Technovation 33 (2013) 333–344

Contents lists available at ScienceDirect

Technovation

journal homepage: www.elsevier.com/locate/technovation

Political market failure? The effect of government unity on energy technology policy in industrialized democracies ☆

Alexandra E. Cirone, Johannes Urpelainen *

Political Science at Columbia University, 420 West 118th Street, 712 International Affairs Building, New York, NY 10027, USA

ARTICLE INFO

Available online 26 July 2013

Keywords:
Technology
Energy policy
Political economy
Government
Energy intensity
Public policy

ABSTRACT

When do governments implement technology policies that allow society to solve social problems at a lower cost? Focusing on the case of energy, we argue that in industrialized democracies, severe social problems provoke an effective technology policy response when the government is unified. A unified government can easily strike the bargains required to secure political support for new technology programs. We test this theory against data on public energy research and development (R&D) in 22 OECD countries, 1980–2006. We find that as government fractionalization increases in a country, the sensitivity of public energy R&D to wasteful energy use, which presents economic and environmental difficulties to the society, declines. The analysis reveals a new reason for ineffective technology policies and contributes to the broad literature on political market failure.

1. Introduction

Technological innovation can help societies solve market failures (Cohen and Noll, 1991; Cheon and Urpelainen, 2012). For example, new production techniques can reduce the pollution intensity of manufacturing. However, technological innovation itself is often underprovided in markets because firms fail to internalize the full societal benefits of new technology (Fischer and Newell, 2008). Why do some governments invest heavily in new technologies to solve social problems, while others remain inactive? While many scholars have lamented ineffective technology policies in different countries (Barrett, 2009; Nemet and Kammen, 2007), there exists a dearth of rigorous theory and systematic evidence on the sources of technology policy failure. Given the importance of technology as an engine of societal change, it is troubling that political economists have yet to develop and systematically test theories of technology policy.

The empirical focus of this paper is on energy technology. Building on earlier research on the determinants of public policy formation, we argue that *government unity* exerts significant influence on the efficacy of the technology policy response to social problems in industrialized democracies. By government unity, we refer to homogeneity of interests within the ruling coalition. In practice, we measure government unity as partisan unity. Technology policies require public investments that carry opportunity costs. Even in trying times, fragmented governments are unable to strike the political bargains that would secure political support for new technology policies. By contrast, unified governments are able to garner support for technology policies through political deals that procure net benefits to important political constituencies. Thus, we expect government unity to condition the technology policy response to social problems.

We test this argument against data on energy technology policy. Modern societies use immense amounts of energy, mostly in the form of fossil fuels. While energy use is an essential element of economic activity, the production and consumption of energy carry negative environmental externalities, such as water and air pollution. Therefore, although the significance of wasteful energy use as a social problem varies across countries and over time, wasteful energy use often causes economic and environmental difficulties that technology policy could address. Volatile energy prices may weaken economic performance, and excessive reliance on foreign fuels compromises the energy security of the nation (Müller-Kraenner, 2010). Yet many industrialized countries have achieved limited success in addressing their reliance on fossil fuels. The International Energy Agency (IEA) stated in October 2010 that "[e]ven the countries that are most proactive on energy efficiency have implemented less than 60 percent of the IEA energy efficiency recommendations … barriers remain for governments to put effective policies in place" (United Press International, 2010). Thus, energy policy seems to be characterized by *political market failure*: despite the availability of mutually profitable policy

☆This research was presented at the 2011 annual convention of the Midwest Political Science Association. We thank Paula Castro, Leigh Raymond, and the audience for constructive comments on a previous version. We also thank the editors of *Technovation* and the anonymous reviewers for their comments. A supplementary appendix and a replication package are available on-line.

* Corresponding author. Tel.: +1 734 757 0161.
E-mail address: ju2178@columbia.edu (J. Urpelainen).

0166-4972/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.technovation.2013.06.001

adjustments, policymakers fail to agree on a common course of action (Spiller and Tommasi, 2003). Moreover, new energy technology is arguably key to addressing wasteful energy use (Geller et al., 2006; Jaffe and Stavins, 1994). To evaluate the empirical validity of our general theory, we thus test it against data on public energy R&D in IEA member states, 1980–2006. We find evidence in support of our theoretical argument: states increase energy R&D expenditures in response to abnormally high energy intensity, but the strength of this response depends on the unity of the government. The effects are substantively large and robust to various specifications.

The primary contributions of this paper are empirical. First, we shed new light on why some countries are better equipped to address their political and economic vulnerabilities through technology policy. Although previous research has developed theories of political market failure (Spiller and Tommasi, 2003; Weingast and Marshall, 1988), we are not aware of systematic applications to technology policy. Second, we provide new empirical evidence for the importance of government unity as a precondition for public policy as a response to social problems. Previous empirical analyses have focused on a narrow range of economic issues, such as budget deficits (Poterba, 1994; Roubini and Sachs, 1989), and this narrow focus raises questions regarding the generalizability of these findings. We expand the scope of the general theory by applying it to technology policy, and our empirical findings indeed lend support to the general thesis.

2. Political market failure and technology policy

Public policies can address economic market failures, or situations wherein firms and consumers fail to internalize the societal costs and benefits of their actions. However, economic market failure does not guarantee an effective policy response. Political market failure ensues when a government fails to implement public policies that produce public goods or reduce negative externalities (Acemoglu, 2003; Olson, 1982). Much of the extant literature subscribes to the *transaction cost theory* of political market failure (McCubbins and Schwartz, 1984; Weingast and Marshall, 1988). According to these theories, the political market for public policies is imperfect due to information asymmetries, commitment problems, and other strategic issues that prevent public policymakers from implementing good public policies. The ability of a government to address these imperfections of the political market will to a large extent determine the public policies that it enacts. On the one hand, this ability will influence the choice of public policies: governments tend to choose public policies that carry low transaction costs. On the other hand, it will also influence the government's ability to enact these public policies in the first place: due to transaction costs, a disorganized government will fail to implement public policies that would be profitable in ideal political circumstances.

In the extant literature, transaction cost theories attempt to explain political market failure. These theories focus on uncovering the sources of variation in the cost of policy formation. Spiller and Tommasi (2003) emphasize the importance of intertemporal exchanges in competent policy formulation, and thus the relevance of political institutions that enable credible commitment. In their view, effective public policies cannot be formed unless the government can credibly promise to procure benefits to the potential supporting coalition of the policy in the future. Thus, time inconsistency prevents governments from garnering political support for public policies that would allow the realization of joint gains. Similarly, Acemoglu (2003) emphasizes the importance of credible commitment as a determinant of economic growth.

Other explanations for political market failure focus on special interests. These theories state that if influential interest groups oppose policy reforms to address market failures, the implementation of such policy reforms is difficult. According to Olson (1982), the problem is the worst if special interests are organized as narrow groups who have little interest in improving national welfare. Similarly, Bailey et al. (1997) emphasize the perverse incentives of individual legislators to cater to protectionist special interests in trade policy. Conversely, Binder and Neumayer (2005) show that in environmental politics the strength of the environmentalist coalition is also an important determinant of air pollution regulations.

We focus on the government's capacity to act. In previous research, this theoretical perspective has been applied to budget deficits and fiscal policy. For example, Roubini and Sachs (1989, p. 903) have argued that fragmented national governments often fail to address budget deficits. Adopting the transaction costs approach, they argue that the failure to reduce budget deficits can be attributed to “the difficulties of political management in coalition governments … [t]here is a clear tendency for larger deficits in countries characterized by a short average tenure of government and by the presence of many political parties in a ruling coalition.” From a similar perspective, Poterba (1994) also reports similar results for state governments in the United States. Moreover, Alesina and Drazen (1991) argue that “wars of attrition” among political constituencies may delay adjustments to economic crises in a society, as fragmented interest groups compete over the distribution of gains and thus fail to address the crisis at hand.

In the field of comparative politics, “veto player” theories are often applied to explain governmental policy (Henisz, 2000; Tsebelis, 2002). According to these theories, the number of political actors with the ability to block a decision determines the probability of policy change. As the number of veto players increases, the probability of policy change decreases. While increasing the number of veto players enhances policy stability and the credibility of policy commitments, it also reduces the government's ability to act.

While a literature on political market failure exists, we are not aware of applications to technology policy. In a partial exception, Cohen and Noll (1991) show that technology programs in the United States often devolve into pork barrel politics. However, they do not explain variation in the quality of technology programs. Other studies of technology policy are descriptive (Margolis and Kammen, 1999) or focus on explaining an individual case (Heymann, 1998). A large body of economic literature exists on the effectiveness of technology policy (Gillingham et al., 2008; Popp, 2006; Stiglitz and Wallsten, 1999), but this literature does not examine the political side of the issue.

3. Theory and hypotheses

We aim to explain technology policy in industrialized democracies. We focus on industrialized countries because few developing countries invest substantial resources in technology policy, and thus there is little variation that requires explanation. We limit our attention to democracies because we are interested in a government's ability to address social problems under institutionalized political competition and constraints. While some authoritarian countries, such as China, now invest in new technology, the vast majority of technology policy is implemented in OECD countries. In principle, the argument could also be applied to developing countries. However, this would require considering issues such as weak bureaucratic capacity.

The argument can be summarized as follows. First, we argue that technology policy presents a potential solution to many social problems that the government could remedy for political gain.

Second, we assume that the measures to increase technological innovation are based on political bargaining. Most importantly, we explain why an internally divided government or legislature may fail to enact them. These assumptions imply that politically unified governments are the most capable in addressing technology gaps.

3.1. Governments and social problems

Our first assumption is that governments have political incentives to address social problems. Governments secure political survival by solving problems that constituencies cannot address under voluntary collective action. The assumption may not apply to repressive dictatorships whose political survival does not depend on social welfare, but it captures an important element of democratic political competition (Bueno de Mesquita et al., 2003). If a government fails to generate material benefits for citizens, political opponents seize the opportunity to gain office.

This assumption does not depend on the government's intrinsic preferences. Even if the government is motivated by power or material gain, political competition induces it to implement public policies that benefit influential constituencies. Similarly, the assumption is not invalidated by the influence of special interests. Policies that improve national welfare can also be used for distributive purposes so long as they increase the size of the economic pie that constituencies can share through political bargaining (Becker, 1983; Olson, 1982). As long as technology policy allows the size of the pie to grow, either by enhancing productivity or controlling negative externalities, such a policy is Pareto-efficient.

Not all governments effectively address all social problems. Public policies are generally imperfect. Even if they produce substantial societal gains, they may carry a high cost to organized special interests, such as organized industry groups. Consequently, public policymakers must be able to reduce the political cost of a public policy to an acceptable level without "watering it down" while also successfully implementing it in a complex socioeconomic environment. Unless they manage to strike a political bargain with influential interest groups and develop an effective implementation plan, the technology policies either fail to be enacted or prove ineffective.

3.2. Government unity and technology policy

Our second assumption is that government unity facilitates bargaining on technology policy. If severe social problems can be addressed through technology policy, the potential for collectively profitable policy formation exists. However, the government cannot form these policies without striking internal bargains. One way to model this process is to assume the executive (prime minister or president) designs a policy package and proposes it to the legislature. If the policy package garners sufficient support among the legislators, it is approved so that the government mounts a technology policy response to the social problem.

When can the government strike the political bargains needed to create effective public policies? We argue that if the government is unified, finding and implementing the requisite political bargains will be easier than otherwise. This is so for several reasons. First, distributional conflict within the government is limited. A unified government is composed of a small number of parties, and each party has a preference for implementing technology policies that benefit their constituencies. Thus, a unified government can easily agree on the broad contours of a technology policy. A unified government also has no need to suffer from excessive bargaining delay, as legislators with similar preferences can relatively easily agree on burden sharing. In contrast, a fragmented government will remain internally divided over the distribution of costs and benefits even if a large majority of legislators agrees that technology policies would be useful, at least in principle.

Second, the government need not bribe a large number of policymakers with very different preferences. If the government is unified, it need not transfer expensive side payments to a high number of policymakers whose consent is important for the implementation of an effective technology policy. Stated differently, the number of veto players in the legislature is lower in a unified than in a fragmented government. Legislative logrolling is common in politics, but it is also costly according to conventional transaction cost arguments (Spiller and Tommasi, 2003; Weingast and Marshall, 1988). Consequently, unified governments should generally pay a lower transaction cost for the formation of a technology policy.

For these two reasons, when the number of political parties is high, so that the legislature is fragmented, the executive cannot pass a technology policy without simultaneously catering to multiple political constituencies with parochial interests. For example, suppose the executive wants to promote renewable energy to reduce the country's dependence on foreign oil imports. In this case, the presence of large number of small parties would mean that the government's renewable energy policy would have to be filled with specific concessions to some subset of these small parties. One party might request a subsidy for wind energy while another party would request a subsidy for solar photovoltaics. These specific concessions reduce the expected effectiveness of the technology policy due to potential inconsistencies. Moreover, the concessions increase the cost of the technology policy.

To illustrate consider Italy's nuclear power program. When Beneditto "Bettino" Craxi began his term as the Prime Minister of Italy in August 1983, his government emphasized, in accordance with previous electoral promises, the importance of nuclear power (Franchino, 2011, 15). However, the coalition of five parties, *pentapartito*, was highly fragmented and internally divided, failing to "design workable energy policies in the face of resistance to nuclear power" (Times, 1987). In 1983, the government invested almost two billion US dollars (2010 constant prices) in energy research, with more than 1.6 billion dollars dedicated to nuclear power. By 1987, funding for energy research had fallen to 1.4 billion dollars and nuclear research to 900 million dollars, even as Italy's energy problems became more and more serious over time.

The problem of government fragmentation is further aggravated by the possibility that small political parties emphasize particularistic interests in their campaigning and legislative activity. This argument can be found in Lizzeri and Persico (2005). They show that as the number of political parties in a legislature reaches high levels, these parties begin to emphasize particularistic "pork barrel" policies (Ferejohn, 1974) at the expense of providing public goods. In the case of technology policy, this would mean that a fragmented legislature would require even more concessions from the executive to respond to severe social problems. This would reduce the government's ability to mount a policy response.

3.3. Other influences

While we focus on government unity, it is important to consider other influences on technology policy. We acknowledge that technology policies are often the most effective in conjunction with other policies. For example, Gillingham et al. (2008) note that to combat climate change the most effective approach is to combine environmental policy, such as carbon taxes or emissions trading, with clean technology policy. However, in the case of negative societal externalities, "private firms do not have incentives to provide the socially optimal level of research activity" (Popp, 2006, p. 313). Moreover, the type of technology developed may modify the effectiveness of the policy response (Dolfsma and Seo, 2013).

The slowly changing political institutions of a country may also condition the effect of government unity on technology policy. In some countries, such as the United States, political institutions amplify the consequences of government unity because institutional "veto points" allow the opposition to undermine the government's policy initiatives (Lohmann and O'Halloran, 1994). In other countries, even seemingly weak governments may be able to govern effectively due to limited constraints on executive decision making. However, the expected direction of the effect is the same across countries. In addition to our quantitative test, below we also provide qualitative illustrations of policy dynamics within several countries.

3.4. Hypotheses

Social problems and government unity should have an interactive effect on technology policy. A social problem generates the demand for various public policies. Weak governments often fail to respond to this demand. The transaction costs of technology policy must not exceed the political benefits of a policy response. These expectations are summarized in Table 1.

To begin with, consider the social problem in focus.

Hypothesis 1. As the severity of a social problem increases, the technology policy response becomes more forceful.

All else constant, we expect increased social problems to create demand for new technology policies that mitigate the problem in focus. What is the expected effect of government unity on technology policy?

Hypothesis 2. As government unity increases, the technology policy response becomes more forceful.

This hypothesis states that the government's ability to respond to social problems should increase with its unity. Here we rely on the idea of political market failure: governments prefer to address social problems, but they are unable to do so unless they can agree on a common course of action without incurring prohibitively high negotiation costs.

Most importantly, we also expect an interactive effect.

Hypothesis 3. As government unity increases, the positive effect of social problem severity on the technology policy response increases.

This hypothesis states that the primary function of government unity is to mediate the effect of social problem severity on the technology policy response.

To illustrate this hypothesis further, consider a country where a given social problem, such as air pollution, simply does not exist. In this country, increased government unity should not cause an improved technology policy response. Indeed, increased government unity may even *reduce* the technology policy response: technology policy is obviously costly, so a strong and unified government would not implement technology policies in the absence of severe social problems. By contrast, a weak and fragmented government might do so, in view of promoting parochial interests.

The validity of these hypotheses does *not* depend on the government's ideology. We expect both left-wing and right-wing governments facing social problems to enact technology policies. While the details of these technology policies may reflect ideological preferences, we do not expect the strength of the response to do so.

Our empirical approach allows us to contrast our theory with alternative explanations that focus on social problems and government unity. First, a social engineering approach to technology policy would imply that government unity is irrelevant for energy policy, and so the magnitude of the social problem largely determines the strength of the policy response (Fischer and Newell, 2008). Second, a strictly neoclassical economic theory of technology policy based on competitive markets would imply that governments need not respond to social problems, and so problem intensity is dominated by rent seeking as a motivation for policy formation (Stigler, 1971; Becker, 1983). Finally, one could also expect that government unity is actually the least important under sufficiently severe social problems, as even weak governments manage to respond to major challenges due to overwhelming public pressure and attention (Drazen and Grilli, 1993).

Table 1
Theoretical expectations. Each cell presents the expected technology policy response as a function of government unity and the severity of the social problem in focus.

Government	Social problem	
	Major	Minor
Unified	Strong response	Weak response
Fractionalized	Weak response	Very weak response

4. Wasteful energy use and technology policy in industrialized democracies

If a society consumes large amounts of energy for economic production and other social activities, it becomes vulnerable to various threats. First, high energy intensity increases the vulnerability of a society to changes in international energy prices (Geller et al., 2006; Ikenberry, 1986). Second, it carries negative environmental externalities (Müller-Kraenner, 2010). Finally, it may even threaten the national security of the country (Yergin, 1988). For these reasons, governments can potentially benefit from responding to wasteful energy consumption through public policy.

The state apparatus may play a productive role in reducing the consumption and enhancing the supply of clean energy, because wasteful energy consumption is a form of market failure. As Jaffe and Stavins (1994) and DeCanio (1998) explain, energy producers and consumers often fail to internalize the pernicious societal consequences of wasteful energy consumption. Energy producers naturally have few incentives to inform consumers of ways to reduce their energy bills, while consumers often have limited information regarding ways to improve energy efficiency (Gillingham et al., 2012). Additionally, both consumers and producers ignore the negative environmental and security externalities of wasteful energy consumption.

If the government of a state identifies wasteful energy consumption as a problem, what can it do to solve the problem? There are two main solutions. First, the government can implement public policies towards energy conservation and reduced energy intensity (Geller et al., 2006). Potential solutions are comprised of energy taxes, efficiency standards for appliances and buildings, fuel efficiency regulations, and public investments in research and development. Second, the government can attempt to improve and diversify energy supply (Margolis and Kammen, 1999). It may invest in nuclear power or renewable energy sources, for example, or develop hydrogen and electric vehicles. The exact diversification strategy depends among other things on natural resource endowments, public opinion, and the economic cost of developing a new energy source.

For such a policy response, technology is important. It is costly to achieve a given reduction in energy consumption or diversify the supply. The cost of each solution can be reduced with new energy technologies (Gillingham et al., 2008; Popp, 2006). Energy conservation technologies allow energy consumption to be reduced at a low or even negative cost, whereas new energy generation technologies, such as wind energy, can help the government increase the diversity of supply by tapping into previously unavailable resources. For these reasons, technology policy is an integral component of addressing wasteful energy use under resource constraints.

Although both practitioners and scholars mostly agree on the importance of energy policy, the ability of industrialized nations – not to even mention developing countries – to address energy market failures varies widely. Indeed, failures are frequent. According to Margolis and Kammen (1999), the United States has mostly failed to create effective public support mechanisms for new energy technologies, despite the negative environmental, economic, and national security consequences of dependence on coal for electricity and oil for transportation fuel. Heymann (1998) argues that while Denmark managed to develop an effective wind energy industry, both the United States and Germany have, until very recently, failed to create a national innovation system capable of developing wind energy technology for commercialization.

The literature offers several potential explanations for energy policy failures. Fredriksson et al. (2004) argue that corporate special interests oppose energy regulations, and so the ability of organized special interests to lobby against energy regulations is a key reason why energy policy fails. They also provide empirical evidence on industrial energy efficiency in OECD nations. Similarly, Stenzel and Frenzel (2008) note that major energy utilities can strategically delay the deployment of clean energy sources, unless alternative energy promises substantial economic profits. Hadjilambrinos (2000) and Szarka (2007) note that in the case of France, the dominance of nuclear energy has for decades prevented alternative energy sources from appearing on the political agenda.

Others emphasize weak political institutions. In his study of oil crises, Ikenberry (1986) explores variegated state responses to increased energy vulnerability: while crude notions of “state strength” may be highly misleading, the institutional abilities of different countries nonetheless shed light on the comparative policy responses. Similarly, Hadjilambrinos (1996) finds that although Greece has repeatedly attempted to promote renewable energy, implementation has failed.

We argue that government unity is a key explanatory variable for public energy R&D. As government unity increases, the *likelihood* that government parties are able formulate a consensus on investment priorities increases. If the society currently uses energy in a wasteful fashion, government unity thus allows a policy consensus that, all else constant, begins to address the problems created by a high energy intensity. Conversely, the lack of government unity would present a high barrier to a partisan consensus on investment priorities for public energy R&D.

5. Research design

We test our hypotheses with an empirical analysis of pooled time series data for 22 OECD countries that had joined the IEA by 2006. All countries in the dataset are industrialized democracies, as is required for testing our theory, and there are no authoritarian reversals in our sample. Of the countries included, Turkey may be considered a somewhat unstable democracy at different times. In the robustness appendix, we note that exclusion of Turkey from the dataset did not change any of our empirical results. The dataset covers the years 1980–2006, and this temporal coverage is largely determined by data availability.

Our goal is to test the interactive effect of government unity (response capacity) and wasteful energy use (problem severity) on public energy R&D funding. We chose to analyze OECD countries because they are the most likely countries to have the resources or political motivation to invest in research and development and reliable data are available for an extended time period. The basic unit of our compiled dataset is a country–year, with countries indexed by i and years by t. The only reason why some OECD members are missing from the dataset is that they do not provide the IEA with data on their public energy R&D expenditures, and thus we do not have a dependent variable for them.

The model is specified as follows:

$$RD_{i,t} = \beta_0 + \beta_1 ENERGY_{i,t} + \beta_2 FRAC_{i,t} + \beta_3 ENERGY_{i,t} * FRAC_{i,t} + \lambda CONTROLS_{i,t} + \epsilon_{i,t}, \quad (1)$$

where λ is a vector of coefficients and *CONTROLS* is a vector of control variables. The model will also include country and year fixed effects. The dependent variable *RD* measures the ratio of public investment in energy R&D to GDP. On the other side, *ENERGY* measures variation in energy intensity, *FRAC* measures government fragmentation, and *ENERGY**FRAC* is the interaction term. Robustness checks are summarized in the supplementary appendix.

5.1. Dependent variable

Our dependent variable is the ratio of public energy R&D summed across seven different sectors to the GDP of a country, excluding direct production subsidies. We sum across the sectors because each country's preferred sectoral response could depend on a variety of factors, such as public opinion on nuclear power and interest in renewable energy. For example, a country that has already invested significantly in nuclear power may find it difficult to address energy problems in the short run by investing in renewable energy. Similarly, a country that does not have a nuclear sector cannot rapidly address immediate energy problems by building nuclear power. Thus, it would be inappropriate to focus on any specific sector of public energy R&D. The data for this variable are provided by the IEA. While technology policies are generally complex, public investment in R&D serves as a reliable and quantifiable proxy for energy policy. The advantage of this measure is that it can successfully account for a number of different types of public policy decisions across countries, as all of them require fiscal investments. The measure captures the following sectors: renewable energy, energy efficiency, fuel cells, hydroelectricity, nuclear electricity, storage and conversion technologies, and fossil fuels. Notably, the measure includes both energy conversion *and* generation measures. A government can respond to energy problems either by (i) reducing consumption or by (ii) increasing domestic generation. Both approaches produce societal benefits, and our theory does not predict that one would be favored over the other.

To deal with outliers, in some models we use the natural logarithm of the variable. To verify the robustness of our findings, we also tried an alternative normalization: public energy R&D divided by population (measured in millions of inhabitants). With this normalization, we obtain very similar results.

A possible objection to our dependent variable is endogeneity: technology policy could exert influence on energy intensity, so some of the coefficients could be biased. To guard against this possibility, we also estimated our statistical models while excluding the energy efficiency R&D. All other technologies in the dataset focus on the supply side, and thus increase rather than decrease energy use. We found that the exclusion of energy efficiency R&D

did not compromise our main results, so it seems improbable that our findings are driven by endogeneity bias.

Our dependent variable cannot directly capture technology policies on the demand side. In addition to directly investing in energy R&D, governments could also stimulate end user demand to create a "demand pull" (Nemet, 2009). While we do not discount the importance of such policies, they present a major challenge for empirical analysis because it is very hard to quantify and compare policies across nations and over time. Given that basic R&D is an important element of technology policy (Klaassen et al., 2005), and frequently undersupplied by both firms and national governments (Nemet and Kammen, 2007), a focus on public R&D funding in the energy sector is both theoretically appropriate and relevant to policy formation.

Indeed, the extant literature agrees that public energy R&D has been a central feature of energy policy in industrialized countries (Mowery et al., 2010; Nemet and Kammen, 2007). Every year, industrialized countries invest billions of dollars in public energy R&D. Additionally, the empirical evidence on the positive effects of public energy R&D is compelling. Using data on the cost of wind energy generation, Klaassen et al. (2005, p. 237) show that "R&D policy in Denmark was most successful in supporting innovation." Norberg-Bohm (2000, p. 134) similarly notes that in the United States solar industry, "the large impact of publicly funded research and development … is clear." Harris et al. (1987) analyze seven energy efficiency R&D projects funded by the federal government and find that "federal investments totaling $16 million generate eventual savings of $68 billion." Given this evidence, it should be clear that studying public energy R&D is a worthwhile effort for political scientists.

5.2. Independent variables

Our primary independent variables are energy intensity and legislative fractionalization. We discuss each variable in turn. Descriptive statistics by country are found in Table 2.

Energy intensity: To test our theory, we first need a measure of the social problems. Given our focus on energy policy, we use energy intensity as our measure of problem severity. Countries with a low energy intensity are already exploiting energy resources in an effective fashion, so the potential benefits of technology policy are limited. Following convention, we measure energy intensity as total primary energy consumption per dollar of economic output. The data were obtained from the United States Energy Information Administration (EIA) in Btu per US dollar in 2005 prices at market exchange rates.

Table 2
Descriptive statistics for countries included in the dataset. R&D, energy intensity, and fractionalization are mean values summed over time. First year indicates the beginning of the time series for the energy R& D variable, and # of years indicates the total number of observations for this variable.

Country	R&D	Energy intensity	Fractionalization	First year	# of years
Australia	0.49	8.2	0.59	1980	15
Austria	0.30	5.4	0.64	1980	27
Belgium	1.01	8.0	0.85	1980	16
Canada	0.94	14.4	0.58	1980	27
Denmark	0.34	4.1	0.80	1980	26
Finland	0.60	7.8	0.80	1990	17
France	0.63	5.7	0.68	1985	22
Germany	0.76	5.5	0.68	1980	27
Greece	0.36	6.1	0.54	1980	23
Ireland	0.24	4.7	0.65	1980	15
Italy	1.12	4.7	0.67	1980	25
Japan	1.29	5.1	0.65	1980	27
Netherlands	0.86	7.4	0.78	1980	26
New Zealand	0.36	9.5	0.58	1980	24
Norway	0.70	7.8	0.74	1980	27
Portugal	0.18	5.5	0.63	1980	26
Spain	0.41	5.8	0.63	1980	27
Sweden	0.72	8.1	0.73	1980	27
Switzerland	0.79	3.9	0.82	1980	27
Turkey	0.03	7.4	0.59	1983	24
United Kingdom	0.59	5.7	0.54	1980	27
United States	0.60	10.1	0.49	1980	27

Energy intensity depends on such national characteristics as the availability of domestic energy resources. In our empirical analysis, we always include country fixed effects. Thus, we are not using energy intensity to compare problem severity across countries but instead within each country. The fact that Canada has a higher energy intensity than Denmark may reflect the fact that Canada has access to abundant hydropower and oil supplies. But since we include country fixed effects, we are able to examine the effect of changes in energy intensity within each country. Even a country with adequate energy resources will pay a cost for high energy intensity, both as environmental pollution and wasteful resource use.

Alternative measures of the social problem exist. One approach would be to use international oil prices. However, the use of international oil prices is potentially problematic for our empirical analysis because they only vary over time, and not across countries. Thus, it would not be possible to account for other common exogenous shocks and technological change. For these reasons, we prefer to use energy intensity as the measure. By including year fixed effects in our empirical analysis, we nonetheless control for the possible conflating effect of international oil prices. We also considered air pollution – possibly measured as sulphur dioxide emissions – but rejected the approach because most of the solutions to air pollution problems are simple technological fixes of the "end of the pipe" variety, and thus do not require any actual energy technology innovation (Popp, 2006). Finally, we considered energy import dependence but ultimately rejected it because countries with large energy imports may have few domestic energy sources that would benefit from public energy R&D. In this case increased problem severity would be correlated with inability to solve it, and thus the coefficients would be biased.

Legislative fractionalization: The second independent variable that we utilize measures government unity. We opted for the legislative fractionalization measure from the 2009 Database of Political Institutions. It measures the probability that two deputies picked at random from the legislature will be of different parties. The higher the index number, the more potential for political division and consequently increased difficulty in forming effective public policies in response to social problems. This measure allows us to compare government unity across a variety of political institutions, without focusing on any specific institutional arrangement such as bicameralism or presidentialism. Furthermore, fractionalization varies over time and thus allows us to account for unobservable variation across countries through the inclusion of country fixed effects. While this measure obviously cannot account for such phenomena as divided government in the United States, we are not aware of any other measures that would allow us to compare dynamics across almost two dozen industrialized democracies with very different political systems. As qualitative illustrations, we examine the logic of divided government in the United States below. In conclusion, we discuss possible ideas for future research in this regard.

As a robustness check, we include an alternate measure of political division, also from the Database of Political Institutions. Government fractionalization is the probability that two deputies picked at random among the government parties will be of different parties. This measure focuses only on the ruling coalition, so it cannot account for legislative fragmentation and the size of the government. However, it does have the advantage of not including fragmentation in the opposition parties. As we show below, our empirical results are unchanged if we replace legislative with government fractionalization.

Interaction: To measure the interactive effects of energy intensity and fractionalization (or government fractionalization), we multiple the two variables for the regression. This variable allows us to test whether the effect of energy intensity on R&D depends on government unity. In particular, we expect that fractionalization reduces the effect of energy intensity on public energy R&D.

5.3. Control variables

To account for other influences on public energy R&D, we chose several theoretically informed control variables. We account for domestic energy supply, national income, trade and industrial structure. In addition to these control variables, we include country and year fixed effects. Of these, country fixed effects allow us to account for the effects of relatively stable political institutions, such as mean district magnitude or bicameralism. Similarly, year fixed effects capture common exogenous shocks. Models with no control variables and additional control variables are analyzed in the supplementary appendix.

Nuclear: Nuclear electricity requires costly capital investments, yet it produces electricity at a low variable cost (Szarka, 2007). Therefore, nuclear electricity may increase energy intensity. At the same time, governments have generously subsidized nuclear research (Cowan, 1990). Countries that rely on nuclear electricity may select public energy R&D in different ways than other countries. The variable is measured as the share of nuclear power in total electricity generation and the data come from the EIA.

Hydro: Hydroelectricity is similar to nuclear electricity because it produces electricity at a low variable cost. It is also a mature energy technology that does not require much research. We account for the possibility that countries with abundant hydroelectricity resources may reduce public energy R&D. The variable measures the share of hydropower in electricity generation (EIA).

Renewable share: Renewable electricity is rapidly growing worldwide, and many countries are investing aggressively in renewable energy technologies (Laird and Stefes, 2009; Cheon and Urpelainen, 2012). Additionally, renewables do not produce as many negative externalities as fossil fuels (Agnolucci, 2007). Thus, we include it to account for the possibility that renewables condition a government's public energy R&D response. The variable measures the ratio of electricity generated from non-hydro renewable sources to total electricity generation. The variable is from the EIA and includes geothermal, wind, solar, and biomass energy.

GDP per capita: Public energy R&D carries a fiscal cost, and this cost is relative to the total economic wealth of a country. Thus, wealthy countries may be more willing to invest in energy R&D than poor countries struggling with more immediate economic problems (Grossman and Krueger, 1995). To account for possible income effects, we include GDP per capita. The data are from the World Developing Indicators (WDIs) in thousands of constant USD2000.

Trade/GDP. A substantial literature exists on technology policy as industrial policy, and much of it emphasizes the creation of export industries (Lewis and Wiser, 2007). To account for the possibility that economically open countries have strong incentives to use public R&D to create new export industries in clean energy technologies, we include a variable that measures the ratio of exports to total GDP (WDI).

Industry/GDP: We also need to account for the economic structure of the country. In particular, manufacturing consumes a lot of energy. Thus, high energy intensity could simply reflect the importance of manufacturing for the national economy. Additionally, manufacturers may support increased energy R&D because it reduces the cost of electricity (Smith and Urpelainen, 2013). We measure the size of the industrial sector as the ratio of value added to total GDP. Value added is the net output of a sector after summing all outputs and subtracting intermediate inputs, and industries included mining, manufacturing, construction, electricity, water, and gas. The data are from the WDI.

Energy imports: High energy intensity is not the only social problem. We add energy import dependence to the regressions to account for energy security concerns (Müller-Kraenner, 2010). The variable is measured as the ratio of energy imports to consumption, and the data are from the WDI.

Partisanship: Previous research on policy formation indicates that leftist governments are often more willing to use public funds to correct negative externalities (Neumayer, 2003; Shipan and Lowry, 2001). While our theory does not predict partisan differences, we include a measure of the executive's partisanship. These data are from the 2009 Database of Political Institutions. Each country–year was coded “right” in cases of parties defined as conservative, Christian democratic, or right-wing; and “left” in cases of parties defined as communist, socialist, social democratic, or left-wing. Centrist parties serve as the baseline. Ideally, we would also include a measure of green party strength in the government. However, these data are not available for many years and countries in our dataset.

Executive constraints: Based on “veto player” theories (Tsebelis, 2002), not only legislative fractionalization but also institutional veto points could impede technology policy. To account for this, we include the CHECKS variable from the 2009 Database of

Table 3
Summary statistics. The table shows the distribution of the variables used in the empirical analysis.

Variables	Min	p25	p50	p75	Max	Mean	SD
RD/GDP	0.0031	0.16	0.38	0.76	3.8	0.58	0.63
Energy intensity	3.1	5.2	6.2	8.2	17	6.9	2.6
Frac	0	0.56	0.66	0.76	0.9	0.66	0.12
Energy intensity*Frac	0	3.4	3.9	5.6	10	4.5	1.6
Nuclear	0	0	0.058	0.28	0.79	0.16	0.2
Hydro	0	0.058	0.16	0.53	1	0.28	0.29
Renewable	0	0.0045	0.016	0.031	0.29	0.028	0.038
GDP PC	2.6	14	20	26	42	20	8.8
Trade/GDP	0.07	0.22	0.29	0.4	0.94	0.32	0.16
Industry/GDP	0.19	0.27	0.3	0.33	0.45	0.3	0.046
Energy imports	−8.4	0.11	0.54	0.69	0.95	0.082	1.5
Left	0	0	0	1	1	0.38	0.49
Right	0	0	1	1	1	0.5	0.5
Checks	1	3	4	5	16	4.1	1.4
Energy utilities	0.56	4.5	6.5	10	31	8.4	6

Political Institutions. It measures the extent of institutional constraints on the executive. We expect it to reduce technology policy.

Energy utilities: While direct measures of interest group strength in the energy sector are not available, it is important to account for sectoral interests (Laird and Stefes, 2009). As an indirect measure, we divide total electricity generation by population. The data are from the EIA. This measure captures the importance of *domestic* electricity generation per capita, so it should be positively associated with the political-economic clout of energy utilities. Table 3 provides the descriptive statistics and Table 4 provides a correlation matrix.

5.4. Model specification

The Wooldridge test indicated the presence of serial correlation, and the Breusch–Pagan and Pesaran tests indicated the presence of heteroskedasticity and cross-sectional dependence. Given that all three problems exist simultaneously, Driscoll and Kraay (1998) standard errors are ideal. We allow for serial correlation of up to two years. The supplementary appendix presents results with alternative standard errors. Models with panel corrected standard errors and a common AR(1) process could not be identified with year fixed effects. If we exclude year fixed effects, all our results continue to hold.

We used the Harris and Tzavalis (1999) test for models with time fixed effects to examine the possibility of nonstationary data. We found no evidence for nonstationarity in the dependent variable. This is important because it means that any temporal trends in the dependent and independent variables do not bias the results.

6. Findings

Our empirical analyses support our theoretical argument. Table 5 reports estimates from seven models. Model (1) is our

Table 4
Correlation matrix. The table shows the correlations between the variables used in the empirical analysis.

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. RD/GDP	1.00														
2. Energy intensity	0.23	1.00													
3. Fractionalization	0.04	−0.27	1.00												
4. Energy int.*Frac	0.23	0.85	0.26	1.00											
5. Nuclear	0.09	−0.03	0.23	0.10	1.00										
6. Hydro	0.03	0.32	0.04	0.33	−0.19	1.00									
7. Renew.	−0.21	−0.20	0.23	−0.10	−0.09	−0.10	1.00								
8. GDP PC	0.03	−0.13	0.28	−0.04	0.28	0.06	0.18	1.00							
9. Trade/GDP	−0.06	−0.10	0.58	0.21	0.05	0.05	0.25	0.16	1.00						
10. Industry/GDP	0.48	0.11	0.05	0.15	−0.14	0.31	−0.25	0.04	0.02	1.00					
11. Energy imports	−0.00	−0.18	−0.14	−0.26	0.21	−0.52	0.11	−0.36	−0.11	−0.31	1.00				
12. Left	−0.10	0.07	0.03	0.10	−0.02	0.17	0.06	−0.01	−0.01	−0.13	−0.07	1.00			
13. Right	0.05	0.06	−0.13	0.00	−0.02	−0.19	−0.09	−0.03	−0.08	0.06	−0.03	−0.79	1.00		
14. Checks	0.06	−0.04	0.42	0.15	0.15	−0.20	0.04	0.23	0.27	0.01	−0.07	−0.03	0.07	1.00	
15. Energy utilities	0.06	0.48	0.15	0.54	0.11	0.61	0.00	0.56	0.12	0.21	−0.73	0.17	−0.11	0.08	1.00

Table 5
Regression results. (1) Main model; (2) 1985–2006; (3) 1980–2004; (4) logarithmized DV; (5) government fractionalization; (6) population normalization; (7) independent variables lagged by one year.

Variables	(1) RD/GDP	(2) RD/GDP	(3) RD/GDP	(4) RD/GDP (Log)	(5) RD/GDP	(6) RD/Pop	(7) RD/GDP
Energy intensity	0.290*** (0.055)	0.210*** (0.061)	0.295*** (0.056)	0.128*** (0.025)	0.161*** (0.030)	6.236*** (0.776)	
Fractionalization	2.629*** (0.696)	2.636*** (0.697)	2.601*** (0.786)	1.085*** (0.274)		45.828*** (8.484)	
Energy int.*Frac	−0.232*** (0.079)	−0.258*** (0.083)	−0.246*** (0.086)	−0.094** (0.034)		−4.601*** (0.883)	
Nuclear	−0.718** (0.257)	0.203 (0.388)	−0.796*** (0.280)	−0.324** (0.145)	−0.650** (0.243)	−5.362 (4.378)	−0.919** (0.377)
Hydro	0.142 (0.303)	−0.271* (0.137)	0.254 (0.280)	0.068 (0.170)	0.163 (0.269)	−0.539 (4.467)	0.181 (0.287)
Renewables	1.766** (0.834)	0.880** (0.385)	2.423* (1.204)	0.965** (0.371)	1.905** (0.765)	42.780*** (12.438)	1.914** (0.794)
GDP per capita	−0.000 (0.009)	−0.003 (0.009)	−0.013 (0.008)	0.006 (0.004)	0.002 (0.011)	1.025*** (0.223)	0.008 (0.006)
Trade/GDP	1.017* (0.562)	0.180 (0.182)	1.488** (0.596)	0.378** (0.181)	1.331** (0.574)	−13.420** (5.610)	0.618 (0.431)
Industry/GDP	1.196* (0.655)	0.215 (0.695)	1.107 (0.694)	0.573 (0.367)	1.350* (0.734)	10.078 (8.295)	0.801 (0.479)
Energy imports	−0.088** (0.039)	0.023 (0.014)	−0.115** (0.043)	−0.034** (0.015)	−0.108** (0.042)	−0.641 (0.598)	−0.081** (0.035)
Left	−0.100 (0.077)	−0.096* (0.053)	−0.024 (0.076)	−0.065* (0.033)	−0.052 (0.079)	−1.334 (1.126)	−0.074 (0.083)
Right	−0.181** (0.082)	−0.095* (0.050)	−0.121 (0.075)	−0.093*** (0.032)	−0.166** (0.072)	−1.971** (0.845)	−0.139* (0.079)
Checks	−0.018 (0.013)	−0.021** (0.008)	−0.007 (0.011)	−0.008 (0.005)	−0.022** (0.009)	−0.249 (0.0185)	−0.012 (0.009)
Energy utilities	0.022** (0.010)	0.028** (0.013)	0.017 (0.016)	0.014*** (0.005)	0.025*** (0.009)	0.185 (0.434)	0.033**(0.014)
Gov. frac.					0.927** (0.377)		
Energy int.*Gov frac.					−0.072 (0.043)		
Energy intensity (lag)							0.244*** (0.048)
Frac (lag)							2.185*** (0.587)
Energy int.*Frac (lag)							−0.162** (0.072)
Constant	−3.107*** (0.639)	−1.939** (0.733)	0.000 (0.000)	−1.433*** (0.299)	−1.904*** (0.538)	−61.859*** (7.267)	−2.919*** (0.633)
Within R^2	0.753	0.646	0.757	0.812	0.747	0.554	0.744
Observations	514	412	456	514	523	514	496
Number of groups	22	22	22	22	22	22	22

Standard errors in parentheses.
Year and country fixed effects estimated but omitted.

*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

main model. Models (2) and (3) restrict the temporal coverage of the analysis in an effort to check that our results are not driven by the high oil prices of the early 1980s or the 2005–2006 period. Model (4) uses a logged dependent variable and Model (5) uses government fractionalization instead of legislative fractionalization. Model (6) uses population instead of total GDP as a normalization. For robustness purposes, Model (7) lags the independent variables. All models are estimated using Driscoll and Kraay (1998) standard errors and allowing for autocorrelation up to two years. The supplementary appendix reports results from additional models.

The interactive effect of energy intensity and fractionalization is consistently negative. In every model, the effect of energy intensity on energy R&D is positive and statistically significant for low levels of fractionalization. But as fractionalization increases, the effect of energy intensity begins to decrease. Given that the fractionalization measure falls on the interval $[0,1]$, the expected effect is never negative.

Fig. 1 shows the marginal effect for different levels of fractionalization. The estimation is based on Model (1). The effect is always positive, but it decreases as fractionalization grows. For the lowest levels of fractionalization in the data, a unit increase in energy intensity has three times the effect observed for the highest levels of fractionalization. Indeed, the substantive effects at the lowest levels of fractionalization are large: a standard deviation's increase in energy intensity increases energy R&D relative to GDP by more than one standard deviation.

To summarize these findings, the sign of the interactive effect supports the theory. An increase in fractionalization corresponds to a decrease in government unity, and this reduces the government's ability to use public energy R&D as a response to wasteful energy use. Accordingly, the effect of energy intensity on per capita R&D *decreases* as fractionalization grows. The government's lowered unity prevents it from acting in spite of high levels of energy intensity.

Interestingly, the marginal effect of fractionalization itself is *positive* for low levels of energy intensity. This suggests that if wasteful energy use is *not* a social problem, then fractionalization actually increases the use of energy R&D. This is quite intuitive, as the government may choose to use energy R&D subsidies as side payments to veto players in the fractionalized legislature. Conversely, for high levels of energy intensity, fractionalization has a negative effect on energy R&D. When wasteful energy use is a severe social problem, fractionalization prevents the government from mounting an effective technology policy response.

The control variables offer useful insights. Nuclear electricity decreases energy R&D, perhaps because nuclear energy is a relatively mature energy technology. Investing in mature energy technologies is not a rational response to social problems. In contrast, renewable energy is associated with increased energy R&D, probably because it is an immature technology that requires public support. Surprisingly, energy imports have a negative effect on energy R&D. This may reflect the lack of domestic opportunities for profitable energy R&D. If a country does not have potential domestic energy resources, investing in energy supply is not profitable. General economic openness seems to increase energy R&D, perhaps because governments are interested in supporting potential export industries in energy technology. Equally interesting, the interest group variable has a positive and often statistically significant coefficient. There is little difference between left-wing and right-wing governments. Both seem to invest slightly less than the baseline category of centrist governments, but the coefficients are substantively very small. These findings suggest that partisan ideology does not play much of a role in public energy R&D.

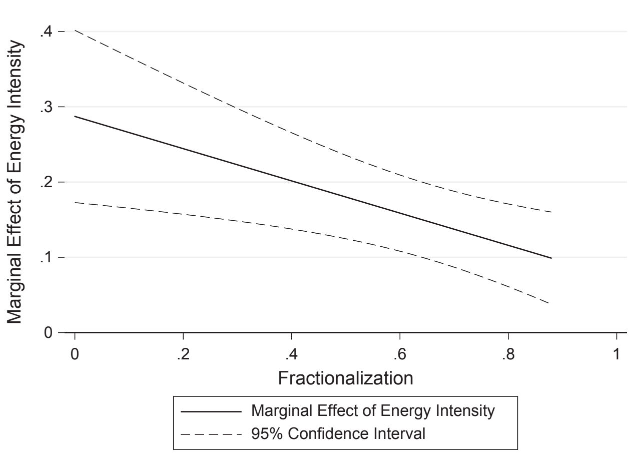

Fig. 1. Marginal effect of energy intensity on per capita R&D expenditures for varying levels of fractionalization. The marginal effect is estimated using Model (1).

Of the models reported in the supplementary appendix, three are particularly notable. First, our results continue to hold without any control variables. This suggests that the result is not biased by inclusion of irrelevant variables. Second, we estimate a model that adds a control for sulphur dioxide emissions per capita. Our results continue to hold, and the coefficient for the emissions variable is positive throughout. This suggests that countries also enact technology policies in response to pollution problems. Finally, we also interacted energy intensity with our measure of executive constraints. We found that the interactive effect between energy intensity and legislative fractionalization remains strong and statistically significant, while the coefficient for the interaction with executive constraints is small, inconsistent across models, and never statistically significant. This suggests that conventional theories of veto players cannot explain our findings; instead, an account of legislative bargaining and the advantages of unified government is needed.

7. Country illustrations

For illustration, we now turn to the trajectories of the United States and the Netherlands. We chose these two countries because, as shown in Fig. 2, each has seen a dramatic decrease in public energy R&D over the past three decades. Since both countries have relatively high mean energy intensities, as shown in Table 2 above, the conditions for applying our theory of the role of government unity are met. If our theory is valid, our theory should be able to explain these dramatic decreases with reference to corresponding decreases in government unity. While the mean legislative fractionalization levels are very different due to very different voting rules in national elections, both countries have also seen an increase in fractionalization. This increase in fractionalization, we argue, can shed light on the consistent decline in public energy R&D.

Consider first the United States. As Fig. 2 shows, relative investment in energy R&D has decreased from more than two to less than 3/10 USD for each USD1000 of GDP. This decrease is much faster than the simultaneous growth in GDP, and it largely reflects the fact that decreased investment in nuclear energy has not been replaced by corresponding increases in renewable sources and energy efficiency. At the same time, fractionalization has increased over time: the negative correlation between energy R&D and fractionalization is as high as -0.53. Indeed, qualitative evidence corroborates the notion that partisan conflict and fractionalization have been important drivers of this trend (Laird and Stefes, 2009). Already in the 1980s, federal nuclear policy had run into trouble due to profound disagreements among policymakers and the resulting fragmentation of technology programs (Joppke,

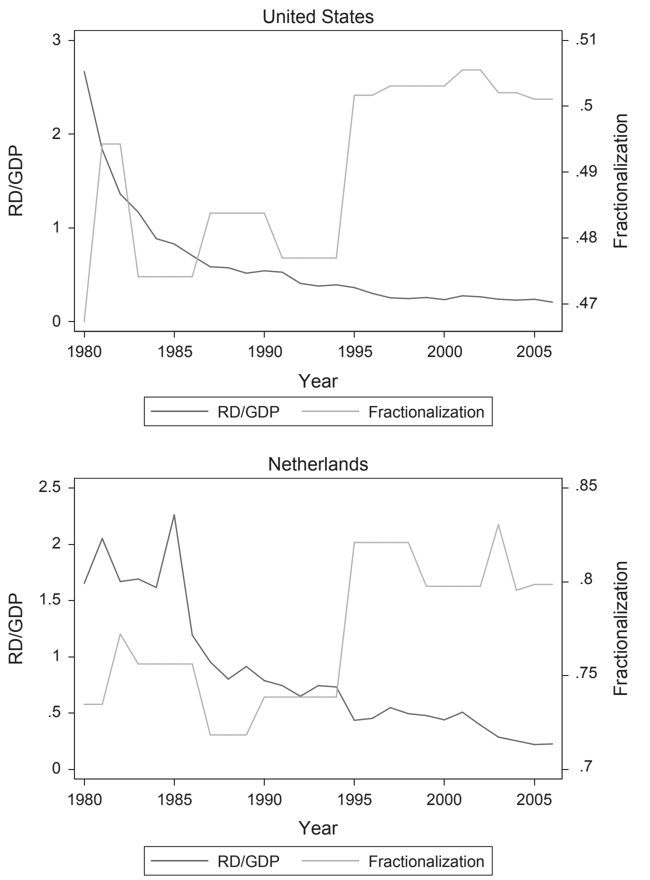

Fig. 2. Legislative fractionalization and public energy R&D per capita in the United States and the Netherlands, 1980–2006.

1992–1993). In spite of dwindling domestic oil resources and concerns regarding energy security, both Democrat and Republican administration have repeatedly failed to invest in new energy technologies (Nemet and Kammen, 2007). While Democrat administrations have generally regarded public energy R&D as a worthwhile investment, multiple access points have allowed Republicans to reduce the budget for energy technology. Similarly, Republican administrations have not been able to invest in nuclear energy because Democrats and environmental organizations have actively opposed these efforts. As a result, an energy technology policy vacuum exists: the two political parties cannot agree on a sustained and predictable technology program, so federal spending has continued to steadily decline over the past three decades. Variation in the administration's partisanship, oil prices, security and environmental concerns, and global clean technology markets have all failed to change this.

The Dutch case is similar, as the correlation coefficient between fractionalization and energy R&D is almost identical to the US, −0.56. In the 1980s, the Dutch government invested heavily in nuclear energy, achieving high levels of public energy R&D. But as the popularity of nuclear energy began to wane, at least partly due to the Chernobyl nuclear disaster, the government never replaced the public investments in nuclear energy with a similarly ambitious technology program in renewables or energy efficiency. In the case of renewables, for example, Dinica and Maarten (2001, p. 61) conclude that the overall policy response in the 1990s was too fragmented and unreliable to be effective: "in spite of the high number of support mechanisms that renewable generators might have benefited from, the financial support coming from each was modest and not too reliable." van Rooijen and van Wees (2006, p. 60) also ascribe the failure of the Dutch renewable energy policy to the fact that "the policies have not been stable and policy objectives have frequently been partly ambiguous." Consistent with our theoretical argument, they in turn attribute the inconsistent policy response to disagreements among policymakers. Similarly, recent events show that the Dutch energy policy approach continues to be rather unpredictable. In an unprecedented move, the Dutch government decided in February 2011 to reduce the country's renewable energy target, "slashing the subsidies for wind and solar power" (Register, 2011). While the previous government had planned to invest significantly in offshore wind, the center-right government of Prime Minister Mark Rutte cut the subsidy for offshore wind and solar panels to zero only four months after the October 2010 elections (Financial Times Deutschland, 2011).

To summarize, we see the pattern that our theory predicts in both countries. Despite high energy intensities throughout the period of investigation, public energy R&D has decreased in both countries. Why? The evidence above suggests that fragmentation in the government played a key role in causing this decline. As government unity declined in the Netherlands and United States, the administration's ability to maintain high levels of public energy R&D faltered. As a result, the government was no longer able to address the problem of wasteful energy use through heavy investment in public energy R& D.

Do these correlations apply to other countries in the dataset? An elegant, non-parametric way to investigate this question is to examine the correlation between legislative fractionalization and public energy R&D as a share of GDP in each country, and then examine whether this correlation coefficient *decreases* with energy intensity, as our theory would predict. This approach allows us to scrutinize our empirical hypotheses without imposing the linearity assumptions required for conventional regression models, so it is a particularly useful technique for verifying that our results do not depend on purely technical assumptions. In countries with a very high energy intensity, low fractionalization levels should produce large investments in public energy R&D, whereas such a relationship should not exist in countries with a low energy intensity.

The results are shown in Fig. 3. In addition to the coefficients, the figure presents a lowess regression fitted to the data. The term "lowess" refers to locally weighted scatterplot smoothing. It allows us to estimate the relationship between two variables without the linearity assumption needed to fit a straight line using ordinary least squares. As the figure shows, the correlation between fractionalization and energy R&D becomes increasingly negative

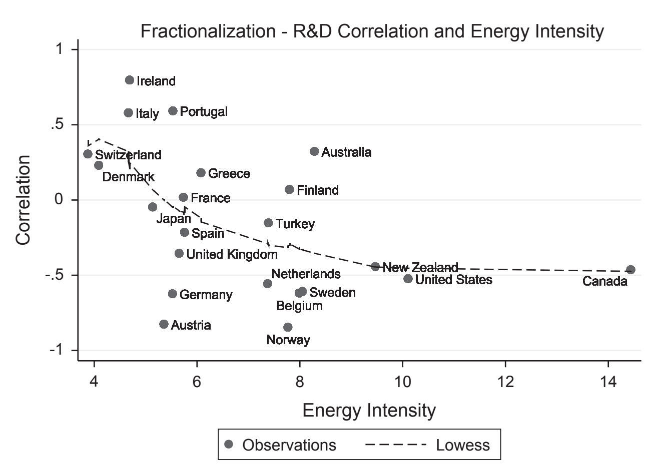

Fig. 3. Correlation coefficient between legislative fractionalization and energy R&D for the countries included in the dataset. The *y*-axis shows the correlation coefficient and the *x*-axis shows the mean energy intensity of the country in focus.

as mean energy intensity increases; since Canada's energy intensity is far higher than any other country's, the rightmost end of the lowess regression is not very informative. The increasingly negative correlation is consistent with our theory, as high levels of fractionalization should prevent governments from implementing otherwise desirable energy R&D investments in the presence of wasteful patterns of energy use.

8. Conclusion

We have examined the role of government unity in technology policy. Problem severity induces a policy response, but the strength of this policy response depends on government unity. For unified governments, political bargains are easy to strike. Therefore, policy responses create political surplus that can be distributed to constituencies. Fragmented governments are less effective because the transaction costs of implementing policy are high.

We have applied this general logic to technology policy, thus expanding the scope of the political-economic analysis of public policy. We have found that wasteful energy use, captured by the indicator of energy intensity, increases the sensitivity of public energy R&D to government unity. Our data analysis of the relationship between wasteful energy use, government unity, and public energy R&D in OECD countries during the 1980–2006 period supports the theory, and a deeper analysis of the Dutch and American cases further validates the hypothesis. When governments are unified, they react to high energy intensities by investing in public energy R&D. This is consistent with the idea that unified governments are able to address the problem of wasteful energy use through technology policy whereas fractionalized governments fail to do so despite a clear societal demand for a policy response.

This paper offers several useful contributions to the social sciences. First, it is among the first systematic empirical analyses of technology policy. Governments can solve social problems in several ways, and one frequently overlooked response is new technology. We have demonstrated that the effectiveness of this response depends on government unity. Second, we address the broader question of political market failure. Theoretically, we have examined the interactions between problem severity and government unity. Empirically, we have expanded the scope of this literature by focusing on technology policy. Our analysis of public energy R&D is novel in that similar quantitative analyses have rarely been conducted in the social sciences, and is substantively important, given the centrality of the energy sector for the environmental and economic performance of industrialized countries.

An important policy implication of our argument is that sustained and reliable R&D programs in the energy sector require the development of institutions that reduce the transaction costs of technology policy formation for fragmented governments. In public energy R&D, consistency and predictability is particularly important for leveraging contributions from the private sector. We have found that lack of government unity is a particularly important obstacle to this goal. In the Dutch and American cases, increased political polarization over time seems to nicely explain the decrease in public energy R&D, whereas competing explanations, such as the direct effect of partisan ideology, appear to have much less explanatory power.

We are cognizant of the limitations of our analysis. To fully validate our theory and to generalize our findings to other sectors of technology policy, further historical and institutional analysis is needed. Our focus here has been quantitative, and a direct qualitative approach focusing on the causal processes that connect government unity and technology policy would offer a useful complement to our study. One promising approach could be to return to the Dutch and American cases and conduct a more detailed historical analysis of how government unity related to key energy policy decisions within the governments of these two countries. If this analysis provides useful insights, it could then be validated with similar analyses in other industrialized countries.

Future research could also contribute to the development of effective energy technology policy by devising effective institutional strategies that would mitigate the negative effect of political fragmentation on technology policy. For example, policy analysts could focus on developing institutional structures and systems that allow governments to implement effective technology policies even in circumstances characterized by partisan fragmentation. Such structures could, to give an illustration, promote consensus building by isolating legislators from public pressures and ensuring that enough time is provided for policy formulation. While we lack the space to contribute to this line of inquiry here, we do hope that future research finds answers to these important questions.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.technovation.2013.06.001.

References

Acemoglu, Daron, 2003. Why not a political Coase theorem? Social conflict, commitment, and politics. Journal of Comparative Economics 31 (4), 620–652.

Agnolucci, Paolo, 2007. Wind electricity in Denmark: a survey of policies, their effectiveness and factors motivating their introduction. Renewable and Sustainable Energy Reviews 11 (5), 951–963.

Alesina, Alberto, Drazen, Allan, 1991. Why are stabilizations delayed? American Economic Review 81 (5), 1170–1188.

Bailey, Michael A., Goldstein, Judith, Weingast, Barry, 1997. The institutional roots of American trade policy: politics, coalitions, and international trade. World Politics 49 (3), 309–338.

Barrett, Scott, 2009. The coming global climate-technology revolution. Journal of Economic Perspectives 23 (2), 53–75.

Becker, Gary S., 1983. A theory of competition among pressure groups for political influence. Quarterly Journal of Economics 98 (3), 371–400.

Binder, Seth, Neumayer, Eric, 2005. Environmental pressure group strength and air pollution: an empirical analysis. Ecological Economics 55 (4), 527–538.

Bueno de Mesquita, Bruce, Smith, Alastair, Siverson, Randolph M., Morrow, James D., 2003. The Logic of Political Survival. MIT Press, Cambridge.

Cheon, Andrew, Urpelainen, Johannes, 2012. Oil prices and energy technology innovation: an empirical analysis. Global Environmental Change 22 (2), 407–417.

Cohen, Linda R., Noll, Roger G., 1991. The Technology Pork Barrel. Brookings Institution Press, Washington, DC.

Cowan, Robin, 1990. Nuclear power reactors: a study in technological lock-in. Journal of Economic History 50 (3), 541–567.

DeCanio, Stephen J., 1998. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. Energy Policy 26 (5), 441–454.

Dinica, Valentina, Arentsen, Maarten, 2001. Green Electricity in the Netherlands. Report 2/2001. Center for Energy and Environment, Norwegian School of Management.

Dolfsma, Wilfred, Seo, Dong Back, 2013. Government policy and technological innovation: a suggested typology. Technovation 33 (6–7), 173–179.

Drazen, Allan, Grilli, Vittorio, 1993. The benefit of crises for economic reforms. American Economic Review 83 (3), 598–607.

Driscoll, John, Kraay, Aart, 1998. Consistent covariance matrix estimation with spatially-dependent panel data. Review of Economics and Statistics 80 (4), 549–560.

Ferejohn, John A., 1974. Pork Barrel Politics: Rivers and Harbors Legislation, 1947–1968. Stanford University Press, Stanford.

Financial Times Deutschland, 2011. Holland's Radical U-Turn on Climate and Energy Policy. February 9, 2011.

Fischer, Carolyn, Newell, Richard G., 2008. Environmental and technology policies for climate mitigation. Journal of Environmental Economics and Management 55 (2), 142–162.

Franchino, Fabio, 2011. Leading and Lagging: Innovation, Delays, and Coalition Politics in the Italian Nuclear Energy Policy. Working Paper. University of Milan.

Fredriksson, Per G., Vollebergh, Herman R.J., Dijkgraaf, Elbert, 2004. Corruption and energy efficiency in OECD countries: theory and evidence. Journal of Environmental Economics and Management 47 (2), 207–231.

Geller, Howard, Harrington, Philip, Rosenfeld, Arthur H., Tanishima, Satoshi, Unander, Fridtjof, 2006. Policies for increasing energy efficiency: thirty years of experience in OECD countries. Energy Policy 34 (5), 556–573.
Gillingham, Kenneth, Harding, Matthew, Rapson, David, 2012. Split incentives in residential energy consumption. Energy Journal 33 (2), 37–62.
Gillingham, Kenneth, Newell, Richard G., Pizer, William A., 2008. Modeling endogenous technological change for climate policy analysis. Energy Economics 30 (6), 2734–2753.
Grossman, Gene M., Krueger, Alan B., 1995. Economic growth and the environment. Quarterly Journal of Economics 110 (2), 353–377.
Hadjilambrinos, Constantine, 1996. Development of renewable energy resources in Greece. Energy Policy 24 (6), 563–573.
Hadjilambrinos, Constantine., 2000. Understanding technology choice in electricity industries: a comparative study of France and Denmark. Energy Policy 28 (15), 1111–1126.
Harris, Jeffrey P., Levine, Mark D., Rosenfeld, Arthur H., 1987. The role of federal research and development in advancing energy efficiency: a $50 billion contribution to the US economy. Annual Review of Energy 12, 357–395.
Harris, R.D.F., Tzavalis, E., 1999. Inference for unit roots in dynamic panels where the time dimension is fixed. Journal of Econometrics 91 (2), 201–226.
Henisz, Witold J., 2000. The institutional environment for economic growth. Economics and Politics 12 (1), 1–31.
Heymann, Matthias, 1998. Signs of Hubris: the shaping of wind technology styles in Germany, Denmark and the United States, 1940–1990. Technology and Culture 39 (4), 641–670.
Ikenberry, G. John, 1986. The irony of state strength: comparative responses to the oil shocks in the 1970s. International Organization 40 (1), 105–137.
Jaffe, Adam B., Stavins, Robert N., 1994. The energy-efficiency gap. Energy Policy 22 (10), 804–810.
Joppke, Christian, 1992–1993. Decentralization of Control in U.S. Nuclear Energy Policy. Political Science Quarterly 107(4), 709–725.
Klaassen, Ger, Miketa, Asami, Larsen, Katarina, Sundqvist, Thomas, 2005. The impact of R&D on innovation for wind energy in Denmark, Germany and the United Kingdom. Ecological Economics 54 (2–3), 227–240.
Laird, Frank N., Stefes, Christoph, 2009. The diverging paths of German and United States policies for renewable energy: sources of difference. Energy Policy 37 (7), 2619–2629.
Lewis, Joanna I., Wiser, Ryan H., 2007. Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms. Energy Policy 35 (3), 1844–1857.
Lizzeri, Alessandro, Persico, Nicola, 2005. A drawback of electoral competition. Journal of the European Economic Association 3 (6), 1318–1348.
Lohmann, Susanne, O'Halloran, Sharyn, 1994. Divided government and U.S. trade policy: theory and evidence. International Organization 48 (4), 595–632.
Margolis, Robert M., Kammen, Daniel M., 1999. Evidence of under-investment in energy R&D in the United States and the impact of federal policy. Energy Policy 27 (10), 575–584.
McCubbins, Mathew D., Schwartz, Thomas, 1984. Congressional oversight overlooked: police patrols versus fire alarms. American Journal of Political Science 28 (1), 165–179.
Mowery, David C., Nelson, Richard R., Martin, Ben R., 2010. Technology policy and global warming: why new policy models are needed (or why putting new wine in old bottles won't work). Research Policy 39 (8), 1011–1023.
Müller-Kraenner, Sascha, 2010. Energy Security: Re-Measuring the World. Earthscan, Sterling.
Nemet, Gregory F., 2009. Demand-pull, technology-push, and government-led incentives for non-incremental technical change. Research Policy 38 (5), 700–709.
Nemet, Gregory F., Kammen, Daniel M., 2007. U.S. energy research and development: declining investment, increasing need, and the feasibility of expansion. Energy Policy 35 (1), 746–755.
Neumayer, Eric, 2003. Are left-wing party strength and corporatism good for the environment? Evidence from panel analysis of air pollution in OECD countries. Ecological Economics 45 (2), 203–220.
Norberg-Bohm, Vicki, 2000. Creating incentives for environmentally enhancing technological change: lessons from 30 years of U.S. energy technology policy. Technological Forecasting and Social Change 65 (2), 125–148.
Olson, Mancur, 1982. The Rise and Decline of Nations: Economic Growth, Stagflation, and Social Rigidities. Yale University Press, New Haven.
Popp, David, 2006. R&D subsidies and climate policy: is there a free lunch?. Climatic Change 77 (3–4), 311–341.
Poterba, James M., 1994. State responses to fiscal crises: the effects of budgetary institutions and policies. Journal of Political Economy 102 (4), 799–821.
Register, 2011. Holland Slashes Carbon Targets, Shuns Wind for Nuclear. February 10, 2011.
Roubini, Nouriel, Sachs, Jeffrey D., 1989. Political and economic determinants of budget deficits in the industrial democracies. European Economic Review 33 (5), 903–938.
Shipan, Charles R., Lowry, William R., 2001. Environmental policy and party divergence in congress. Political Research Quarterly 54 (2), 245–263.
Smith, Michael G., Urpelainen, Johannes, 2013. Why has public R&D on alternatives to fossil fuels decreased in industrialized countries? Environmental Science and Policy 25, 127–137.
Spiller, Pablo T., Tommasi, Mariano, 2003. The institutional foundations of public policy: a transactions approach with application to Argentina. Journal of Law, Economics, and Organization 19 (2), 281–306.
Stenzel, Till, Frenzel, Alexander, 2008. Regulating technological change: the strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets. Energy Policy 36 (7), 2645–2657.
Stigler, George J., 1971. The theory of economic regulation. Bell Journal of Economics and Management Science 2, 3–21.
Stiglitz, Joseph E., Wallsten, Scott J., 1999. Public–private technology partnerships: promises and Pitfalls. American Behavioral Scientist 43 (1), 52–73.
Szarka, Joseph, 2007. Why is there no wind rush France? European Environment 17 (5), 321–333.
Times, New York, 1987. In New Italy Crisis, a Drastic Proposal. February 23, 1987.
Tsebelis, George, 2002. Veto Players: How Political Institutions Work. Princeton University Press, Princeton.
United Press International, 2010. IEA Wants Govts. to Do More on Efficiency. October 11, 2010.
van Rooijen, Sascha N.M., van Wees, Mark T., 2006. Green electricity policies in the Netherlands: an analysis of policy decisions. Energy Policy 34 (1), 60–71.
Weingast, Barry R., Marshall, William J., 1988. The industrial organization of congress: or, why legislatures, like firms, are not organized as markets. Journal of Political Economy 96 (1), 132–163.
Yergin, Daniel, 1988. Energy security in the 1990s. Foreign Affairs 67 (1), 110–132.