The Political Economy of Oil Security Investments - Domestic Factors and International Dynamics
First Draft

Elina Brutschin[a], Andreas Fleig[b],

[a] *International Relations Department, Webster University Vienna, Praterstrasse 23, A-1020, Vienna, Austria, E-mail: elina.brutschin@webster.ac.at.*
[b] *Department of Political Science, Heidelberg University, Bergheimer Str. 58, D-69115, Heidelberg, Germany, E-mail: andreas.fleig@ipw.uni-heidelberg.de.*

Abstract

We test empirically whether investments in energy security are affected by the level of supply dependence, suppliers' political stability and the structure of the importing country's industry. We collect data on 27 OECD members from 1978 to 2012, and limit our analysis to the investments in oil security. Our theoretical model shows that investments in energy security are more likely when the level of supply dependence is high and the supplier is politically unstable. At the same time, when hosting a substantial domestic energy producers group, a country's investments in new technology might be hampered. We find the strongest evidence linking growing dependence on a single supplier to increased investments and some evidence that OECD members with a substantial domestic energy producer sector might be less willing to invest in alternative energy resources. Additionally, we find that there is an association between increased levels of RD&D expenditures and major oil suppliers' involvement in international war, but not with suppliers' domestic instability.

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1. Introduction

Multiple studies have discussed how states could improve their level of energy security (Bahgat, 2006; Bielecki, 2002; Correljé and van der Linde, 2006; Metcalf, 2013; Mueller-Kraenner, 2008; Turton and Barreto, 2006; Yergin, 2006), but systematic analyses of how countries actually react to security concerns are rare (Cheon and Urpelainen, 2015; Ikenberry, 1986). A number of studies have looked into general determinants of energy policies (Ikenberry, 1988; Markus, 2014; Nye et al., 1981; Tosun et al., 2015). More recent studies focus on renewable technologies (Hughes and Urpelainen, 2015; Laird and Stefes, 2009), but did not aim for falsifiable hypotheses on the issue of energy security (Cheon and Urpelainen, 2015). Most of the difficulties stem from energy security being difficult to conceptualize (Winzer, 2012), and given the "complex set of social, economic, political, legal and technical variables in the energy and security calculus" (Deese, 1979, p. 141), developing empirical tests is equally challenging. Still, more empirical research on energy security policies is essential because the "political, economic, and ecological implications [of these policies] are profound" (Hughes and Lipscy, 2013). We supplement recent efforts to close this gap (Cheon and Urpelainen, 2015; Hughes and Lipscy, 2013) by investigating the topic of energy security from a political science perspective, while incorporating insights from adjacent scholarly debates on energy security (Cherp and Jewell, 2011, see section 2.1).

Our analysis is based on data available for OECD members over the period from 1978 to 2012 and claims three main contributions. First, we acknowledge the complex, multifaceted and dynamic character of the energy sector and explicitly concentrate on the security of oil supply. We then operationalize investments in oil supply security by looking at public RD&D expenditures in technology related to oil security improvements.[1] Second, we discuss country-specific risks of oil supply disruption based on the degree of dependence on one major fuel supplier as well as the respective suppliers' internal and external political stability. Finally, we deviate from the common assumption of the state being a unitary actor and consider the role of domestic energy producers, who might not be to interested in fostering alternative technologies.

Our preliminary results, based on fixed effects panel models, indicate that OECD members raise energy security RD&D expenditures if their oil dependence increases. Additionally, there is some evidence that countries react to their suppliers' involvement in international wars, but do not react to supplier states' domestic political transformations. Most interestingly, we provide first evidence that the presence of domestic oil producers might hamper energy security investments even during times of increased supply risks.

The remainder of this paper is structured as follows. Section 2.1 starts by reviewing previous literature. In section 2.2 we discuss our theoretical model before section 2.3 provides an overview on our data sources. Section 3 presents the preliminary findings of our analysis in two

[1] This includes, among others, transport, biofuels and advancements in the oil sector. For a more detailed discussion of the technologies covered see section 2.3.1. In addition, the table in section AppendixA contains a full list of related technologies.

steps. While section 3.1 discusses the descriptive findings, section 3.2 elaborates the regression estimates. Finally, section 4 concludes and evaluates the policy implications of our research.

2. Determinants of Energy Security Investments

2.1. Literature

Studies on the security of energy supply gained on prominence especially after the oil shock of 1973 (Cherp and Jewell, 2014), but discussions can already be traced back to the Suez Crisis of 1956 (Lubell, 1961). While early analyses of energy security followed perspectives of different disciplines[2], more recent contributions engage in connecting different approaches (Cherp and Jewell, 2011). Common to many studies of oil security has been the close attention to the political developments in the Middle East (e.g. Deese, 1979), a region still hosting the most important oil producers as well as crucial transit choke points.

Some of the early studies point out that leaders of the major oil consumer states did not think that interruptions of oil supplies for political reasons were a credible threat for a long time (Lubell, 1961). Additionally, until oil producing countries nationalized the oil companies, (crude) oil extraction was mostly controlled by Western companies. Investments in energy security like looking for new suppliers or investing in new technology were thus not a top priority for policy makers in the 1960s and the early 1970s. This changed with the growing political instability in the Middle East and the increased market power of the Organization of Petroleum Exporting Countries (OPEC), which was founded in 1960. In the wake of another oil disruption in 1979 associated with the revolution in Iran, US president Jimmy Carter proclaimed that energy interruptions presented a "clear and present danger to [US] national security" (Nye, 1982, p. 122). After 1980 contingency planning in the Middle East became an important part of US military strategy (Delucchi and Murphy, 2008, p. 2258).

Interestingly, scholars still disagree on whether interruptions of oil supplies present a major security concern after the 1980s and, consequently, whether states should actively regulate energy security issues. Prominent arguments for this perspective point to the globalization of the oil market within the last decades (Goldthau and Witte, 2009; Hughes and Long, 2015) and dismiss the claim that OPEC countries "steer" the oil market as a "rational myth"(Colgan, 2014). Additionally, Gholz and Press (2010) emphasize that the oil market is much less vulnerable to disruptions than is commonly assumed because it is able to adjust to disruptions through a variety of mechanisms. However, Levi (2013) argues that this perspective substantially underestimates how vulnerable the oil markets can be, not only from decreasing OPEC reserve supply, but also due to the concentration of oil transportation routes in the Strait of Hormuz and the Strait of Malacca. The major drawback across all these studies is that they are often descriptive,

[2] Cherp and Jewell (2011, p. 202) list "the 'sovereignty' perspective with its roots in political science; the 'robustness' perspective with its roots in natural science and engineering; and the 'resilience' perspective with its roots in economics and complex systems analysis.

providing mostly anecdotal evidence rather than falsifiable hypotheses (Cheon and Urpelainen, 2015). Overall, it is plausible to assume that oil importers rely on a portfolio of suppliers (Vivoda, 2009) with different capacities and, therefore, varying levels of vulnerabilities in order to offset potential delivery impairments - at least to a certain degree.

The most recent contribution by Cheon and Urpelainen (2015, p. 955) focused on 27 OECD members[3] in the period from 1970 to 2007 and showed "that security considerations can be a powerful determinant of energy policy." More specifically, states invest in energy security during times when they perceive a major security threat and when the share of oil production in the Middle East is high. Cheon and Urpelainen (2015) rely on a Nash bargaining game, where a state's energy policy is endogenously determined by balancing economic and (so far "undertheorized") security benefits of reduced import dependency with the resulting costs of this policy. Oil importing countries thereby behave strategically and adjust their policies to changing conditions (e.g. the probability of inter-state disputes) over time. We elaborate on this argument in the following section.

2.2. Theoretical model and hypotheses

Energy security is "a matter of degree"(Nye, 1981, p.6), and a government's willingness to foster it (as opposed to investments in other sectors) will largely depend on the constellations between domestic actors and international threats. Importantly, "energy policy is the core of energy security [as] modern military is itself highly dependent on oil" (Cheon and Urpelainen, 2015, p. 957). Thus, military buildup (Delucchi and Murphy, 2008) alone might not be sufficient.

In order to gain insights into possible effects of domestic factors on energy security, we assume that energy policies reflect interests of important groups that are related to the energy sector and essential for government's re-elections (de Mesquita and Smith, 2009). Out of self-interest, the incumbent government reacts to "political threats from any source so as to diminish the risk that they will lose the office"(de Mesquita and Smith, 2009, p. 171). We argue that it is important to "recognize the difference in response of a country and a firm to energy security" (Kim, 2014, p. 402) because objectives and means differ substantially while affecting legislative action (Markus, 2014). Following Hughes and Urpelainen (2015), we model energy policies as a common agency problem, where a government is viewed as an agent to special interest groups (Grossman and Helpman, 1994). In other words, policies *endogenously* result from the struggle between "consumer" and "producer" interests over who will bear the costs of certain legislation (Ikenberry, 1988, p.176). For example, research on environmental regulation shows that policies that economically benefit powerful interest groups are more likely to be enacted (Bernauer and

[3]The focus on oil importing countries, which we also maintain throughout our analysis, relies on the assumption that oil exporters face a different choice as they (probably) are able to secure sufficient oil by raising exploitation quotas. We acknowledge that this is a simplifying assumption as deposits are commodity specific, unevenly distributed, finite and overall quotas might be determined through geopolitical agreements. However, it allows us to keep the analysis legible and to focus on the specific determinants of energy politics in importing countries.

Caduff, 2004). In addition, and in more general terms, any legislative change becomes more likely when "advocates of the existing policy are in some ways weakened and so they are unable to stop it" (Laird and Stefes, 2009, p. 2627).

Of course, bargaining of interest groups alone cannot explain certain changes in a state's energy policy. By studying US oil policy after the oil embargo of 1973, Ikenberry (1988) poignantly points out that governments have to take into consideration not only domestic interests, but also changes in international oil markets. Notably, Cheon and Urpelainen (2015) find that security concerns can be a powerful determinant of energy policy investments.[4], apart from economic (international oil market, world economic growth, etc.) and political constraints ("the logic of political survival", de Mesquita and Smith, 2009).

This leads us to the following model in which we assume that any government has to select an energy security policy $E \in [0, \infty]$, where higher values of E are associated with higher levels of energy security.[5] The government's objective function then comprises two parts: one being the benefits of a policy and the other the associated costs.[6] Equation 1 represents the objective function:

$$E \times [\, d + v + (c - p)] - \frac{1}{2} E^2 \times [\,(1 - d) + (1 - v)] \tag{1}$$

Where $d \in [0, 1]$ stands for the probability of an oil disruption, $v \in [0, 1]$ for the degree of oil import dependence, c for the share of consumer and p for the share of producer interests in the considered industry, while we assume that $c + p = 1$. By differentiating equation 1 with respect to E and equating marginal benefits and costs, we obtain the following optimal energy policy $E^\star$:

$$E^\star = \frac{d + v + c - p}{2 - d - v} \tag{2}$$

This simple model produces testable hypothesis regarding the role of domestic and international factors. First of all, it highlights that if consumer and producer interests are balanced, the prevailing international security situation as well the level of import dependence will be decisive in determining a government's willingness to invest in energy policy. One of the possible empirical examples for this are the US in the 1970s, when consumer and producer interests balanced and therefore foreign policy considerations provided a valuable explanation for alternating US energy policies in the late 1970s (Ikenberry, 1988).

In the long run, energy security investments are associated with lower energy prices (due to an increase in reserves, multiple alternative energy sources, more efficient consumption, etc.)

[4] This ties in nicely with the argument of Baldwin (1997) that "security is multidimensional".

[5] Please note that the formal framework corresponds to the model of Hughes and Urpelainen (2015, p. 54).

[6] As in previous studies (Cheon and Urpelainen, 2015; Hughes and Urpelainen, 2015), we model policy benefits as being linear and costs as being quadratic in order to ensure increasing marginal costs and solvability.

and decreasing market shares of dominant energy producers.[7] With respect to current special interests groups, a drop in prices and market share (and in turn, revenues) is contrary to producers' intentions while consumers would be in favor of more energy security measures. Based on this assumption and equation 2 we can conclude that if p is higher than c, meaning that the share of producer interests is higher than the share of consumer interests, $E^\star$ is decreasing. This leads us to the following first hypothesis:

Hypothesis 1: The higher the share of producer interests, the lower the level of investment in energy security.

Based on our model, we expect an increase in v as well as in d to have a positive effect on the level of energy security investments. When we focus on these variables alone (by assuming c=p and v or d equal to zero) we end up with the following equation:

$$E^\star = \frac{v}{2-v} \quad ; \quad E^\star = \frac{d}{2-d} \tag{3}$$

Equation 3 shows an exponential relationship of both v and d with $E^\star$. This implies that alternations in low levels of these variables lead to smaller changes in $E^\star$ as compared to variation in higher levels. Thus, a state's increase in oil dependence from for example 0.2 to 0.3 should lead to less pressing security concerns as compared to a rise from an already high degree of 0.7 to 0.8. This leads us to the following hypotheses:

Hypothesis 2: There is a curvilinear relationship between the level of oil import dependence and the level of investments in energy policy.

Hypothesis 3: There is a curvilinear relationship between the probability of oil disruption and the level of investments in energy policy.

2.3. Research Design

Our unit of analysis for testing the hypotheses presented in section 2.2 is country-level data per year during the observation period from 1980 to 2014. Unfortunately, this means that we lack information on states' behavior before, during and after the oil crisis of 1973. This shortcoming applies to our and previous studies (Smith and Urpelainen, 2013) for reasons of data availability. Nonetheless, our sample period covers substantial variation of energy market developments. For example, according to Bielecki (2002, p. 238), the international oil market evolved throughout three distinct periods: low and stable prices from 1960 to 1973, turbulent fluctuations between

[7] A similar line of argument on shifting investment patterns and their potential effects can be found in the discussion of a fossil fuel divestment movement (Ayling and Gunningham, 2015).

1973 and 1986, and ever declining prices from 1986 to 2000. After 2000, oil price levels remained relatively high until it collapsed (again) in 2014.[8]

While the following sections discuss our choices for operationalization in more detail, the (AppendixA) provides a description of all variables and list the relevant data sources.

2.3.1. Dependent variable - Energy security investments

There is a broad agreement in the scientific community that energy security is "contextual and dynamic in nature" (Ang et al., 2015, p. 1077). Still, in line with the general concept of 'security' (Baldwin, 1997; Wolfers, 1952), it is difficult to find an operational concept for energy security (Winzer, 2012). This has led multiple studies to debate on how to conceptualize energy security (Cherp and Jewell, 2014; Chester, 2010) as well as what types of indicators might be most appropriate (Ang et al., 2015; Kruyt et al., 2009; Löschel et al., 2010).

This literature can be broadly divided into two categories. While some studies look into the different dimensions of energy security (Chester, 2010; Kruyt et al., 2009; Sovacool and Mukherjee, 2011),[9] others strive for a more holistic approach. Winzer (2012, p. 41) point out that "the common concept behind all energy security definitions is the absence of, protection from or adaptability to threats that are caused by or have an impact on the energy supply chain". This view is further elaborate by Jewell et al. (2014, p. 744-746), who propose an overreaching definition of energy security as "low vulnerability of vital energy systems" [10] Other accounts come from a more economic perspective (Bohi and Toman, 2012), where "energy security exists if the energy sector does not cause (major) welfare-reducing frictions in the economy at national and global levels" (Löschel et al., 2010, p. 1665).

Given that overall security implies "the ability of a nation to deter an attack or to defeat it" (Wolfers, 1952, p. 484) and that deterrence is difficult to observe, energy security is often viewed as a latent variable. Scholars that propose operational measures thus concentrate on observable manifestations: resilience as well as risk factors (Cherp and Jewell, 2014). Figure 1 graphically presents the link between unobservable and measurable elements of energy security and offers corresponding examples.[11]

[8]With respect to other primary sources of energy, Villar and Joutz (2006) show that the correlation between oil and gas prices has historically been quite high.

[9]Such as availability, affordability, accessibility and acceptability (Kruyt et al., 2009) or availability, adequacy, affordability and sustainability (Chester, 2010).

[10]Cherp and Jewell (2014, p. 418) define vital energy system as "those energy systems (energy resources, technologies and uses linked together by energy flows) that support critical social functions" and list oil supplies to armies as a possible example of a vital system. While emphasizing the social importance of energy, the authors point out the need to differentiate security risks according to whom, which value and from what threat is at risk.

[11]Figure 1 is based on the framework developed by Cherp and Jewell (2014).

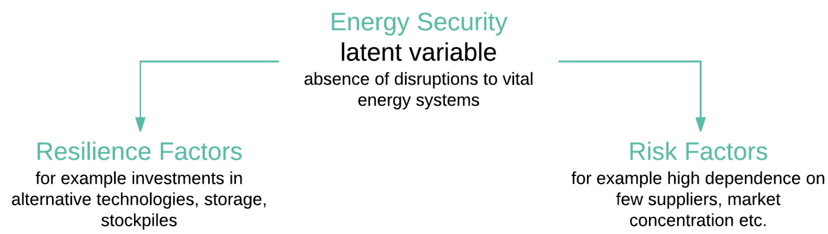


Figure 1: Conceptualizing Energy Security

This framework facilitates the identification of potential variables that could be used in order to test our hypotheses. We assume that "risk factors" motivate certain policy changes (independent variables), while "resilience factors" present possible policy instruments (our dependent variable) that countries might utilize in order to minimize risks in the context of energy policies. The following paragraphs therefore focus on "resilience factors", while we elaborate on "risk factors" in section 2.3.2.

When looking at "resilience factors", scholars concentrate on diversification of supplies (Yergin, 2006), as well as technological diversification (Stirling, 1994) among other things. Both of these measures are closely associated with investments in alternative technologies (Bielecki, 2002). [12] Building upon this "interconnectedness" (Kim, 2014, p. 401) and following Cheon and Urpelainen (2015), we operationalize energy security investments as RD&D expenditures in alternative sources of energy.[13]

In addition, while energy security is a broad concept that encompasses various sectors, technologies, fuels, etc., we concentrate on one of the major "vital energy systems" (Jewell et al., 2014): a state's security of oil supply (Deese, 1979). This follows the idea of treating oil as a benchmark for the world energy economy (Banks, 2015, p. 448). Overall, fossil fuels, and in particular oil, dominate the world energy market as the main source of energy production and consumption (IEA, 2015; OECD and IEA, 2012). Therefore, it is not surprising that many scholars have focused on systematically measuring different levels of oil security (Greene, 2010; Vivoda, 2009).

As we concentrate on the security of oil supply, additional explanations on the meaning of the term "alternative sources" are necessary. While most of the OECD countries were successful in

[12] Further evidence for this relationship can also be found in Davis and Owens (2003, p. 1589-1592) who characterize the "objectives of the United States' federal non-hydro renewable electric R&D program [as] to serve as an insurance policy that ensures domestic energy security" and in Schock et al. (1999) who specifically estimate the value of energy R&D as an insurance investment against, among other risks, energy disruptions.

[13] While, of course, other operationalizations such as stockpiles or subsidies for emerging alternative technologies are also possible, we choose RD&D expenditures because they present an easily accessible and widely researched measurement.

phasing out oil from electricity generation (Bielecki, 2002), there "are currently no viable large-scale substitutes for oil, particularly in the transportation sector" (Yetiv, 2011, p. 161). For this reason we deliberately exclude electricity related alternative sources of energy (renewable sources such as wind, hydro or solar power) from the sample considered in our analysis.[14] The sectors included in our public RD&D expenditures comprise of technology related to transport sector, biofuels, electric vehicle infrastructure, non-conventional oil and gas, etc. (AppendixA lists all included sectors) for which we obtain data from the International Energy Agency (IEA) database according to their classifications. In short, we assume that by supporting innovation across these technologies, governments improve their security of oil supply.

2.3.2. Independent variables

Our primary independent variables for explaining a country's oil security policy are the following "risk factors" (see 1): aggregated social interest of oil producers, an economy's oil import dependence and the probability of an oil supply disruption.[15] The following paragraphs give a short description of the respective data sources, while a more detailed discussion can be found in the AppendixA.

The influence of energy producer interests. Most studies measure interest group influence through proxy variables.[16] For example, Fredriksson et al. (2004) look at the industry sector's contribution to total value added. Hughes and Urpelainen (2015) use the share of energy intensive industry in total gross output. We rely on a measure similar to Hughes and Urpelainen (2015) and collect data from the OECD structural analysis database on production gross output of the mining and quarrying of the energy sector. We use this measure as proxy for the importance of energy producers within an economy and to test Hypothesis 1.

Oil import dependence. The vulnerability of an economy to oil market disruptions is often measured by the Herfindahl-Hirschmann concentration index (HHI),[17] which takes the sum of squared oil dependency levels (Löschel et al., 2010). In addition, scholars have also engaged in simulating economic costs in case of supply constraints (Greene, 2010) or composite indexes of oil vulnerability (Gupta, 2008). We follow the common approach related to HHI, but use a slightly different strategy. Because we are interested in the political developments in major oil importing countries, we first generate a dyadic data set on oil imports between the OECD members and the fourteen major exporting countries.[18] We then rank the dyads per OECD member and year to

[14]Interestingly, Kim (2014, p. 401) pointed out that "almost all of the previous literature on energy and technology innovation focuses on the electricity sector".

[15]In general, one of the most widely used operationalizations of 'risk factors' is oil market concentration (Löschel et al., 2010).

[16]For a more elaborate discussion of this topic see Dür (2008).

[17]For a more detailed overview of individual indicators see Gupta (2008).

[18]This includes the following countries: Saudi Arabia, Russia, Iraq, UAE, Canada, Nigeria, Kuwait, Angola, Venezuela, Kazakhstan, Norway, Mexico, Oman, UK (data for Iran is not available).

identify the annual main supplier for any oil importing country. Only this entry is utilized in our regression analysis. Finally, we divide the share of the major oil exporter by the total oil demand and square it afterwards. All data for imports as well as oil demand is measured in *kt* and based on OECD data sources. We rely on this specification to capture an economy's oil vulnerability for testing Hypothesis 2. In order to account for the possibly curvilinear relationship between oil import dependence and investments in oil security, we also include a squared value of oil import dependence in our models.

Probability of oil disruption. We argue that the probability of supply disruption is related to certain domestic, regional or international instabilities affecting oil exporting countries. This follows the idea of Gupta (2008) who used data from the International Country Risk Guide to account for political instabilities of exporting countries.[19] For the operationalization of the exporting country's security environment, we rely on two indexes[20]: these are the squared values of the POLITY2 score of the Polity IV project (Marshall et al., 2016),[21] and the information on international war (conflict existence and intensity) from the data set on Major Episodes of Political Violence (Marshall, 2016).[22] By using both indexes we obtain a comprehensive overview on possible disruptions for each OECD member per year. While there have been studies that have looked at patterns of similar measures over time and across different countries Gupta (2008); **?**, to our knowledge this is the first study to include this type of measurement in a cross country time series analysis. In order to account for the possibly curvilinear relationship between suppliers' political stability and investments in oil security, we also include a squared value of both indexes in our models.

2.3.3. Model specification

Our data is structured as an unbalanced panel, with, depending on the exact model specification, containing between 20 to 27 countries and 1 to 34 years. Based on a Dickey-Fuller test on our dependent variable of public RD&D expenditures in transport related technology, we reject the null-hypothesis that our time-series is non-stationary. We therefore do not take

[19]While including this data in our analysis would be desirable, the data set is commercial and we therefore rely on publicly available sources.

[20]Both data sets are accessible through: www.systemicpeace.org/warlist.htm. If not stated otherwise, we use the versions from May, 2016.

[21]The POLITY2 score measures democracy levels based on a 21 point scale from -10 to 10. A score of -10 accounts for an authoritarian regime while 10 indicates a full democracy. As we are interested in political (in)stability, we therefore square the score to reflect the inconsistency of political institutions (as proposed by Hegre and Sambanis, 2006). Now, high levels indicate a stable regime (either authoritarian or democratic) while low scores point towards a phase of political transition.

[22]The database offers information on seven different types of conflicts (international violence, international war, international independence war, civil violence, civil war, ethnic violence and ethnic war) and their magnitude of societal impact, which ranges from 1 to 10. If a country experiences no political violence then the year is coded as 0, if a country experiences more than 1 episode of political violence per year, the intensities of impact are summed per year.

the first difference of our dependent variable as it is often done in similar studies (Cheon and Urpelainen, 2012, 2015).

The sample does not apply to standard OLS regression given the data structure and heterogenteity across countries and years (see graphs in **??**). Based on further diagnostics for deciding between fixed or random effects (Hausman test) and on the inclusion of time effects (Lagrange Multiplier Test), we specify a fixed effects ARIMA(1,0,0) model with time fixed effects.[23] In addition, we control for heteroskedasticity by including Huber robust standard errors (ϵ_{it}) clustered by country. Our model specification is summarized in equation 4:

$$E_{i,(t+1)} = \alpha_i + \beta_1 p_{it} + \beta_2 v_{it} + \beta_3 {v^2}_{it} + \beta_4 d_{it} + \beta_5 {d^2}_{it} + \beta_6 t + \epsilon_{it} \quad (4)$$

where $E_{i,(t+1)}$ stands for the energy security investment of country i at time $t{+}1$, p_{it} stands for the influence of energy producers within country i at time t, v_{it} stands for oil import dependence of a country i at time t and d_{it} stands for the level of possible supply disruption based on the political (in)stability of the main oil exporting partner of a country i at time t. In addition, α_i controls for unobservable country fixed effects (for example, a culture of innovation within a state) and $\beta_6 t$ captures shocks that are common to all countries (for example, a sudden increases of oil prices).

With this specification it is important to address the issue of endogeneity that might relate investments in alternative energy sources and the level of import dependence. Overall, it is plausible to assume that if a country invests (more) in alternative energy technology, its (future) level of import dependence might decrease (all else being equal). However, given the time lag between investments in RD&D and the resulting gain in knowledge or the commercialization of new technology (Prodan, 2005), endogeneity is not a major concern in our study. For example, Bointner (2014, p. 734) summarizes that most studies have identified lags up to five years when assessing RD&D investment and respective outcomes.

3. Results

In this section we discuss our findings in two steps. First, section 3.1 gives an overview of the descriptive findings of the collected information. Second, section 3.2 looks at our estimation models.

3.1. Descriptive Statistics

Figure 2 highlights that across our sample period RD&D expenditures on transport related technology exhibited a clear downward trend: from the early 1980s on, the average share of RD&D per GDP across all OECD members shrunk from around 0.02 percent of GDP to around

[23] All models were estimated with the plm package developed for the R cran environment. The fixed effects are computed from the lm framework to transformed data(Croissant et al., 2015).

0.01 in the late 1990s.[24] Costa-Campi et al. (2014) suggest that the lower investments might be due to the overall liberalization and deregulation in the energy sector (especially when considering private RD&D investments), while Smith and Urpelainen (2013) argue that this trend is associated with the decreasing importance of energy intensive industry within OECD members.

Explanatory note: Points indicate the mean values averaged over countries, and vertical lines the 95 percent confidence intervals for the means.

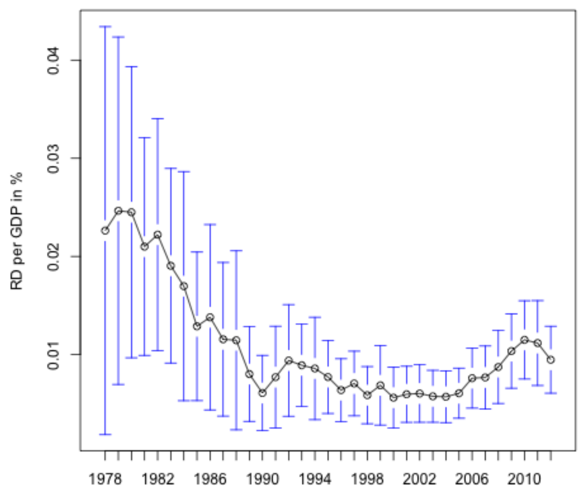


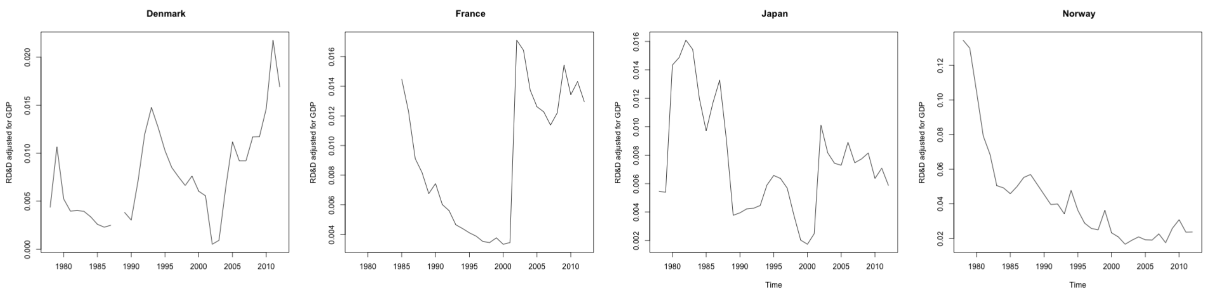
Figure 2: RD&D expenditures related to oil security over time in OECD countries

In addition, Figure 2 suggests that the variation across OECD countries has decreased substantially over time, resulting in a more uniform RD&D spending pattern. However, taking a look at the RD&D expenditures at the country level reveals interesting variation across and within states. Figure 3 depicts the development for Denmark, France, Japan and Norway, while analog graphs for every country of our sample can be found in AppendixB. First of all, it is obvious that the downward trend of investments is not pronounced across all countries. While on the one hand, Denmark and France have increased their RD&D expenditures since 2000, on the other hand, Japan and Norway are far off from reaching their RD&D levels from early 1980s. This insight might be most surprising in the case of Norway which is considered one of the global leaders with respect to the renewable energy sector (Johnstone et al., 2009). Still, the country has substantially decreased its RD&D investments from around 0.13 percent of GDP in early 1980s to around 0.02 percent by 2010. [25] Overall, while deregulation of energy markets

[24]This findings also holds for RD&D investments in the energy sector in general (Smith and Urpelainen, 2013) and, in particular, for the United States (Nemet and Kammen, 2007).

[25]Please note that our selection of technologies excludes renewable energy for electricity generation.

(Costa-Campi et al., 2014) as well as the decreasing importance of energy intensive industry (Smith and Urpelainen, 2013) might explain some of the variation across countries, we argue that variables presented in our theoretical model might shed more light on the predictors of RD&D expenditures.

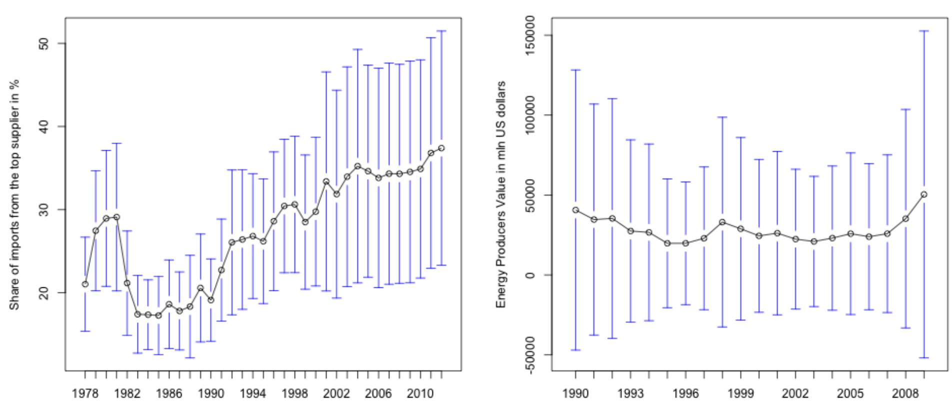


(a) Denmark (b) France (c) Japan (d) Norway

Figure 3: RD&D expenditures on transport related technology for selected countries over time

Interestingly, at the same time as RD&D expenditures on oil security related technology decreased, many OECD members have become more dependent on a single supplier of oil. Figure 4(a) shows that the average import dependence on a single supplier rose up to around 35 percent across OECD member states since 2000.

Explanatory note: Points indicate the mean values averaged over countries, and vertical lines the 95 percent confidence intervals for the means.



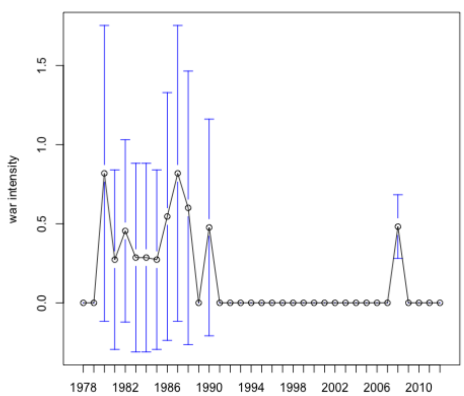
(a) Major Supplier Share (b) Importance of domestic Energy Producers

Figure 4: Concentration tendencies within the oil industry

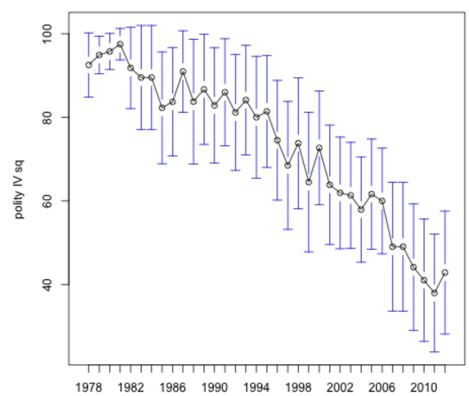
Contrary to this intra-state development towards fewer but larger suppliers, we observe great variation within national industry relations. Figure 4(b) depicts the average importance of domestic oil producers across OECD member states. We use this data in section 3.2 to investigate if a larger share of energy producers within an economy might hamper investments in alternative energy sources and therefore be associated with the downward investment trends in certain countries (Hypothesis 1).

Our second theoretical argument relates to the probability of oil disruption, which we proxy by looking at two distinct indexes: the international war intensity as well as squared POLITY2 score of the major oil supplier per OECD country (for more details see section 2.3.2). Figure 5 depicts the development of both indexes over time. While the main oil suppliers of OECD members have not been involved in major military conflicts since the 1990s as shown in figure 5(a), there has been a substantial variation with respect to the stability of political system. According to figure 5(a), also a clear trend towards more instability can be seen.

Explanatory note: Points indicate annual average values across countries, and vertical lines the 95 percent confidence intervals across countries.



(a) International war intensity



(b) Polity IV squared

Figure 5: Probability of oil disruption

In the next section we further analyze the relationship between oil vulnerability, the importance of national oil producers as well as the internal and external stability of the major oil exporters.

3.2. Model estimates

Our estimation results are reported in tables 1 and 2. Both tables depict, according to our model specifications, the influence of within country variation of the variables of interest (influence of energy producer interests, oil import dependence and probability of oil supply disruption; see section 2.3.2) on within country variation in RD&D expenditures as defined in 2.3.1 . Please note that the two inquiries are based on different samples for reasons of data availability. As table **??** accounts for all explanatory factors discussed in section 2, the small number of observations ($N = 348$) is primarily due to missing information on producers' output. Therefore, table 1 shows the estimations in case a country's energy producers' output is not considered. This raises the number of observations significantly ($N = 607$). As the evidence for the confirmation of our hypotheses is mixed, we discuss the results in more detail below.

	Dependent variable:		
	RD per GDP		
	(1)	(2)	(3)
RD per GDP	0.824***	0.830***	0.832***
	(0.041)	(0.042)	(0.025)
Producers Output per GDP	−0.00001	−0.00001	−0.00001
	(0.00002)	(0.00002)	(0.00002)
Import		−0.0001	−0.0001
		(0.0001)	(0.0001)
Import sq		0.0001	0.0001*
		(0.0001)	(0.0001)
International War		−0.0001	
		(0.00004)	
International War sq		0.00001*	
		(0.00001)	
Interaction		−0.00000*	−0.00000*
		(0.00000)	(0.00000)
Polity IV			−0.00000
			(0.00000)
Polity IV sq			−0.000
			(0.00000)
Fixed effects	yes	yes	yes
Time-fixed effects	yes	yes	yes
Years	1-30	1-34	1-30
Countries	20	20	20
Observations	348	348	348
Note:			*p<0.1; **p<0.05; ***p<0.01 Robust standard errors clustered by country

Table 1: Sample with data on energy producers' output

First of all, Hypothesis 1 on energy industry influence can only be assessed through table

2. Please note that, given the selection bias of available information on a country's industry structure, these results should be interpreted with caution. While the effect of producers output per GDP is, as expected, negative, it is not statistically significant across all model specifications. It is noteworthy that the interaction variable between the share of energy producers and international war exhibits a negative sign and is statistically significant (table 1, model 3). As the effect of international war is positive and statistically significant, this suggests that for countries with domestic energy producers, an involvement of their major oil supplier in an international conflict might lead to lower expenditures in favor of alternative energy sources.

	Dependent variable:	
	RD per GDP	
	(1)	(2)
RD per GDP	0.796***	0.800***
	(0.030)	(0.030)
Import	−0.0001	−0.0001
	(0.0001)	(0.0001)
Import sq	0.0001*	0.0001**
	(0.0001)	(0.0001)
Polity IV		−0.00000
		(0.00000)
Polity IV sq		0.000
		(0.00000)
International War		−0.00003
		(0.00002)
International War sq		0.00001
		(0.00000)
Fixed effects	yes	yes
Time-fixed effects	yes	yes
Years	1-34	1-34
Countries	27	27
Observations	607	607
Note:		*p<0.1; **p<0.05; ***p<0.01
		Robust standard errors clustered by country

Table 2: Sample without data on energy producers' output

We find the strongest evidence across both samples for Hypothesis 2 on curvilinear relationship between the level of oil import dependence on a single major supplier and the level of investments in energy policy. Here, we observe a statistically significant and positive relationship for squared oil dependence (with the exception of model 2 in table 1). While this finding does not sound surprising, our study presents one of the rare cases of systematic evidence for the association between a country's dependence on one major oil supplier and investments in energy security. Additionally, we show that the effect of oil dependence is not linear, but increases with rising levels of dependency.

With respect to the political stability in oil supplying countries, we proposed two measures for the operationalisation of Hypothesis 3. For "internal" stability we look at the squared POLITY2 score and for "external" stability we consider the violence intensity of international wars. While the estimates display the expected signs across different specifications, the results are only statistically significant in our smaller sample (table 1) and just for the intensity of international wars in which the supplier country is involved (model 2). While this does not constitute a robust finding, it at least hints that OECD members might perceive external conflicts as a more substantial danger to oil supply security as compared to internal political transitions.

4. Conclusions

Our study is largely motivated by the most recent work on energy security and alternative energy investments (Cheon and Urpelainen, 2015; Hughes and Urpelainen, 2015; Smith and Urpelainen, 2013). While studies on each topic alone are common, efforts to link and gain insights from these issues remain rare (Cheon and Urpelainen, 2015). We contribute to this efforts by linking research of two epistemic groups: our theoretical framework is based on approaches from political science, while our energy security operationalization is based on literature that is specialized on interdisciplinary energy research.

This study focuses on why states invest in oil supply security while investigating the role of oil import dependence on a single major supplier, internal and external instabilities of major oil suppliers as well as the possible influence of domestic energy producers. We find confirmation for the exponential association between oil dependence and RD&D expenditures, while empirical evidence linking oil suppliers political stability and RD&D expenditures is less consistent.

To our knowledge, this is the first study that has developed detailed cross country time series data on oil dependence for major suppliers and linked them to political stability. Even though a number of studies have used similar measurements, they are largely limited to a small number of countries (Löschel et al., 2010) or to a specific year (Gupta, 2008).

Still, the precise measurements of oil security risks come at a cost. One of the major weaknesses of our study is that our results might be biased given the high amount of missing information. This is particularly problematic when looking at the influence of domestic producers. Therefore, to improve upon our analysis, one could apply multiple imputation technique to decrease the amount of missing information. Additionally, as we discussed in section 2.3.1, investing in alternative energy is just one type of energy policy. Different countries might react differently, and economies might react to energy security concerns by increasing their stockpiles or providing subsidies for alternative energy sources. We will therefore also test whether our results hold under additional operationalizations of energy security policies.

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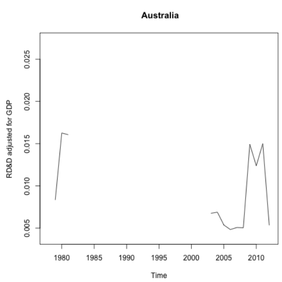
AppendixA. Overview of variables

Variable	Description	Data source[26]
RD&D budgets in Total RD&D in Million USD (2014 prices and PPP)	transport (13) includes on-road vehicles (131), vehicle batteries and storage technologies (1311), advanced power electronics, motors, EV/HEV/FCV systems (1312), advanced combustion engines (1313), electric vehicle infrastructure (1314), fuel for on road vehicles (1315), materials for on-road vehicles (1316), other on-road transport (1317), unallocated on-road vehicles (1319),off-road transport and transport system (132), other transport (133); oil and gas (21) includes enhanced oil and gas production (211), refining, transport, storage of oil and gas production (212), non-conventional oil and gas production (213), oil and gas combustion (214), oil and gas conversion (215), other oil and gas (216); biofuels (34) include production of liquid biofuels (341), gasoline substitutes (3411), diesel, kerosene and fuel substitutes (3412), algal biofuels (3413), other liquid fuel substitutes (3414), unallocated production of liquid biofuels (3419), production of solid biofuels (342), production of biogases (343), other biofuels (345), unallocated biofuels (349), thermochemical (3431), biochemical (3432), other biogases (3433), unallocated production of biogases (3439), application for heat and electricity (344).	IEA (2016), RD&D Budget, IEA Energy Technology RD&D Statisics (Database)

[26]If not stated otherwise, the data source was accessed in May 2016.

GDP in Mln USD	Gross domestic product (GDP) at market prices is the expenditure on final goods and services minus imports: final consumption expenditures, gross capital formation, and exports less imports. "Gross" signifies that no deduction has been made for the depreciation of machinery, buildings and other capital products used in production. "Domestic" means that it is production by the resident institutional units of the country. The products refer to final goods and services, that is, those that are purchased, imputed or otherwise, as: final consumption of households, non-profit institutions serving households and government; fixed assets; and exports (minus imports). Data are internationally comparable by following the System of National Accounts. This indicator is measured in USD per capita (GDP per capita) and in million USD at current prices and PPPs.	OECD (2016), Gross domestic product (GDP) (indicator). (Accessed on 02 June 2016)
Total Oil Demand in kt	Demand is total inland deliveries plus refinery fuels and bunkers minus backflows from the petro-chemicals sector. It is thus equivalent to oil consumption plus any secondary and tertiary stock increases.	IEA(2016),"World oil statistics", IEA Oil Information Statistics(database).
The role of oil producers (production gross output in mln USD)	Mining and quarrying of energy producing materials(C10T12)	OECD STAN database. ISIC Rev. 3.
Polity IV	We use Revised Combined Polity Score. The polity score is computed by subtracting the authocracy score from the democracy score; the resulting score ranges from +10 (strongly democratic) to -10 (strongly autocratic)	Marshall et al. (2016)
International War Intensity	Magnitude score of episode(s) of international warfare involving that state in that year Scale: 1 (lowest) to 10 (highest) for each major episode of violence	Marshall (2016)

AppendixB. Additional graphs and tables



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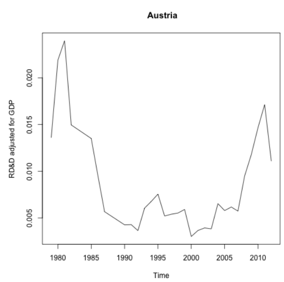

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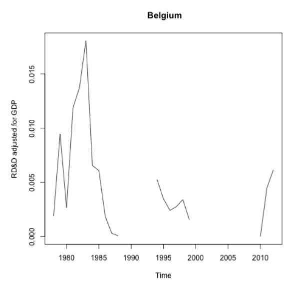

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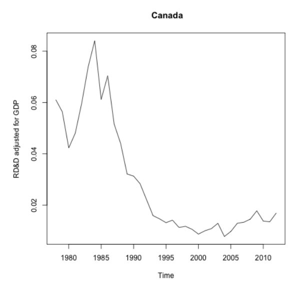

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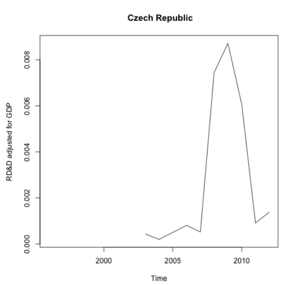

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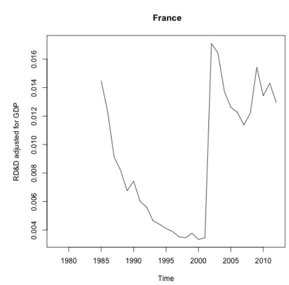

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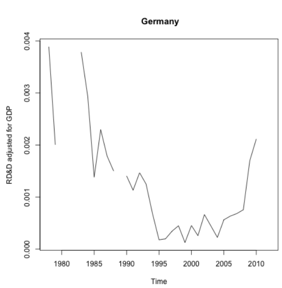

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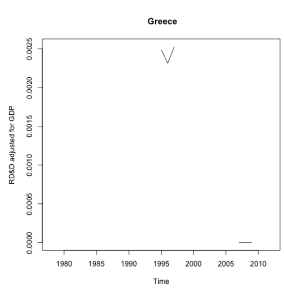

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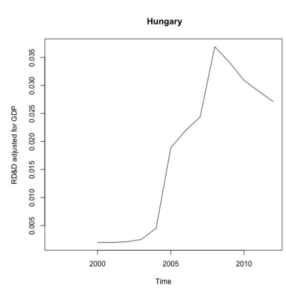

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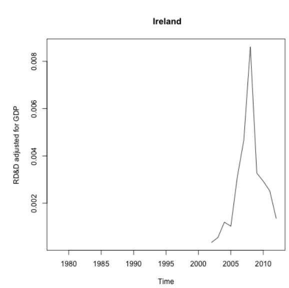

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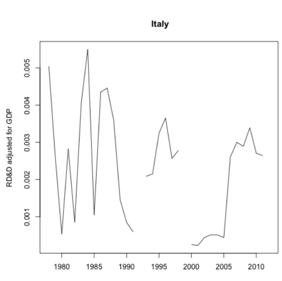

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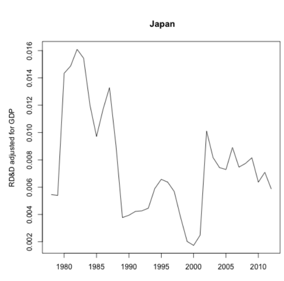

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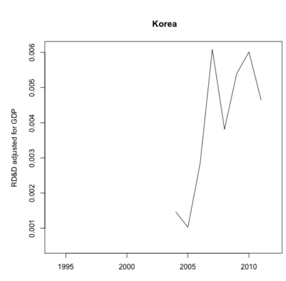

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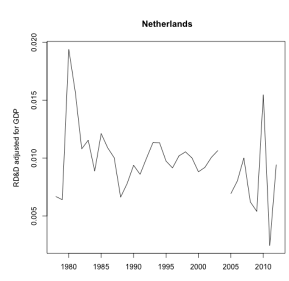

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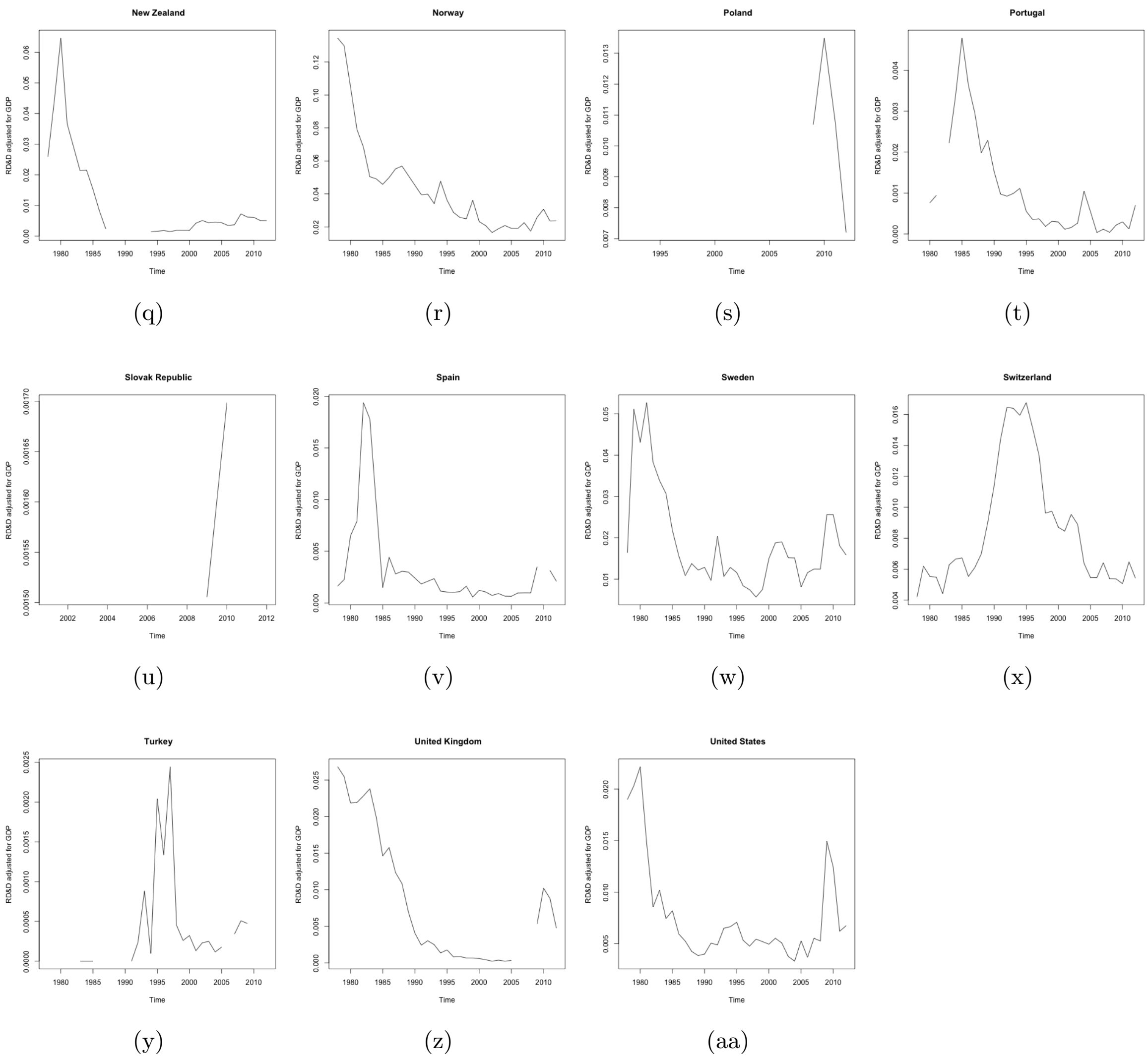

Figure B.6: Annual RD&D expenditures in the energy sector by country