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Legislative Fractionalization and Partisan Shifts to the Left Increase the Volatility of Public Energy R&D Expenditures☆

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Abstract

This article shows that legislative fractionalization and leftward (but not rightward) partisan shifts increase the volatility of public R&D expenditures in new energy technologies. We develop a highly accurate estimator for public energy R&D expenditures, and examine deviations from the estimated values using data for member states of the International Energy Agency, 1981-2007. Given that unpredictable fluctuation in public spending on new energy technology reduces the positive effect of such spending on innovation, our empirical analyses imply that countries with fractionalized legislatures can improve the performance of their energy technology programs through institutional mechanisms that reduce the volatility of public spending. Similarly, the results indicate that left-wing and right-wing governments can improve the performance of public technology programs through agreements that distribute gains in such a fashion that partisan shifts do not cause spending cuts. Contravening the conventional wisdom, we also find that public energy R&D is unusually stable in the United States.

Keywords: public energy R&D; volatility; legislative politics

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1. Introduction

According to the International Energy Agency (IEA), there is a "global gap" between current levels of public energy R&D and those warranted by environmental and energy security problems (IEA, 2010). New energy technologies could reduce countries' vulnerability to oil price shocks and mitigate climate change, but governments have not made large investments in new energy technologies. Public energy R&D is important because the private sector does not fully internalize the positive externalities from energy technology innovation (Margolis and Kammen, 1999). While companies can sell new energy technologies for profit, many of the indirect benefits of such technologies cannot be commercialized (Fischer and Newell, 2008). For example, new clean energy technologies such as offshore wind power can help governments mitigate climate change and reduce air pollution. These benefits are public goods, so private companies underprovide them.

The problem of underinvestment is compounded by expenditure volatility. The development of new energy technologies is a long process, and investments begin to produce net profits only after years of R&D (Grübler et al., 1999). Unreliable "boom and bust" technology programs rarely produce substantial social benefits because they are not being implemented in full (Cohen and Noll, 1991). The government invests substantial sums of money in the early years even if the productivity of those investments is limited, and then suddenly reduces funding as the program finally advances towards commercialization. This threat of abrupt termination reduces the effectiveness of technology programs.

Uncertainty also reduces private investors' incentives to participate in technology programs because the availability of future public funding is uncertain (IEA, 2007). A key benefit of public technology programs is that they can leverage complementary private investments, and thus multiply the benefits of the public investment (IEA, 2010). But if private investors do not believe that the program is durable, they have little incentive to invest given the long time from initial research to profitable commercialization (Norberg-Bohm, 2000). If governments are unable to commit to stable technology programs in the long run, how are companies supposed to invest in clean technology innovation?

The United States solar photovoltaics commercialization program offers a useful illustration of the consequences of volatility. Under high oil prices, the size of the program increased from 4.6 in 1974 to 177.0

million dollars in 1980, and then decreased to 46.6 in 1984 (Pelgram, 1991, 326). While the program did reduce the cost of electricity generation from solar photovoltaics, Pelgram (1991, 341-342) argues that the volatility of the budgetary appropriations implies that during rapidly increasing expenditures, "incremental dollars were spent on activities with fairly low productivity ... because it was a long-term program, one would expect that its chance for success would have improved if the boom and bust pattern of the decade after 1975 had been replaced by a smoother path of expenditures."

This article presents a statistical analysis of the causes of energy R&D volatility. Using data on public energy R&D by IEA member states, 1981-2007, we demonstrate that legislative fractionalization (multiple small parties competing for political influence) and shifts to the left in the executive's partisanship contribute to volatility. Consequently, institutional innovations that enable fractionalized governments to credibly commit to a consistent technology policy could help reduce the volatility of public energy R&D. For example, governments in countries with high legislative fractionalization could establish trust funds for technology programs and delegate their governance to independent regulators.

These findings are relevant for policy because both volatility and underinvestment have been common in industrialized countries. Figure 1 shows the total public R&D investment in non-fossil fuel energy technologies in IEA member states, 1976-2007. Public investment reached high levels in the aftermath of the second oil crisis in 1979, but since then the levels have declined. Additionally, the overall levels have shown remarkable volatility, especially during high oil prices in the late 1970's and early 1980's.

The literature on public energy R&D recognizes the problem (Cohen and Noll, 1991; Fuss et al., 2008; Nemet, 2010; Nemet and Kammen, 2007). However, few studies examine the causes of the problem. Cohen and Noll (1991) argue that in the United States, federal technology programs have been volatile because it is difficult for the government and legislators to build a large and stable support coalition for technology programs. Additionally, budget constraints and business cycles prevent the executive and legislature from credibly committing to stable support levels over time. Dooley (1998) argues that deregulation has undermined governments' incentives to invest resources in public energy R&D, but his analysis focuses mostly on levels at the expense of volatility Other than these arguments, the causes of volatility in public energy

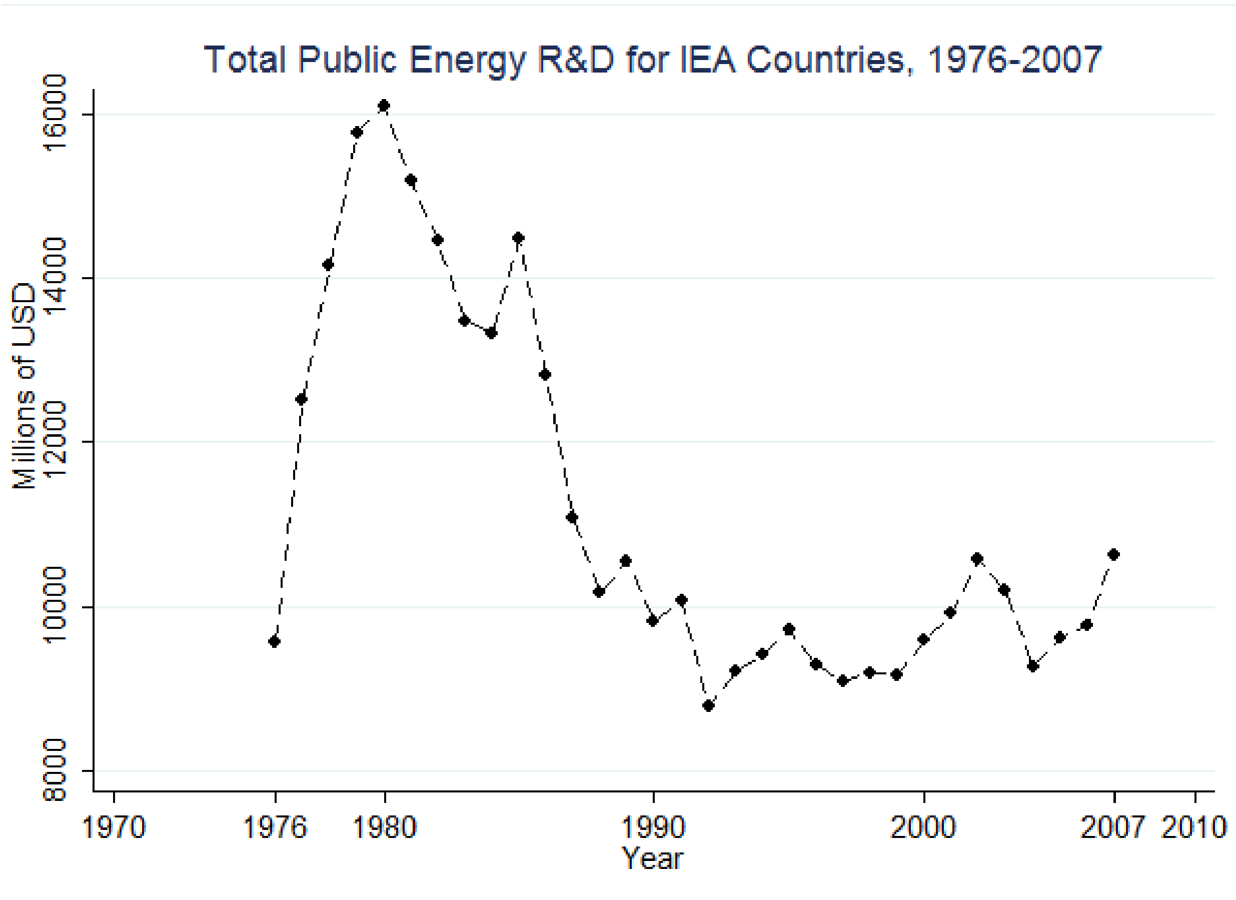

Figure 1: Total public energy R&D in non-fossil fuel energy technologies for 22 OECD countries that are IEA members, 1976-2007. The values are in millions of USD, 2009 constant prices.

R&D remain poorly understood. While volatility has also been an issue in many European economies, such as Germany and Italy, scholars have mostly not analyzed the causes and consequences of volatile research expenditures in other industrialized countries than the United States. This article fills this research gap.

2. Hypotheses

In this section, we offer two preliminary hypotheses on the political causes of volatility. First, we hypothesize that countries with *fractionalized legislatures* are unable to avoid volatility and incredible commitments. Second, *partisan shifts* in the government will also increase volatility due to the ruling coalition's changing

Hypothesis 1. Legislative fractionalization increases the volatility of public energy R&D.

By legislative fractionalization, we refer to a situation wherein multiple small parties in the legislature compete for political influence (Roubini and Sachs, 1989; Nooruddin, 2010). In some countries, governments are often relatively unified because one or two parties possess a clear legislative majority. For example, fractionalization is generally low in the United Kingdom because of the country's two-party system. An example is the 1979 general election, which gave Margaret Thatcher's conservatives a safe majority by 43 seats. Conversely, Italy's fractionalization levels have been generally high. For example, during the 1980-1992 period, Italy was governed by the *pentapartito* coalition of five major political parties. Given the high number of parties, the legislature was highly fractionalized.

Our general premise is that parties with a clear legislative majority can produce new legislation with relative ease. In other countries, multiple small parties compete for political influence and form complex governing coalitions. Consequently, fractionalized legislatures are much less predictable than those characterized by low fractionalization.

Why would legislative fractionalization specifically increase the volatility of public energy R&D? According to previous research, legislative fractionalization reduces the executive's ability to consistently implement useful policies, especially with regard to allocating public expenditures (Alesina and Drazen, 1991; Roubini and Sachs, 1989). Annual budgetary decisions require intensive bargaining, and the political cost of such bargaining is maximized if multiple parties with different interests must find a compromise (Weingast and Marshall, 1988). Given the complexity of such bargaining, it is difficult to predict the level and nature of public energy R&D. Previously funded technology programs may be removed as a concession to their opponents, and new ones may be created to reward their supporters. Previous technology programs may also be canceled or new ones be enacted as part of a larger legislative package.

Hypothesis 2. Partisan shifts increase the volatility of public energy R&D.

By partisan shifts, we refer to changes in the ruling government's partisan ideology. If a leftist party wins the election, so that a left-wing executive replaces a right-wing executive, then a leftward partisan shift has occurred. In democratic countries, such shifts usually stem from an incumbent government's electoral defeat. An example is the Social Democrat Gerhard Schroeder's replacing the Christian Democrat Helmut Kohl as the Chancellor in the 1998 German elections. These shifts are not to be conflated with legislative fractionalization, however, as partisan shifts occur at all levels of legislative fractionalization.

Partisan shifts increase volatility for several reasons. First, partisan ideology influences the government's preferences (Boix, 2000; Garrett, 1998; Potrafke, 2010). If a left-wing government replaces a right-wing government, it may terminate technology programs that the right-wing government supported, such as nuclear research. In Germany, a clear cleavage between the Social Democrats (opponents) and the Christian Democrats (supporters) regarding nuclear power has shaped their policies (Jahn, 1992).[3] Second, both left-wing and right-wing governments may have particular reasons to terminate the previous government's programs. Left-wing governments may oppose subsidies to wealthy high-technology companies, whereas right-wing governments may pursue electoral gains from removing "wasteful" technology programs that the previous left-wing government had enacted.

There are no clear theoretical reasons to expect that leftward and rightward shifts would produce different effects, so we refrain from formulating theoretical hypotheses regarding asymmetric effects. The possibility

[3] In other countries, such as France, this has not been the case (Hecht, 2009).

of such asymmetry is ultimately an empirical question. Below, we show that leftward but not rightward shifts have historically increased the volatility of public energy R&D in industrialized countries.

3. Research Design

Volatility is a difficult analytical concept because it is not directly observable. Therefore, we first have to develop a measure for it. Our approach builds on previous literature. First, we develop an *estimator* for public energy R&D across different countries and over time. Second, we verify that the estimator is an accurate one, so that it correlates very highly with real public energy R&D expenditures. Third, we treat the difference between the estimate and the real data as volatility. Fourth, we examine whether legislative fractionalization and partisan shifts are determinants of such volatility.

In the empirical analysis, we rely on data on public energy R&D expenditures for new (non-fossil fuel) energy technologies from the IEA.[4] The dataset contains annual data on public energy R&D for 16 IEA members and the years 1976-2007. The sectors included in the data are hydroenergy, non-hydro renewables, energy efficiency, nuclear, storage and conversion, and other energy sources. We exclude fuel cells because governments have begun to invest in them only very recently. The data are provided in millions USD using constant 2009 prices. A list of the countries with summary statistics for key variables will be provided below.

From the data analysis, we excluded six of the 22 possible countries. First, we exclude Australia because the country has reported its public energy R&D levels for fewer than ten years. Given this, we cannot estimate the volatility. Second, we exclude five countries – Greece, Ireland, New Zealand, Portugal, and Turkey – because they invest very little in public energy R&D in all years. Given the extremely low investment levels, analyzing volatility in these countries is not relevant for policy formation. To be sure, we also present results for an empirical analysis including all six countries below. From some but not all of the statistical models, we also lose Switzerland because data on partisanship are missing.

We convert the data from total values into per capita values to account for variation in country size. The population data are from the United States Energy Information Administration (EIA) and measured in

[4] See `http://www.iea.org/stats/rd.asp`. Accessed on May 29, 2011.

millions of inhabitants.[5] Therefore, all per capita measures are given in USD with 2009 constant prices.

3.1. Dependent Variable: Volatility

In general, volatility refers to deviations from a stable and smooth pattern of change. Thus, changes in public energy R&D are not equivalent to volatility. Instead, volatility should be regarded as deviations from an expected pattern. How, then, can we develop an accurate estimator for public energy R&D? Our estimator comprises a number of independent variables that we use to predict public energy R&D. First, we include country fixed effects. This variable allows us to capture variation in average investment in public energy R&D across countries. Second, we include the lagged value of public energy R&D to account for temporal trends and the possible stickiness of public energy R&D. Finally, we use oil prices to account for common exogenous shocks that induce demand for new energy technologies, notably alternative energy. For oil prices, we use the price of Saudi light crude oil, measured in constant 2000 USD. This oil price is almost perfectly correlated with alternative measures, such as West Texas or Brent, so the choice of the specific measure is innocuous.

The results of this estimation are reported in Table 1. The model fits the data very well, with an R^2 of 0.92. This statistic states that the model can explain 92 per cent of the variation in the data. The difference between the predicted value and the actual data point – the residual – can then be transformed into a measure of volatility by using the absolute value. Transformed in this fashion, both positive and negative deviations from the trend count as volatility. Notably, the volatility variable is proportional to per capita expenditures in USD with 2009 constant prices. Therefore, our volatility measure has a natural substantive interpretation.

Figure 2 shows the actual public energy R&D for the countries included in the dataset, whereas Figure 3 shows the estimated volatility for the same countries. One particularly notable feature here is the high volatility of the data during high oil prices in the aftermath of the 1979 oil crisis. This observation is reassuring, as it is consistent with the qualitative literature on the volatile nature of energy policy in these years (Cohen and Noll, 1991; Graetz, 2011; Joppke, 1992-1993).

[5] See `http://www.eia.doe.gov/emeu/international`. Accessed on June 3, 2011.

VARIABLES	Energy R&D (pc)
Energy R&D pc (lag)	0.84***
	(0.05)
Oil Price	0.03***
	(0.01)
Country fixed effects	yes
Observations	389
Number of Countries	16
R^2	0.92

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 1: A regression model of per capita public energy R&D that allows the operationalization of volatility. In the empirical analysis to follow, volatility is operationalized for each country-year as the absolute value of the difference between the prediction from this regression model and the actual public energy R&D.

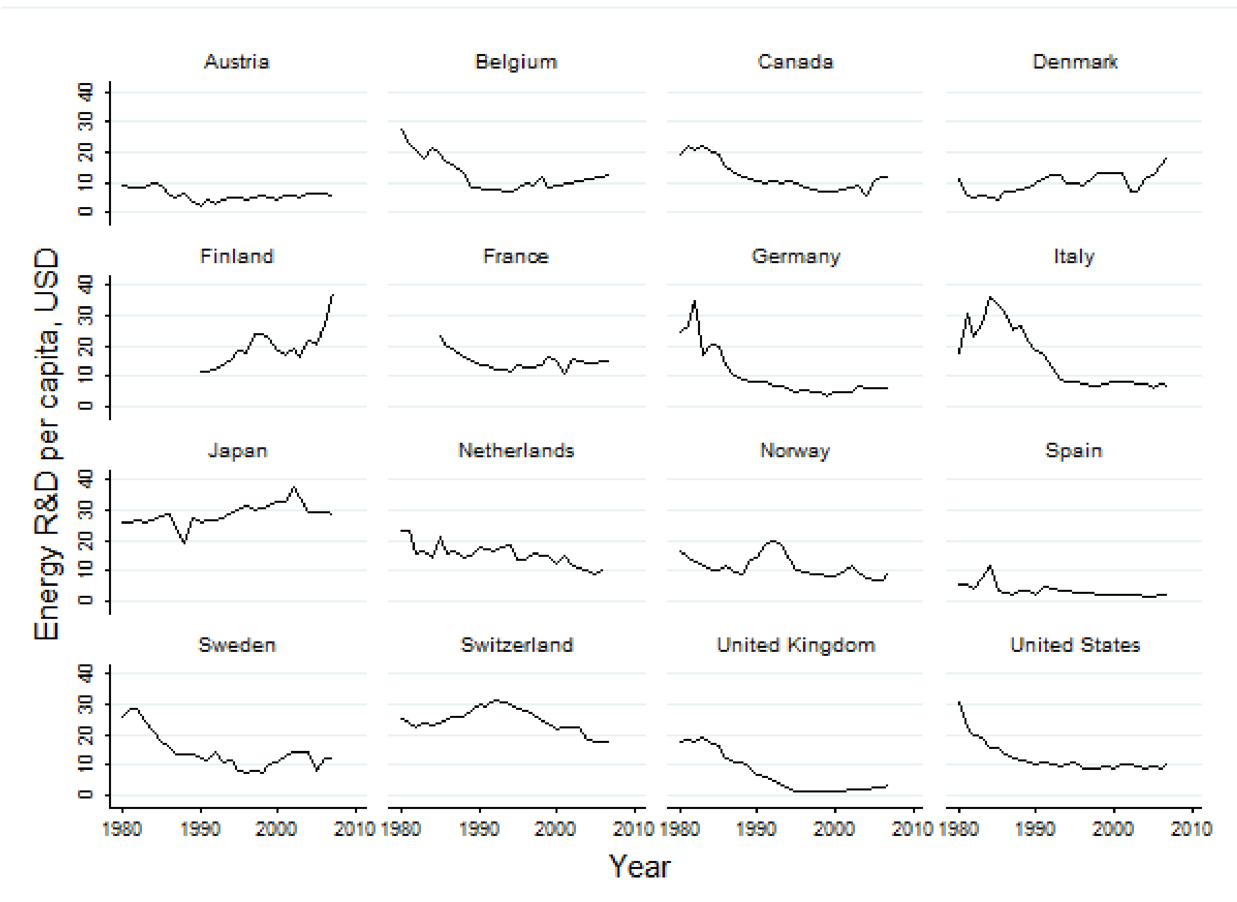

Figure 2: Per capita public energy R&D (USD, 2009 constant prices) for the countries included in the dataset. Switzerland is omitted from some statistical models due to missing data for partisanship.

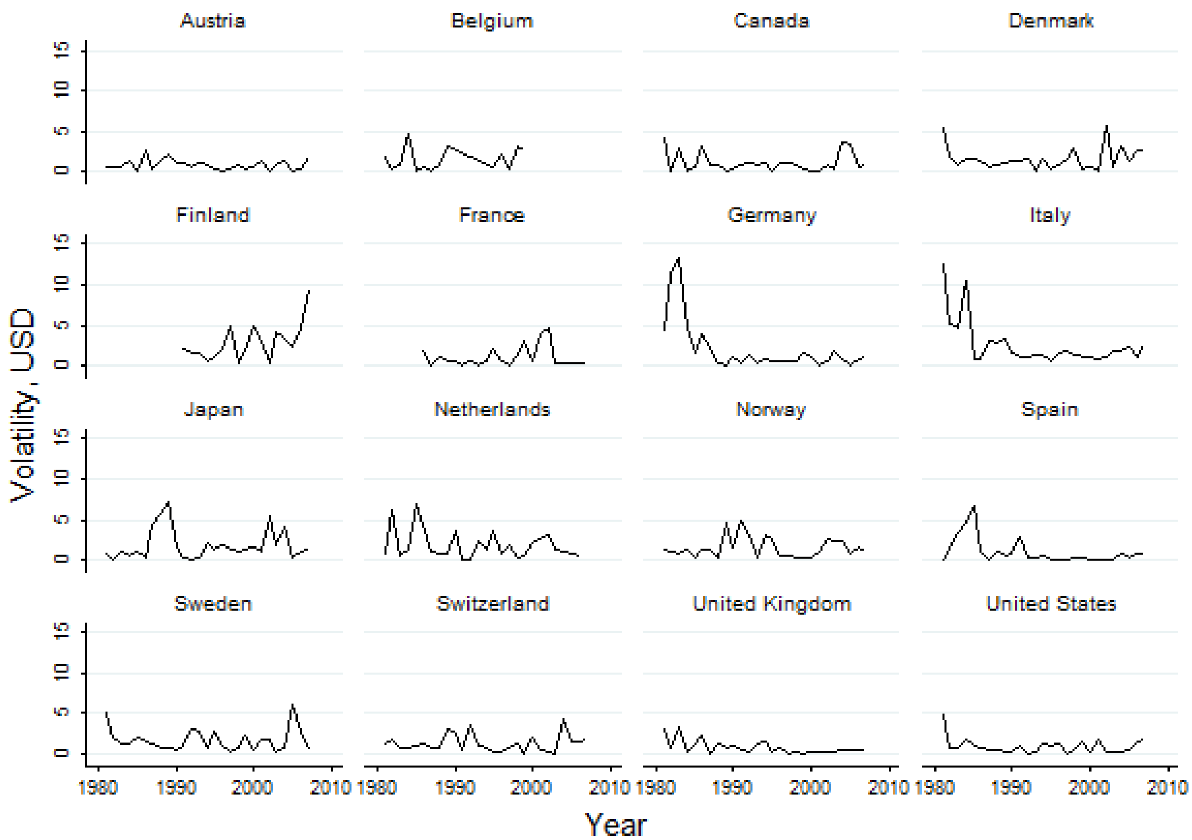

Figure 3: Volatility of per capita public energy R&D (USD, 2009 constant prices) in the countries included in the dataset. Switzerland is omitted from some statistical models due to missing data for partisanship.

To scrutinize the robustness of our estimator, we also added the square of the lagged R&D level in the model. If our current estimator is valid, this addition should not produce very different results. If our current estimator is invalid, perhaps due to nonlinear time effects, it should improve the fit of the regression model. We found that the square term is not statistically significant, and the increase in the R^2 was less than 0.001. Thus, nonlinearity does not seem to be a concern here.

We also considered logarithmizing the per capita values, so as to capture relative instead of absolute volatility. It turned out that the logarithmization results in a highly nonlinear sample, so that a conventional regression method cannot be used. However, we were able to estimate a model that assumes a two-parameter beta distribution.[6] This estimation is provided in the appendix, and it shows that our results are robust.

As another alternative, we also construct an ARCH model that allows us to simultaneously estimate public energy R&D levels and the volatility of these estimates. The ARCH model is more flexible than our primary approach, but it is very difficult to include more than a handful of explanatory variables in the model without causing a convergence failure. Thus, we report results from our primary specification and a simplified ARCH model.

3.2. Explanatory Variables: Legislative Fractionalization, Partisan Shifts

To operationalize legislative fractionalization, we use the legislative fractionalization measure from the Database of Political Institutions (DPI) (Beck et al., 2001). This measure indicates the probability that two randomly chosen legislators are from two different political parties. Thus, it gives a simple and coherent measure for the number of political parties in the legislature. If many small parties compete for political influence, the fractionalization measure obtains a high value. If the number of parties is low, it obtains a low value. To verify the robustness of our results, we also use a government fractionalization measure. It indicates the probability that two randomly chosen legislatures within the government are from two different political parties. Thus, it excludes the opposition.

For partisan shifts we use a measure of partisanship from the DPI. It indicates the partisan orientation of

[6]For details, see Paolino (2001); Ferrari and Cribari-Neto (2004); Smithson and Verkuilen (2006). The model is intended for distributions that fall on the $[0, 1]$ interval, and our logarithmized measure meets this condition. In Stata 12, this model is estimated by the "betafit" command.

the executive: left, centre, or right. A country-year is 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. These measures are converted into partisan shifts as follows. First, a "right shift" occurs if the government's partisanship shifts towards the right from the previous year. Second, a "left shift" occurs if the government's partisanship shifts towards the left from the previous year. Table 2 provides information regarding the dependent variable and the main explanatory variables.

Country	Energy R&D pc	Volatility	Frac	Right	Left	Shift Right	Shift Left
Austria	5.72	0.81	0.64	7	25	2	1
Belgium	14.56	1.49	0.85	31	1	1	1
Canada	11.98	1.12	0.58	10	22	3	2
Denmark	9.93	1.66	0.80	16	16	3	2
Finland	19.51	2.85	0.80	3	17	4	3
France	14.88	1.03	0.68	14	15	8	3
Germany	10.35	2.07	0.68	17	13	4	1
Italy	16.07	2.82	0.67	7	6	5	3
Japan	28.66	1.78	0.64	28	2	3	1
Netherlands	15.61	1.93	0.78	20	11	4	1
Norway	11.37	1.51	0.74	14	17	5	3
Spain	3.46	0.98	0.63	8	16	3	2
Sweden	14.50	1.71	0.73	3	24	4	3
Switzerland	24.7	1.27	0.81	–	–	–	–
United Kingdom	8.07	0.97	0.54	18	13	3	1
United States	12.34	0.92	0.49	18	13	3	2

Table 2: Summary statistics for key variables by country. The cells show mean values, except for the partisan variables they show the number of years with a positive observation.

3.3. Control Variables

To account for possible alternate covariates of volatility, we control in some of our models for additional variables. One set of control variables pertains to the energy sector, and the data are from the EIA. First, energy intensity could reduce volatility if governments have strong incentives to create robust technology programs under wasteful energy use. We thus divide a country's energy consumption by its GDP. Second, hydropower endows a country with a reliable source of electricity at a low variable cost, and this could reduce volatility because large technology programs are rarely needed. We thus divide annual hydroelectricity generation by total electricity generation. Third, nuclear power could also have these effects, so we construct a similar variable for nuclear electricity generation. Finally, we include the price of Saudi light crude oil to account for the possibility that high oil prices create boom and bust cycles in technology programs.[7]

Another set of control variables pertains to the economy. These variables are from the OECD and the World Development Indicators (WDI). First, we include GDP per capita to account for the possibility that wealthy countries are less frugal with regard to public energy R&D, and thus volatility would increase (WDI). Second, we account for trade openness – the sum of imports and exports divided by GDP – because export-oriented economies could initiate large technology programs for export promotion purposes (WDI). Third, we include the share of heavy industry of total GDP to account for the possibility that the industrial sector is able to lobby for large technology programs that increase the total volatility of public energy R&D (OECD).

Next, we include year fixed effects to account for common exogenous shocks that the oil price variable fails to capture.[8] For example, year fixed effects capture common shocks in the energy issue area, such as the 1986 Chernobyl nuclear accident. Summary statistics are reported in Table 3.

We also estimate a model that adds a categorical control variable for the level of public energy R&D in a country. It seems natural to expect that large spenders also see more volatility. However, we cannot include the level itself in the regression because it is correlated with the volatility measure by definition. Thus, we create a categorical variable that measures whether a country-year is in the first, second, third, or fourth quartile of per capita R&D in the total dataset. The variable ranges from 0 to 4. This categorical variable allows us to account for the effect of level on volatility.

Finally, in one model we include total R&D expenditures as a share of GDP, as reported in the OECD Main Science and Technology Indicators. We do not include this variable in all of the specifications because we would lose approximately 40 observations due to missing data.

[7]Given that we include the oil price both in the estimator of public energy R&D levels and the volatility model, we also verified that our results hold if we instead use a simple categorical variable that codes oil prices as very low, low, high, and very high.

[8]We do not include country fixed effects because one of our main variables, legislative fractionalization, varies much more across countries than over time. In some of the models, however, we use a random effects specification.

	N	Mean	Std. Dev.	Min	Max
Energy R&D pc	412	13.75	8.25	1.03	37.71
Volatility	389	1.52	1.79	0	13.44
Fractionalization	496	0.69	0.11	0.41	0.90
Shift Left	506	0.06	0.23	0	1
Shift Right	506	0.17	0.38	0	1
Partisanship	463	0.01	0.96	-1	1
Energy Intensity (log)	436	8.77	0.35	8.06	9.74
Nuclear Share	437	0.24	0.21	0	0.79
Hydro Share	437	0.28	0.30	0	1
Oil Price	448	24.48	10.48	10.03	55.94
GDP pc (log)	506	9.97	0.31	9.07	10.65
Trade / GDP	506	33.37	16.26	7	89
Heavy Industry	469	14.00	3.54	5.96	22.44
Energy R&D pc(categorical)	506	2.50	1.12	1	4
Other R&D / GDP	373	1.94	0.67	0.40	4.13

Table 3: Summary statistics for the regression analysis of volatility.

3.4. Findings

The results are reported in Tables 4, 5, and 6. The first table presents the five primary models that we use. The only difference between them is the choice of control variables. The second table shows the coefficients for the primary explanatory variables for six additional models based on model (3) in the previous table: random effects, using government instead of legislative fractionalization, with bootstrapped standard errors; including the six initially excluded countries; excluding the years 2005-2007; excluding the years 1981-1984. The third table presents an alternative estimation of volatility using an ARCH model with an AR(1) correction for serial correlation. This alternative model allows us to directly estimate the volatility of the public energy R&D instead of constructing an *a priori* indicator such as the one describe above (see appendix for a full description).[9] Thus, it allows us to scrutinize the robustness of our empirical findings.

The results show that both fractionalization and leftward partisan shifts have strong and statistically consistent positive effects on volatility. Fractionalized legislatures produce less reliable public energy R&D expenditures with substantial fluctation from one year to the next, and leftward shifts in partisanship have similar effects. The only exception to this robust result is the ARCH model for leftward partisan shifts. Here

[9]The selection of variables is guided by the statistical requirement of convergence. We included as many variables as possible without causing the model not to converge.

VARIABLES	(1) Volatility	(2) Volatility	(3) Volatility	(4) Volatility	(5) Volatility
Fractionalization	3.34***	3.35***	5.41***	4.87***	3.42***
	(0.75)	(0.83)	(1.29)	(1.40)	(1.09)
Shift Left	0.90**	1.02**	0.99**	1.05**	1.05**
	(0.41)	(0.38)	(0.39)	(0.42)	(0.42)
Shift Right	0.89	0.45	0.41	0.35	0.15
	(0.57)	(0.33)	(0.33)	(0.39)	(0.45)
Partisanship	-0.14	-0.14	-0.11	-0.09	-0.07
	(0.10)	(0.09)	(0.10)	(0.11)	(0.12)
Energy Intensity (log)		0.02	0.43	0.18	-0.16
		(0.38)	(0.25)	(0.31)	(0.29)
Nuclear Share		-0.31	-0.77	-0.99*	-1.16***
		(0.33)	(0.54)	(0.50)	(0.26)
Hydro Share		-0.48	-0.40	-0.25	-0.04
		(0.32)	(0.34)	(0.40)	(0.32)
Oil Price		-0.00	0.00	-0.00	0.00
		(0.01)	(0.01)	(0.01)	(0.01)
GDP pc (log)			-0.07	-0.82	-1.17**
			(0.56)	(0.49)	(0.49)
Trade / GDP			-0.02*	-0.01	-0.01
			(0.01)	(0.01)	(0.01)
Heavy Industry			0.05	0.01	0.00
			(0.03)	(0.04)	(0.04)
Other R&D / GDP				0.42	0.29
				(0.25)	(0.24)
Energy R&D pc (categorical)					0.41***
					(0.10)
Constant	-1.49**	-1.32	-5.56	3.92	10.84
	(0.68)	(3.82)	(6.07)	(5.95)	(6.74)
Year fixed effects	yes	yes	yes	yes	yes
Observations	346	336	334	298	298
R^2	0.19	0.20	0.22	0.24	0.28
Number of countries	15	15	15	15	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Empirical results. This table shows the three main models.

	Random Effects	Gov. Frac.	Bootstrap
Fractionalization	5.41***	1.57**	1.57***
	(1.25)	0.57	(0.47)
Shift Left	0.99***	0.76**	0.76**
	(0.38)	(0.34)	(0.35)
Shift Right	0.41	0.22	0.22
	(0.37)	(0.28)	(0.32)
R^2	0.22	0.20	0.20

	All Countries	1981-2004	1984-2007
Fractionalization	4.95***	5.26***	4.35***
	(1.28)	1.43	(0.79)
Shift Left	0.76**	1.23**	1.07*
	(0.32)	(0.46)	0.55
Shift Right	0.23	0.45	0.48
	(0.27)	(0.36)	(0.37)
R^2	0.21	0.23	0.21

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Empirical results. This table table shows the regression output excluding the coefficients for control variables and the number of observations.

the coefficient is very close to zero and not statistically significant.

Why do leftward partisan shifts have large effects on volatility, whereas rightward shifts do not? One possible explanation is that while left-wing governments have incentives to initiate large technology programs given their willingness to increase public spending to correct market failures, they could also be particularly willing to reduce public energy R&D by terminating previous technology programs upon replacing a right-wing government.

The following example illustrates the role of legislative fractionalization and leftward partisan shifts. In August 1983, the head of the Italian Socialist Party, Beneditto "Bettino" Craxi, began his term as the Prime Minister of Italy. This was a clear example of leftward shift because the previous Prime Minister, Amintore Fanfani, whose term lasted less than a year, was the leader of the Christian Democrats. Additionally, Craxi's tenure was characterized by high levels of legislative fractionalization. The government was based on the *pentapartito*, an alliance of five parties: Christian Democrats, the Italian Socialists, the Italian Democratic Socialists, the Italian Republicans, and the Italian Liberal Party. With five parties holding very different preferences in the legislature, Craxi was forced to forge compromises to retain his rule and implement new

VARIABLES	(1) Energy R&D pc	(2) HET
Energy R&D pc (lag)	0.14***	
	(0.01)	
Fractionalization		3.72***
		(0.11)
Shift Left		-0.08
		(0.39)
Shift Right		0.01
		(0.51)
Partisanship		-0.15
		(0.15)
Energy Intensity (log)	6.84***	-0.02
	(2.17)	(0.02)
Nuclear Share	-1.23	-0.76
	(2.82)	(0.75)
Hydro Share	1.06	-0.07
	(2.02)	(0.36)
Oil Price	0.02**	0.03***
	(0.01)	(0.01)
Constant	-49.06***	-3.44***
	(18.33)	(0.06)
AR(1)	0.99***	
	(0.01)	
ARCH		0.30**
		(0.12)
Year fixed effects	no	no
Observations	336	336
Number of countries	15	15

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Empirical results. This table shows the estimation of the ARCH model. In this model, the column HET indicates the effect of a variable on volatility.

policies.

While the Socialist Party's position on nuclear power had been ambivalent during the elections, Craxi emphasized the importance of ambitious investment in nuclear research (Franchino, 2011, 15). According to our statistical model, the early years of Craxi's tenure were characterized by exceptionally high volatility. In October 1983, the government approved a new program on "research on nuclear fusion, fulfilling an electoral pledge of the Socialist Party" (Franchino, 2011, 15). Indeed, our data show that the 1984 budget allocated almost two billion dollars to energy research, a 500 million increase from the Christian Democrats' 1983 budget. Of the two billions, more than 1.6 billion dollars were allocated to nuclear research. However, by 1987, in Craxi's last budget, funding for nuclear research had again fallen to less than 900 million dollars while the total energy budget fell to 1.4 billion dollars. One of the *pentapartito*'s failures was energy policy, as the government failed to "design workable energy policies in the face of resistance to nuclear power."[10] This case, then, illustrates a leftist government's aggressive but temporary investment in energy research based on an earlier electoral promise. Perhaps due to the 1986 Chernobyl accident and the declining popularity of nuclear power in Italy, the fractionalized and internally divided ruling coalition's emphasis on energy research did not last more than three years.

Figure 4 shows for each country the mean volatility as a function of mean fractionalization. This figure shows that the statistical result is not a mathematical artifact. Mean volatility increases rapidly with fractionalization. A particularly interesting finding pertains to the fact that the United States actually has an unusually low level of volatility. Even though the country has reduced public energy R&D spending over time, it has done so in a relatively consistent fashion. The only exception to this rule are the first years in the aftermath of the 1979 oil crisis. This, we note, cuts against the conventional wisdom: according to Laird and Stefes (2009, 2626), in the United States "sharp conflicts between the executive and legislative branches mean that outside groups cannot predict where the policy is going to go." Our empirical analysis shows that this is not true: the United States has the lowest volatility among OECD countries. The real problem for the United States is the low per capita level of spending, not volatility.

[10] "In New Italy Crisis, a Drastic Proposal" *New York Times* on February 23, 1987.

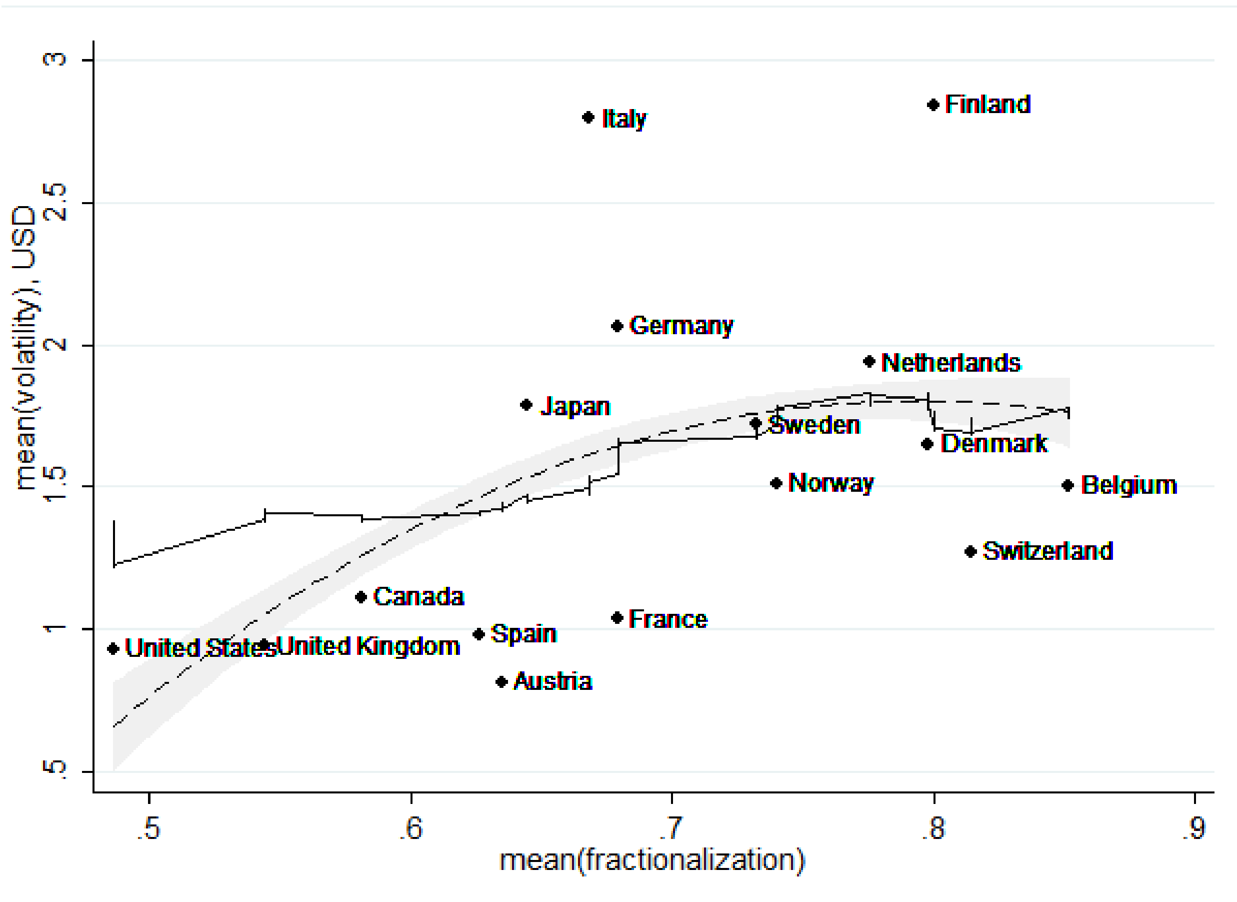

Figure 4: Average volatility of per capita public energy R&D in a country as a function of average fractionalization in the legislature. The figure shows the quadratic fit and the 95 per cent confidence intervals (dashed line), as well as the lowess estimator (solid line).

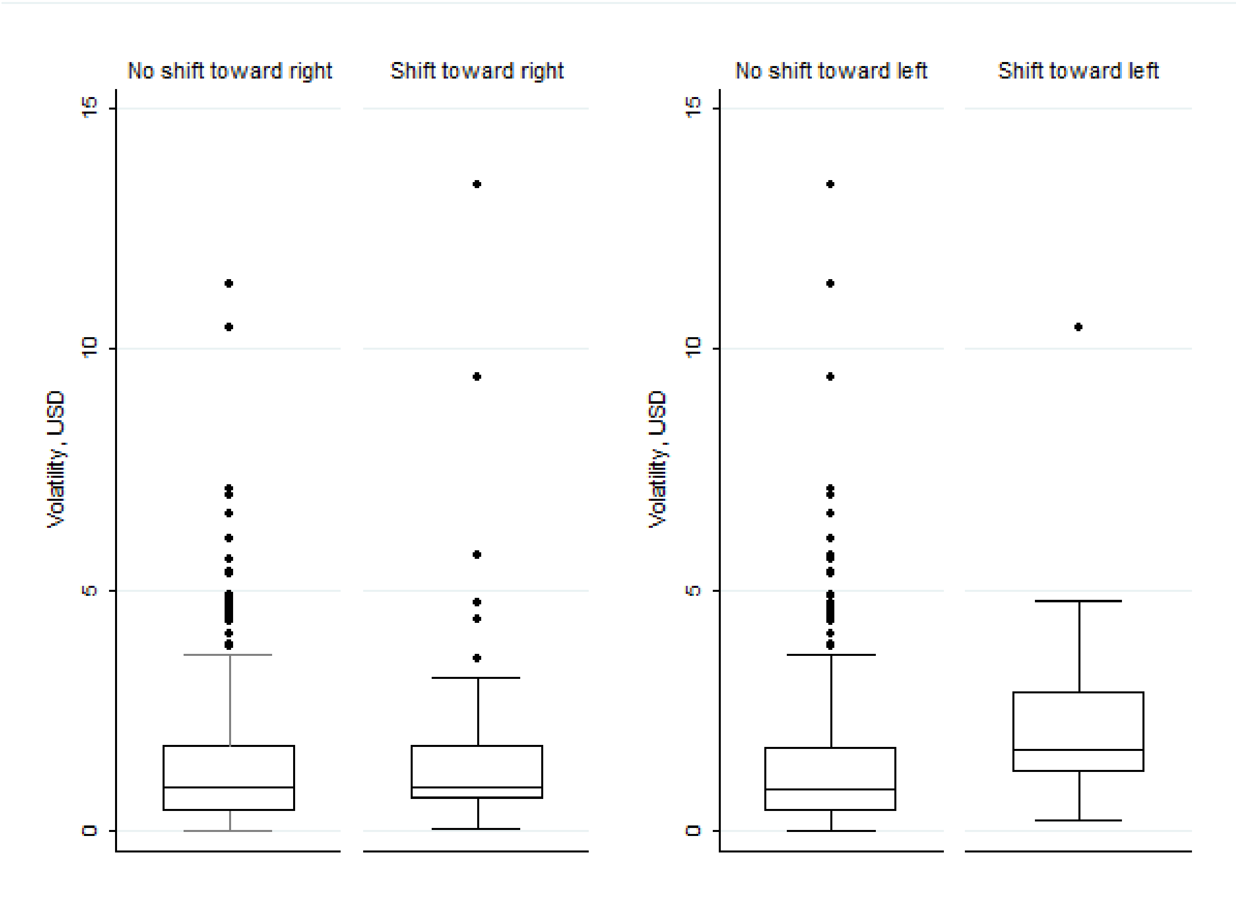

Figure 5: Volatility of per capita public energy R&D as a function of shifts in the government's partisanship.

Figure 5 illustrates the effects of partisan shifts on volatility in the data. It shows that the median volatility is much higher under leftward shifts than without them, and that a similar effect does not exist for rightward shifts. Interestingly, though, the largest individual observations of volatility do not correspond to leftward shifts. This is mostly due to the relatively low number of leftward shifts in the data.

Regarding other volatility influences, the year fixed effects reveal an interesting pattern. Of them, the following years were statistically significant: 1981, 1983, 1986, and 1989. Of these, 1986 was the year of the Chernobyl nuclear accident. Unsurprisingly, the volatility of public energy R&D increased temporarily at that time. The years 1981 and 1983 capture the salience of energy policy following the 1979 Iranian revolution and the unusually high oil prices.

3.5. Robustness

To examine the robustness of our findings, in addition to the models presented above we estimated additional regressions. First, we included a measure of political corruption from the *International Country Risk Guide* to account for the possibility that volatility is influenced by the difficulty of competent implementation. This variable did not have a statistically significant effect on volatility in our models, and all our main results continue to hold. Second, we included a country's population to account for the possibility that small countries are more volatile due to the smaller absolute size of their technology programs. This variable also did not have a statistically significant effect on volatility, and the results continue to hold. Third, we removed year dummies from the estimations. We found that oil prices now have a statistically significant and positive effect on volatility, and all our results continue to hold. Finally, we estimated our models without the partisanship variables to capture Switzerland. The effect of fractionalization remained positive and statistically significant.

4. Conclusion

This article has shown that legislative fractionalization and leftward partisan shifts increase the volatility of public energy R&D. As such, the article offers two primary contributions. First, the results are highly relevant to policy formation. They indicate that countries with fragmented legislatures and governments can enhance the reliability and consistency of their technology programs by developing institutional responses to the problem of policy gridlock in the presence of multiple small parties. For example, these countries could increase the delegation of authority to bureaucracies and create long-run technology programs with capital endowments that allow them to survive changes in the composition of the government. For left-wing governments, the results highlight the importance of developing political countermeasures against technology policy volatility in the early years of their tenure. For example, left-wing governments and right-wing governments could agree to implement technology programs that help them realize joint political gains. Such programs would be less vulnerable to partisan shifts, and the partisan agreement could be made credible through a public declaration and legislation to increase the consistency and resilience of long-run technology programs.

The second contribution pertains to methodology. The estimation of volatility presents a major empirical challenge, yet the importance of applied research on volatility is difficult to overestimate in an era of unprecedented volatility in such factors as global commodity prices and technology policy. We have provided in this article a simple, easily replicated, and robust estimator of volatility. Our empirical results on the determinants of the volatility of public energy R&D testify to the value of this estimator.

Appendix A: Logarithmized Per Capita Public Energy R&D

Table 7 summarizes the prediction regression when we use the natural logarithm of the per capita public energy R&D instead of the raw value. Table 8 shows the volatility estimates using the beta regression. The coefficients are as expected. Note that the coefficient for Φ is used to characterize the estimated beta distribution.

VARIABLES	Energy R&D pc (log)
Energy R&D pc (log, lag)	0.869***
	(0.032)
Oil Price	0.003***
	(0.001)
Constant	0.126*
	(0.074)
Country fixed effects	yes
Observations	389
Number of countries	16
R^2	0.93

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 7: A regression model of the natural logarithm of per capita public energy R&D. This model is used to construct our volatility measure.

VARIABLES	Volatility
Fractionalization	0.88*
	(0.50)
Shift Left	0.32**
	(0.15)
Shift Right	0.16
	(0.19)
Partisanship	-0.14*
	(0.08)
Φ	6.92***
	(1.28)
Constant	-2.50***
	(0.43)
Year fixed effects	yes
Observations	346
Number of countries	15

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 8: Estimation of the main model using the natural logarithm of per capita public energy R&D and a two-parameter beta distribution.

Appendix B: ARCH Model

In Table 6 we estimate a heteroskedastic regression, i.e. a regression with a separate equation for the variance of the errors. Then we model the variance of the errors as a function of our two main independent variables, fractionalization and partisan shift toward left. By doing so, we do not construct a *measure* of volatility ex ante, but we jointly estimate the level of the dependent variable (public energy R&D expenditure per capita) and the variance in the errors of the model. Using the resulting estimates, we can test our hypotheses about the sources of volatility, i.e. sources of variability in the error process. Such an approach has two main advantages. First, it is relatively simple to implement. Second, it is very flexible since it does not use any *a priori* measures of volatility but instead allows the data to speak for themselves.

We implement this test using an ARCH1 approach that is one particular variation in the GARCH family of models. ARCH1 implies that we are able to detect large errors between times t and $t-1$. Moreover, we allow for first-order autoregressive-conditional heteroskedasticity (AR1) in the variance equation to account for temporal dependence. As we did in previous estimation, we use robust standard errors. Formally, we estimate the following model:

$$\begin{aligned} EnergyRDpc_{it} &= \beta_0 + \beta_1 OilPrice_{it} + \beta_2 ln(EnergyInt)_{it} + \qquad (1) \\ & \quad \beta_3 NuclearShare_{it} + \beta_4 HydroShare_{it} + \beta_5 \sigma^2_{it} + \epsilon_{it} \\ \sigma_{it} &= exp(\alpha_0 + \alpha_1 Frac_{it} + \alpha_2 ShiftLeft_{it} + \alpha_3 ShiftRight_{it} + \qquad (2) \\ & \quad \alpha_4 Partisanship_{it} + \alpha_5 ln(EnergyInt)_{it} + \\ & \quad \alpha_6 NuclearShare_{it} + \alpha_7 HydroShare_{it} + \alpha_8 OilPrice_{it}), \end{aligned}$$

where i denotes country and t denotes year. A high value of σ^2 indicates a high volatility, as shown in the column HET in Table 6. We estimate this model using the Stata command ARCH. With all covariates included, the model does not converge even after 1,000 iterations. Therefore, we dropped the minimal number of control variables that is necessary to achieve convergence. Using this conservative approach, our model converges already after 39 iterations.

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