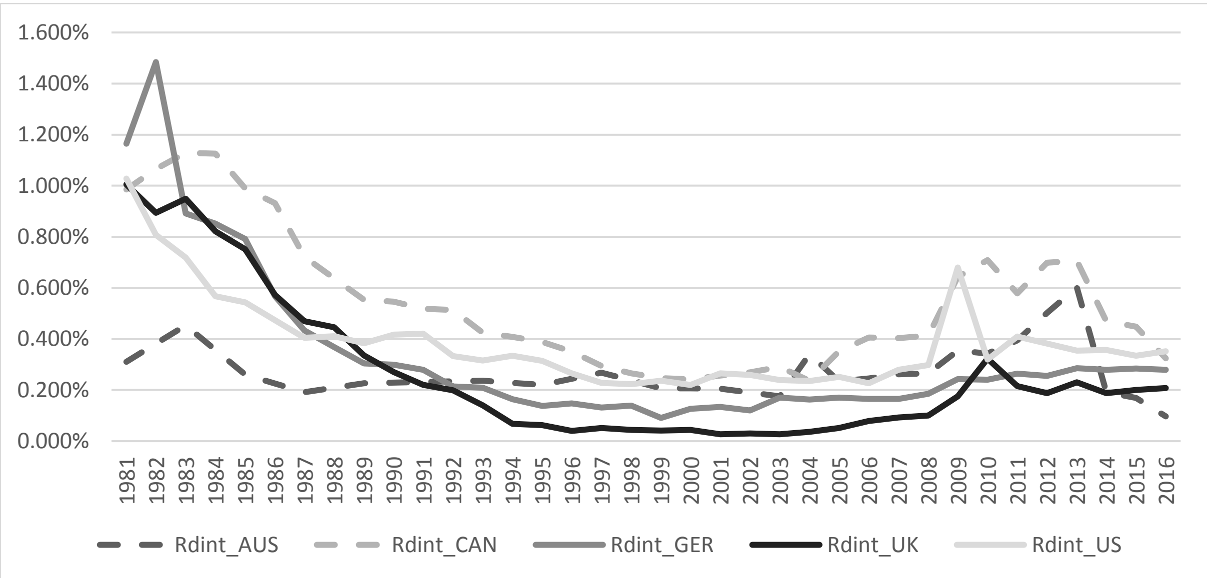


***Figure 5**: R&D intensity (ratio of total R&D to GDP - all in constant prices)*
Sources: Authors calculations with data from Thomson Reuters (2017) and IEA (2018)

Even when looking at the results by country, the pattern remains the same with R&D intensity being mostly a negative contributor, while energy R&D productivity the dominant positive. That means that the rate of return of every unit invested in energy R&D affects positively the energy-related research. The energy R&D productivity can be improved from a policy point of view with better monitoring and reporting, as well as managing expectations when R&D expenditures are made. Also, by including more researchers in energy-related fields, economies of scale from collaboration and research production from the same "unit" of R&D will increase energy R&D productivity more. Finally, creating the right conditions and environment for researchers to produce research is a target for policy makers that do appreciate the value of energy-related research and its importance for the energy sector and the economy, as a whole.

The periods 2001-2010 and 2011-2017 have exhibited a slightly different trend: the dominant positive factor during 2001-2010 is the R&D intensity with energy R&D productivity becoming a negative contributor. In periods of low GDP such as 2008-2009, the positive factor that kept research publications increasing was the R&D intensity: GDP decreased rapidly, while the R&D investment is stickier to shocks as it is a policy decision. When the countries start recovering from the global financial crisis of 2008/09, what boosts again the increase of energy-related papers is the energy R&D productivity while the GDP and R&D intensity are marginal positive and negative contributors respectively.

These results have important implications not only for these five countries but also, for any countries that experience low levels of GDP. During periods of low GDP, the enhancing determinant boosting research productivity can potentially be the R&D intensity. Policy makers should consider that appropriate programmes should be implemented taking into consideration the sustainability and speed of economic growth and generally, the economic conditions of their countries.

However, a boost in such expenditures in energy-related fields have potential risks towards an optimal allocation of R&D expenditures. Popp and Newell (2012) stress the fact that many studies support the positive impacts of R&D expenditure to the development of energy technologies and knowledge, however it is imperative to discuss where this funding is derived from. An example is Roediger-Schluga (2003) that has shown that many firms substituted other types of R&D and redirected their funds to R&D in environmental applications. In past literature, models such as Nordhaus (2002) made strong assumptions such a fixed R&D labour, and hence, energy R&D crowds out either types of R&D. On the other side, studies such as Buaonanno et al. (2003) deal with R&D expenditures in various fields as complementary – in that way, crowding out does not exist. It would be interesting in examining further the within-energy field distribution of research into various applications and their relationship with the supply mix chosen in various countries – does it lead the decision on supply mix or does it depend on it? In addition, the results of this paper open the discussion of “R&D for the sake of R&D” and if that is the case for the energy field as well.

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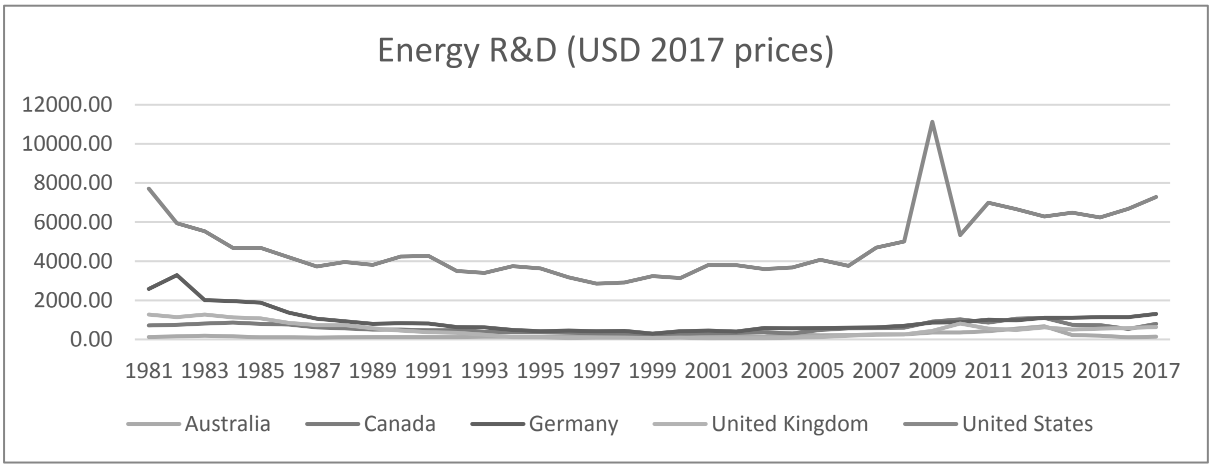
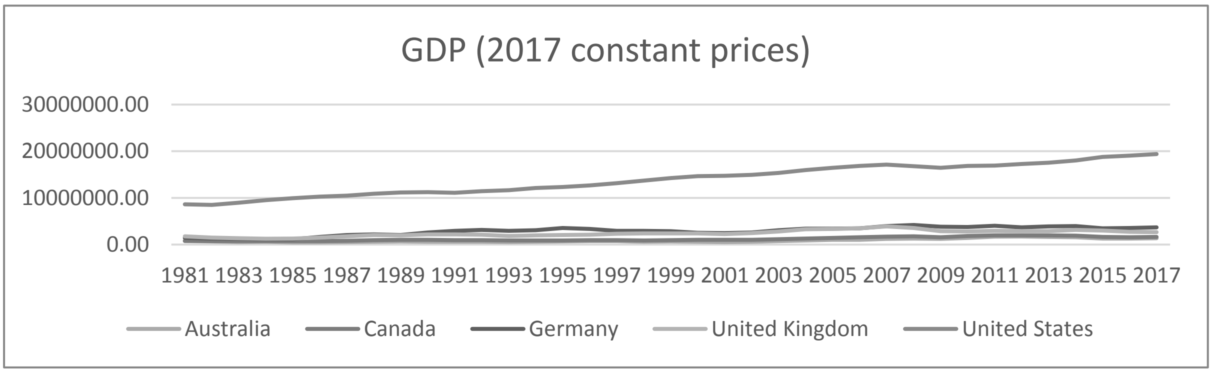
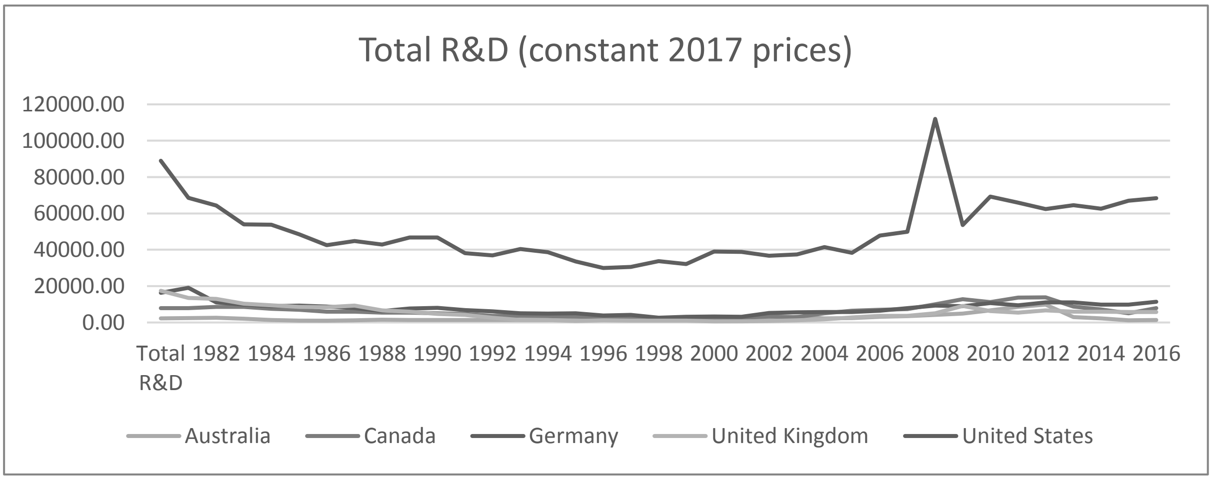
Appendix


Number of research papers
20000
15000
10000
5000
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Australia
Canada
Germany
United Kingdom
United States


Energy R&D (USD 2017 prices)
12000.00
10000.00
8000.00
6000.00
4000.00
2000.00
0.00
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Australia
Canada
Germany
United Kingdom
United States


GDP (2017 constant prices)
30000000.00
20000000.00
10000000.00
0.00
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017
Australia
Canada
Germany
United Kingdom
United States


Total R&D (constant 2017 prices)
120000.00
100000.00
80000.00
60000.00
40000.00
20000.00
0.00
Total R&D 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
Australia
Canada
Germany
United Kingdom
United States