Social Rate of Return to R&D on Various Energy Technologies: Where Should We Invest More? A Study of G7 Countries

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Highlights

- Allocation of R&D funding in various energy technologies is a challenging task.
- This can be done by estimating the social rate of return for R&D investments
- We investigate various technologies' social rate of return for the G7 countries.
- R&D funding yields social benefits from energy efficiency and nuclear technologies.
- R&D investment on fossil fuels has negative social rate of return.

Abstract

The importance of investment in Research and Development (R&D) in the energy sector is undisputable especially considering the benefits of new technologies to sustainability, security and environmental protection. However, the nature and potential of various energy technologies that are capable of improving the energy and environmental conditions globally is a challenging task for governments and policy makers that have to make decisions on the allocation of funds in R&D. To do so, the optimal resource allocation to R&D should be determined by estimating the social rate of return for R&D investments. This paper aims to estimate the social rate of return of R&D on various energy applications and technologies such as energy efficiency, fossil fuels, renewable energy sources, and nuclear for the G7 countries. The results show that primarily R&D investment on Energy Efficiency technologies and Nuclear are the ones that yield high social benefits for all G7 countries while exactly the opposite holds for Fossil fuels.

Keywords: R&D; Energy; Energy fuels; return; G7

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1. Introduction

The severity of investment in Research and Development (R&D) in the energy sector is indisputable especially considering the benefits of new technologies to sustainability, security and environmental protection. Wong, Chang and Chia (2013) have shown that fossil fuel R&D drives economic growth in the OECD countries more than actually the fossil fuels consumption does. However, the nature and potential of various energy technologies that are capable to improve the energy and environmental conditions globally is a challenging task for governments and policy makers that have to make decisions on the allocation of funds in R&D. To do so, the optimal resource allocation to R&D should be determined by estimating the social rate of return for R&D investments.

Theoretical and empirical literature has illustrated the central role of R&D as a significant contributor to growth and development. Primarily empirical studies have estimated the rate of return to R&D in regressions of productivity growth on measures of R&D such as R&D intensity (Grilliches, 1994; Jones and Williams, 1998; Corderi and Lin, 2011). Although, different studies accounted for various spillovers consensus has been reached that the social rate of return of R&D is positive, differs in size among countries and remains significantly above private rates (Corderi and Lin Lawell (2016). Tirole (2001) explain why the private rate of return diverge from the socially optimal rate of R&D: firstly the private sector might under-invest in R&D because there are positive spillovers included and secondly, when perfect price discrimination does not exist the social surplus from innovation is higher than the private one.

In the international context of climate change, fossil fuel dependence, high energy prices and lack of energy sustainability, there are good reasons to draw attention to the returns of R&D on energy technologies and innovations, especially due to the important role energy research plays to the future energy supply, security and sustainability (Vattenfall, 2011).

Bointner (2014) argues that between the two major sources of learning, namely learning by doing and learning by researching (Garrone and Grilli, 2010), the energy R&D is subject to the latter. He then continues in explaining the "four grand patterns of energy technological change" as discussed in Grubler et al. (2012): "…namely (a) clustering of related technologies and technology spillovers prevail over stand-alone technologies; (b) the ability to perform a novel energy service is more important than the cost of a new, immature technology; (c) energy supply follows demand, which is given by the available end-use applications; and (d) a low rate of technology diffusion" (Bointener, 2014). However, Sterlacchini (2012) stressed a staggering decline of energy R&D during the last two decades, due to reforms and restructuring of electricity markets.

However, the R&D spending on energy is broad. The International Energy Agency (IEA) has classified the energy R&D in seven categories according to the technologies and innovations. Table 1 presents the share of these categories in each of the country's total R&D expenditures on energy. It can then be seen that the great majority of the energy R&D in all countries is spent on the nuclear sector, while the cross-country variation of the rest of the energy R&D categories is high.

Table 1: Share of the different R&D Categories to total Energy R&D (%) (average for 1985-2012)

Categories	Canada	France	Germany	Italy	Japan	UK	US
Category 1 Energy Efficiency	14.976	6.318	6.715	14.660	7.814	10.165	15.399
Category 2 Fossil fuels	29.858	10.675	7.742	2.985	9.543	10.442	15.292
Category 3 Renewable energies	8.185	4.400	23.834	12.312	4.855	20.149	10.512
Category 4 Nuclear	35.316	75.184	48.719	39.429	71.559	43.008	23.026
Category 5 Hydrogen and fuel cells	7.038	4.661	5.155	3.290	4.905	5.092	6.322
Category 6 Other power and storage technologies	4.252	0.562	3.736	13.938	2.841	3.838	4.073
Category 7 Other cross cutting technologies	5.151	1.032	7.597	15.622	1.935	10.760	29.665
Statistical differences	-4.776	-2.830	-3.498	-2.237	-3.452	-3.456	-4.290
Total	100	100	100	100	100	100	100

Source: International Energy Agency (IEA, 2014).

This paper aims to estimate the social rate of return of R&D on various energy applications and technologies such as energy efficiency, fossil fuels, renewable energy sources, and nuclear for the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom, United States) by using panel data estimations (primarily fixed effects). As used mostly in the literature (Jones and Williams, 1998; Corderi and Lin, 2011, Corderi and Lin Lawell, 2016), we will quantify the impact of lagged R&D intensity to TFP of the countries. More particularly, the paper can be considered an extension of the thinking process of Corderi and Lin (2011) by using the same methodology. The paper by Corderi and Lin (2011) quantifies the contribution of lagged R&D (totally on energy applications) on TFP growth in specific sectors of the manufacturing industry for a number of OECD countries. This paper here aims at disaggregating the energy R&D into different categories while estimating its contribution (lagged) to the total TFP of the economy. All in all, while Corderi and Lin (2011) disaggregate the effect to various sectors, here, this paper disaggregates the energy R&D in different categories. Energy R&D data will be derived from the IEA databases while economic data will be provided primarily by the OECD STAN database. All in all, this paper's purpose is to identify which of these energy technologies yield a higher social rate of return of R&D (if any) and make important policy recommendations.

2. On the importance of R&D on energy

Most probably the most important aspect of R&D is the end-product of the R&D activity that creates new knowledge and innovations, as well as the economic and social impacts of the actual R&D activity (OECD, 2002). According to Frascati Manual (OECD, 2002: p30):

"*Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications".*

R&D efforts are evaluated by the use of various indicators of input to the activity, such as R&D personnel, and R&D expenditures, and output, such as the bibliometrics, scientometrics and trade data. However, Griliches (1979) points out that the real contribution to the knowledge stock and improved human capital of an economy due to the R&D activities is difficult to be quantified.

The topic of R&D and its contribution to the socioeconomic conditions of a country is not new in the literature. Early contributions in the literature include work by Nelson (1959), Arrow (1962), and Griliches (1979). Most recent empirical studies (Grilliches, 1994; Jones and Williams, 1998; Corderi and Lin, 2011) have estimated the rate of return to R&D in regressions of productivity growth on measures of R&D such as R&D intensity (Grilliches, 1994; Jones and Williams, 1998; Corderi and Lin, 2011). Also studies like Ho et al. (2009) and Bayarcelik and Tasel (2012) explored the effects of R&D on economic growth using the endogenous growth framework, for Turkey and Singapore respectively; while Gyeke et al. (2012) investigated the contribution of R&D activities and innovation on the economic growth of Sub-Saharan Africa (SSA).

It should be noted here that studies focusing on funding directed on energy R&D activities are rare and focusing primarily on developed economies. The reason for that is not only data availability but also, almost 85-90% of world’s energy R&D is conducted in the world’s richest nations (Breyer et al. 2010) Recently, Corderi and Lin (2011) estimated the social rate of return to R&D in the energy manufacturing industry for a group of OECD countries. They quantified the impact of lagged R&D on total factor productivity (TFP) using a panel of data. Their results show that R&D had a positive and significant rate of return with a different magnitude for the various countries.

3. Methods and data

In this study we follow a similar theoretical framework as Corderi and Lin (2011), adopted from Jones and Williams (1998). A Cobb-Douglas production function is adopted in this analysis of the form:

$$Y_t = e^{\mu t} Z_{t-1}^{\gamma} K_t^{\alpha} L_t^{1-\alpha} \qquad (1)$$

$$\dot{Z}_t = R_t \qquad (2)$$

Where Y is the output produced, Z is the R&D expenses, K is the capital, L is the labor and R is the expenditures in R&D. Equation (2) shows no depreciation of stock.

In a growth accounting exercise, we derive the relationship between TFP and R&D:

$$TFP_t = \frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}} \qquad (3)$$

Equation (3) can finally be transformed in:

$$\Delta \ln(TFP_t) = \mu + \tilde{r}\frac{R_{t-1}}{Y_{t-1}} + \varepsilon_t \qquad (4)$$

Where $\tilde{r} = \left(\frac{dY}{dZ}\right)$ is the rate of return to R&D. As can be shown in equation (4), TFP is regressed on the R&D share of output lagged by one period. As Jones and Williams (1998) mention, if the coefficient $\tilde{r}$ is measured at the industry level, it represents the social rate of return.

The data used are derived primarily from the International Energy Agency (IEA) database "Energy Technology RD&D budgets" (R&D expenditure of seven energy categories in million USD constant 2005 prices),[1] the OECD STAN database (Gross capital formation as a proxy for capital stock per country and Gross Domestic Product for each country in USD constant 2005 prices) and the World Development Indicators of the World Bank (labour compensation as a proxy to labour per country in share of labour to income) for the G7 countries during the period from 1985 to 2012. The group of countries was selected because according to Corderi and Lin (2011) these countries conduct on average 88% of the energy R&D in the OECD countries.

Table 2 shows the gross domestic product (GDP) and R&D expenditures in the seven countries as well as their relative size to the country group in percentages. In both indicators, it can be seen that US has the highest share in the sample while Japan follows suit in the G7 group.

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[1] Descriptive statistics of the data on the seven energy R&D categories can be found in Appendix Table A2.

Table 2: Descriptive statistics

	Size in terms of total R&D in energy (US dollars millions, 2005 constant prices)	**Relative size to the G7 group (%)**	**Size in terms of GDP (US dollars millions, 2005 constant prices)**	**Relative size to the G7 group (%)**
Canada	520.024	4.844	982145.345	4.329
France	976.124	9.093	1687321.462	7.437
Germany	660.136	6.150	2454303.972	10.818
Italy	732.646	6.825	1547616.286	6.822
Japan	3470.010	32.326	3538803.193	15.598
UK	311.286	2.900	1757612.186	7.747
US	4064.117	37.861	10719327.596	47.248
Total	10734.342	100	22687130.041	100

4. Empirical results

The model specification has a regression equation of the form:

$$\Delta \ln(TFP_{it}) = \mu_i + \tilde{r}_i(RDint)_{it-1} + \beta Period_t + \varepsilon_{it} \qquad (5)$$

Where TFP is the total factor productivity for each of the countries i in each growth rate (differenced natural logs); RDint is the R&D intensity (lagged 1 period) defined as the ratio of R&D expenditures to value added in each country; μ is the country fixed effects and ε_{it} is the error term which is assumed to be heteroskedastic (by country) and serially uncorrelated. The parameter $\tilde{r}_i$ is the one to be of interest here since it is denoting the country-specific social rate of return of each of the categories of energy R&D. Following Corderi and Lin (2011), "we used fixed effects rather than random effects panel estimation model since we believe that time – invariant country-level unobservables are potentially correlated with some of the regressors" (Corderi and Lin, 2011: 2782).

The dependent variable as seen in equation (5) is growth in total factor productivity and the regressor is the lagged R&D intensity. The White's robust error variance estimation procedure is used accounting for the possibility of heteroskedastic errors. Table 3 presents the social rate of return to the various categories of energy R&D[2].

Table 3: Social rate of return estimates by country (percent)

	Category 1	**Category 2**	**Category 3**	**Category 4**	**Category 5**	**Category 6**	**Category 7**
	Energy Efficiency	**Fossil fuels**	**Renewable energies**	**Nuclear**	**Hydrogen and fuel cells**	**Other power and storage technologies**	**Other cross cutting technologies**
Canada	1.423	-0.635	-2.082	3.640	-25.259	-1.590	-0.777
France	1.122	-0.558	-0.271	4.861	2.216	1.035	1.136
Germany	1.125	-0.294	-7.780	3.571	65.884	-0.726	0.689
Italy	1.183	-0.204	-9.257	3.341	-2.560	-3.971	0.473
Japan	1.236	-0.693	1.480	5.603	10.685	1.775	0.405
UK	0.931	-0.487	1.299	2.611	-0.185	2.666	-0.588
US	1.234	-0.635	0.591	2.897	-3.837	0.723	-0.102

Note: in grey, the cells show estimates that were statistically significant

The first interesting fact that can be observed is that the coefficients for Categories 1 (Energy efficiency) and 4 (Nuclear) are all positive and statistically significant. In a sense, the results for Category 4 were expected as the majority of spending occurs in that category. The results for Category 1 are showing how important is for the economics that betterment of the use of energy overall. Secondly, it is crucial to note that none of the coefficients for Category 2 (Fossil fuels) is either positive or statistically significant denoting that the society as a whole do not benefit by the investment in technologies for fossil fuels usage. The rest of the categories show a variety of

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[2] Appendix A presents the coefficient estimates with their t-statistics.

results depending on the country. It is interesting to see that although US invests most than the other countries, it does not receive the same social return from the investment shows a statistically insignificant coefficient only for Categories 2 and 3 (Fossil fuels and Renewable energies).

5. Conclusion and Policy implications

In this paper we have estimated the social rate of return of R&D on various energy applications and technologies such as energy efficiency, fossil fuels, renewable energy sources, and nuclear for the G7 countries (Canada, France, Germany, Italy, Japan, United Kingdom, United States) by using panel data estimations (primarily fixed effects). Following the literature, the impact of lagged R&D intensity to TFP of the countries was quantified to do so. All in all, this paper's purpose was to estimate a lower limit for the social rate of return by using a narrow definition of spillover effects.

Following the approach used by Corderi and Lin (2011), our results yield a lower bound estimate of the social rate of return due to the assumptions and limitations of our approach. The primary focus is on contemporaneous within-country R&D spillovers, we do not account for R&D spillovers between industries, intertemporal or inter-country spillovers. Also, the way of measuring productivity here does not adjust for improvements in human capital.

The results show that primarily R&D investment on Energy Efficiency technologies and Nuclear energy are the ones that yield high social benefits for all G7 countries while exactly the opposite holds for Fossil fuels. There several policy implications of these results. The results show the variety of social benefits gained by various energy R&D categories in various countries showing that not one policy fits all. Policy makers can count on promoting R&D in the fields of energy efficiency and nuclear in giving them high social returns. They should hence rethink on distinguishing the investment accordingly. By no means, the results suggest that R&D investment should be quit for all the other energy technologies apart from those that improve energy efficiency and nuclear production. It might on the contrary be argued that the lack of sufficient and properly directed R&D investment in other categories of energy R&D is the main reason for the absence of social returns. One should always keep in mind though that our estimates are lower bound estimates and the need for funding nationally and internationally as well as the need for incentives may be even greater. More research should be done in order to investigate how spillovers between countries affect the impact of R&D expenditure to technological progress and economic growth.

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Appendix A

Table A1

Dependent variable: differenced total factor productivity													
Categories	1		2		3		4		5		6		7
	Energy Efficiency		**Fossil fuels**		**Renewable energies**		**Nuclear**		**Hydrogen and fuel cells**		**Other power and storage technologies**		**Other cross cutting technologies**
Canada	0.014	**	-0.006		-0.021		0.036	**	-0.253	***	-0.016	***	-0.008
	2.563		*0.426*		*-1.539*		*2.601*		*-3.043*		*0.000*		*0.186*
France	0.011	**	-0.006		-0.003		0.049	**	0.022		0.010		0.011
	2.193		*0.463*		*-0.413*		*2.436*		*0.275*		*0.327*		*0.667*
Germany	0.011	**	-0.003		-0.078	***	0.036	**	0.659	***	-0.007		0.007
	2.243		*0.647*		*-3.639*		*2.307*		*4.736*		*0.115*		*0.108*
Italy	0.012	**	-0.002		-0.093	***	0.033	**	-0.026		-0.040	***	0.005
	2.374		*0.726*		*-5.337*		*2.604*		*-1.514*		*0.000*		*0.223*
Japan	0.012	**	-0.007		0.015		0.056	**	0.107	***	0.018	**	0.004
	2.036		*0.387*		*0.825*		*2.300*		*4.090*		*0.011*		*0.042*
UK	0.009	**	-0.005		0.013	***	0.026	**	-0.002		0.027		-0.006
	2.267		*0.323*		*2.833*		*2.411*		*-0.170*		*0.112*		*0.474*
US	0.012	*	-0.006		0.006		0.029	**	-0.038		0.007		-0.001
	1.915		*0.409*		*0.828*		*2.380*		*-0.681*		*0.644*		*0.764*
Adjusted R-squared	0.985		0.987				0.986		0.993		0.986		0.985
Obs	144		139				149		50		138		132
Hausman test stat	0.000		0.000		0.000		0.000		NA		0.000		NA

Note: *(**)[***] denote 10%, 5% and 1% level of significance; the figures in italics are the t-statistics; Hausman test results show that the null (that Random and Fixed effects can be used interchangeably) cannot be rejected, meaning that RE and FE will produce similar sets of coefficients→ Corderi and Lin (2011) suggest FE so we can proceed with this intuitively.

Table A2: Descriptive statistics

	CANADA	*FRANCE*	*GERMANY*	*ITALY*	*JAPAN*	*UK*	*US*
	CATEGORY 1: ENERGY EFFICIENCY						
Mean	71.42	68.63	42.60	84.88	285.50	47.00	628.44
Median	62.01	32.66	25.31	87.70	275.96	14.25	563.52
Maximum	124.05	287.60	174.21	195.30	625.40	265.11	2264.18
Minimum	42.58	6.53	13.39	34.07	3.52	0.00	247.24
	CATEGORY 2: FOSSIL FUELS						
Mean	157.67	114.15	64.33	15.98	330.13	29.97	686.71
Median	129.63	70.51	29.27	10.01	339.07	16.10	515.74
Maximum	347.97	254.07	237.60	64.29	459.41	84.59	3578.56
Minimum	61.42	43.92	1.82	0.00	75.09	5.43	224.79
	CATEGORY 3: RENEWABLE ENERGIES						
Mean	44.86	47.96	139.01	70.41	171.04	51.56	462.45
Median	30.34	26.35	120.05	70.62	140.62	36.74	294.65
Maximum	150.53	189.73	322.97	112.48	630.58	256.55	2351.60
Minimum	13.74	4.31	79.08	38.71	104.83	6.57	173.46
	CATEGORY 4: NUCLEAR						
Mean	181.15	702.39	343.33	347.40	2470.69	150.07	945.02
Median	200.55	679.46	235.69	185.38	2521.82	55.05	865.06
Maximum	311.89	1095.74	1230.52	1749.09	2839.05	636.30	2226.69
Minimum	56.32	519.60	170.25	106.78	1669.38	27.98	320.61
	CATEGORY 5: HYDROGEN AND FUEL CELLS						
Mean	45.18	61.68	35.48	17.04	177.84	16.09	325.52
Median	43.15	63.79	35.17	15.33	200.72	16.47	351.11
Maximum	62.42	74.63	42.92	40.17	224.39	30.33	379.50
Minimum	35.40	31.69	31.18	0.00	97.82	4.23	179.04
	CATEGORY 6: OTHER POWER AND STORAGE TECHNOLOGIES						
Mean	21.02	6.55	21.09	80.53	96.24	7.60	179.00
Median	13.55	0.00	16.89	90.02	87.80	5.82	162.78
Maximum	69.91	40.69	61.36	168.53	184.52	24.55	980.72
Minimum	5.15	0.00	2.94	5.85	38.77	0.00	62.37
	CATEGORY 7: OTHER CROSS CUTTING TECHNOLOGIES						
Mean	20.68	11.40	45.92	127.98	69.09	23.13	1041.80
Median	16.30	0.00	16.21	57.23	32.56	18.50	1104.51
Maximum	48.49	78.49	158.61	505.51	344.01	105.61	2231.27
Minimum	8.07	0.00	0.00	13.71	0.00	0.00	5.33