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ABSTRACT

Growing concern for climate change and rising scarcity of fossil fuels prompted governments to stimulate the development of renewables. This paper empirically tests whether feed-in tariff (FIT) policies have been effective in the development of photovoltaic solar (PV), explicitly taking into account structure and consistency of FITs. Panel data estimations are employed for 30 OECD member countries over the period 1990-2011. We find a positive effect of the presence of a FIT and the development of a country's share of PV in the electricity-mix. This effect increases if policies are consistent. Tariff height is the most important characteristic of a FIT, but other characteristics such as cost level, duration of contract and restrictions on capacity levels can also not be neglected if the goal is to increase effectiveness of FITs.

Keywords: Photovoltaic solar, Feed-in tariffs, Policy-consistency, Design characteristics

JEL-codes: C23, G11, H23, N70, Q42, Q48

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1. Introduction

In the last decades an increasing number of governments started to stimulate the development of renewable electricity sources. Important motivations have been the growing concern for climate change and the rising scarcity of fossil fuels. Also international agreements on carbon emission reduction and renewable energy targets and governments' objectives to reduce their dependence on energy imported from abroad played a role.

From the most common sources of renewable electricity – biomass, wind, solar, geothermal and hydropower – photovoltaic solar (PV) has made its growth spurt most recently, with a worldwide average yearly growth of 47% over the last decade. This development has increasingly resulted in up-scaled manufacturing facilities and technology improvements. As both have driven the price of a PV-system down, PV has gradually become a competitive electricity source. At the start of the development of the PV-industry in the 1990s, important conventional electricity sources as nuclear and coal-fired power plants were able to produce electricity at only a fraction of the costs at which one solar kilowatt-hour (kWh) could be generated. For bridging the competitive gap between conventional and renewable electricity sources, the role of governments has generally been considered as crucial.

The development of PV started in the early 90s in Germany and Japan; these two countries were the first to adopt policy-instruments. Since 2005, governments all around the world have started to promote PV. Policy-makers have introduced several combinations of instruments. The most common instrument is a Feed-in Tariff (FIT). The general idea of a FIT is that the owner of a PV-system receives on contract basis a guaranteed price for every produced kWh that is fed into the grid during a fixed period of time. FITs can differ in various characteristics, including tariff amount, limitations on available budget or installed capacity and contract duration.

In the past few years uncertainty increased about how effective FIT policies have been in the development of PV. Policy-makers also have difficulty finding the optimal structure of a FIT. Lacking the right FIT-structure can be the reason that some countries are lagging behind in the development compared to others. In this light, it is worthwhile to analyze the relationship between effectiveness and structure of a FIT. Besides FIT-structure, policy-consistency also influences the effectiveness of a FIT (see White et al., 2013, Owens & Driffill, 2008, Gardner & Stern, 1996). Investors seek maximum returns at an acceptable risk. If government support is vital to provide a reasonable return, policy-consistency is considered as crucial to limit the risk. Investors often complain about the regular changes in policies as they have to decide about multi-year investment plans. If the lifespan of policies and investments differ significantly, risk increases for investors.

This paper studies whether FIT policies have been effective in the development of solar PV. To the best of our knowledge, this is the first paper empirically taking into account design characteristics and consistency of FIT policies. The majority of the existing literature is limited to a descriptive approach in analyzing the effectiveness of policy instruments on the development of renewable energy sources. Haas et al. (2011), who compare quantity-driven (like tradable green certificates based on quotas) and price-driven instruments (like FITs) in seven European countries, state that FIT policy instruments are more effective than others, because they usually have low administration costs, are relatively easy to implement and are technology-focused. They underpin that a well-designed FIT policy provides deployment of renewable energy sources in the shortest time and at the lowest costs for society. Also Gipe (2006), Mendonça (2007), Mendonça et al. (2009), Cory et al. (2009) and Timilsina et al. (2012) show qualitatively that FITs are a major driver for the development of most solar PV markets. Jenner et al. (2013) and Bürer and Wustenhagen (2009) add that investors prefer a FIT over other policy instruments. These qualitative policy evaluation studies generally agree that FITs are important in explaining the development of renewable energy sources in Europe. Stronger FITs with higher returns on investment usually have a bigger impact on the development.

Jenner et al. (2013) and Jenner (2012) are the only two empirical studies that have assessed the effectiveness of FITs in promoting the development of PV. Jenner et al. (2013) develop an indicator for FIT strength that captures several design characteristics such as tariff size, contract duration, degression rate but also electricity price and production cost to estimate the resulting return on investment (ROI). They find that for a 10% increase in ROI, 3.8% more PV capacity will be installed on average per year. All together their conclusion is that FIT policies have stimulated the development of PV in Europe between 1992 and 2008. Jenner (2012), who uses generation in GWh instead of annual solar capacity as dependent variable, comes to the same conclusion for the period 1990-2010. An important shortcoming of these studies is that both the individual design characteristics of a FIT and the price of electricity are not included as separate variables in the regression. Therefore it is hard to determine the impact of the individual elements. Besides that the role of policy-consistency is ignored, just as the possible presence of a cap on cost or capacity. Our study does include these indicators. Moreover, in contrast to the above two studies, our study also captures tariff differences due to installation size (which is a crucial determinant to measure the effectiveness of a FIT correctly).

A related paper, Marques & Fuinhas (2012), analyzes the impact of policy incentives on the total contribution of renewables to total energy supply (and not on the development of solar PV separately) by focusing on 24 European countries. Their results give empirical support for the assumption that public policy measures contribute to the wider use of renewables. In particular direct interventions like incentive and subsidy policies, including FITs, turned out to be effective. Quota obligations, R&D programs and tradable certificates did not increase renewables in the period under study. They also find that strategic planning processes contribute to the PV development. This study does have shortcomings though. All policy variables are composed by counting the number of active policies of that policy type in a specific year and country. This method does not capture any of the heterogeneity in the policy design and does not differentiate between dissimilar market circumstances. Also, only data until 2007 are used, while the development of PV is dominated by more recent years.

The rest of the paper is organized as follows. The next section specifies the structure of the model and describes the data set and variables used. Section 3 gives an overview of the different results and provides an interpretation. Finally, Section 4 concludes.

2. Models and data

2.1 The models

In order to investigate the impact of FITs on the development of PV a series of linear models are investigated.

The specification of the models is as follows:

$$PV_{it} = \beta_1 + \beta_{2jt}\, FIT_{it} + \beta_{3kt}Z_{it} + \beta_{4t}T_t + \eta_i + \varepsilon_{it}, \qquad (1)$$

where PV_{it} is a measure for the use of PV in country i in year t, FIT is a vector of (combinations) of the strength of a FIT (FITSTRENGTH), policy consistency measures and underlying characteristics of the FIT, Z is a vector of other characteristics, T is a time trend, η_i are country fixed effects and ε_{it} is the error term.

PV is measured both as a share in the production of electricity and as added yearly capacity per capita. The first is interesting to throw light on the development of the PV-share, while the second is far more directly related to yearly developments.

FITSTRENGTH is approximated by inventorying the underlying characteristics of the FIT as simple counting whether a FIT is present cannot answer our research questions. This makes it not only possible to have a more precise measure for a FIT, but also to explicitly include the underlying characteristics of the FITs to see whether FIT design matters. We add measures for policy consistency by measuring FITSTRENGTH as the average for several years (if the FIT is high for more years, the average will be higher) and by adding the standard deviation of FITSTRENGTH (if the changes in the FIT are large, the standard deviation will be higher). We expect positive signs, except for the standard deviation (a higher deviation points to less policy consistency).

We correct for several characteristics that differ between countries and years. We discuss this in the data section.

We have included a time-trend to correct for autonomic developments in our analysis, like technological developments. Part of the development of the PV-industry might be caused by these autonomic developments and not by FITSTRENGTH or other variables that are included in the model; the time-trend adjusts for this potential bias.

Country specific effects are included to correct for, for example, differences in availability of sun hours.

2.2 Data collection

Yearly data are collected for 30 OECD member countries over the period 1990-2011, which sums up to 660 observations. Four OECD member countries are not included in our panel: Iceland, Canada, Australia and the USA. Iceland is not taken into account because of the fact that data was lacking on electricity prices. Canada, Australia and the USA are all excluded for the reason that their electricity markets are divided in regions or states with the consequence that different policies are implemented within one country. Since we perform country-level analysis it is not possible to include these countries. The data are primarily obtained from the World Bank, OECD-iLibrary and IEA databases. Other sources are mentioned in the specific data sections.

Some variables had missing observations. Since we had data for two electricity price variables (for households and the industrial segment), we used the growth rate of one variable if observations for the other variable were missing. For country-years where both variables had missing observations, we used the average growth-rate of five consecutive years in the direct past or future. When no policy data was available for a specific country and the development of the share in the production of electricity (PVSHARE) was zero or very close to zero, we assumed that no policy had been in place in this specific country.

2.3 Measuring PV

As already mentioned above PV is measured both as a share in the production of electricity (PVSHARE) and as added yearly capacity per capita (ADDCAPC). Both provide interesting information. PV as a share of electricity production shows whether the goal of many countries, i.e. increasing the share of renewable energy, is reached and what the contribution of FITs is to this goal. Yearly added capacity is also interesting as it measures more directly what the development of PV is.

Having a ratio (PVSHARE) as dependent variable is in contrast to most existing empirical literature where absolute values are chosen. Jenner et al. (2013), for example, have chosen for capacity to reflect the investment decision as purely as possible. A disadvantage of absolute values (e.g. cumulative or added PV capacity) is that the results are dominated by bigger countries which results in heteroskedasticity. We measure added capacity therefore per capita. In a sensitivity analysis we test whether replacing PVSHARE by the quantity of produced electricity per capita changes our conclusions.

Table 1
Descriptive statistics dependent variables.

	Mean	Std.Dev.	Minimum	Maximum
PVSHARE	0.06	0.30	0.00	3.57
ADDCAPC	2.05	10.73	0.00	153.09

Table 1 shows the descriptive statistics of the dependent variables. PVSHARE is still limited with a mean of only 0.06% over the whole panel. Important to note is that until 2004 only one observation has a PVSHARE above 0.06%, i.e. Japan in 2003. In contrast, the average PVSHARE for all observations in the last five years of our dataset is 0.24% and in 2011 even 0.61%. Figure 1 gives an overview of the development of the average PVSHARE in our dataset. Additionally it shows the number of countries with a FIT in place. The figure clearly shows that the share of PV strongly grew in the last few years. Part of this growth might be explained by the increasing number of active FITs. PVSHARE increased significantly in a few forefront countries as Germany (2008: 0.7%, 2011: 3.1%), Spain (2008: 0.8%, 2011: 2.8%) and Italy (2008: 0.06%, 2011: 3.6%).

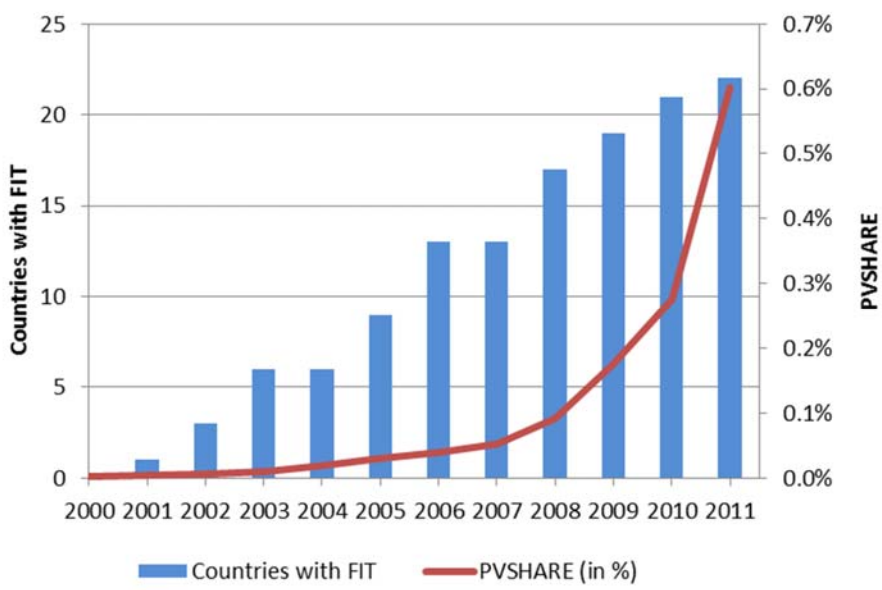

Figure 1. Average PVSHARE and number of countries with FIT

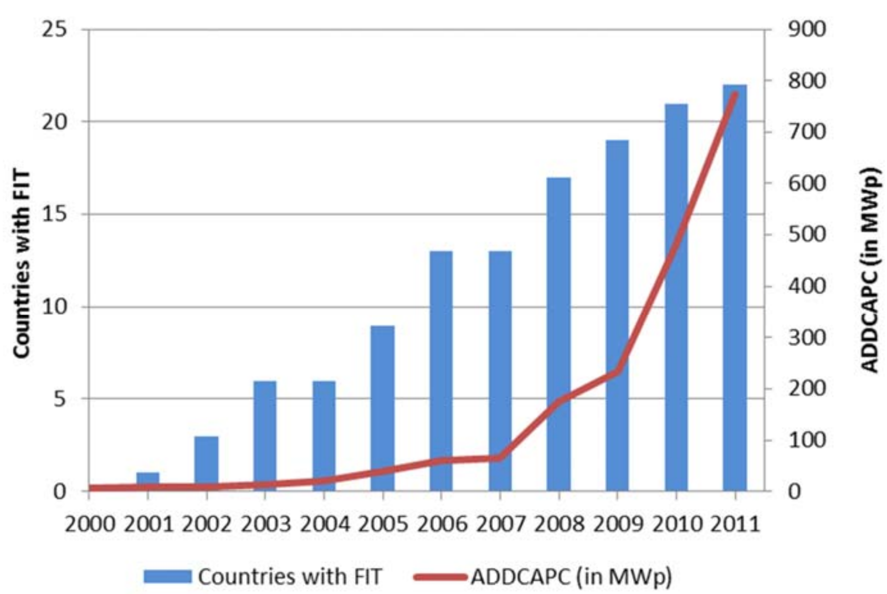

Figure 2. Average ADDCAPC and number of countries with FIT

2.4 Measuring FIT

FITs are evidently the most popular mechanism to promote the PV-industry within our country-panel. Out of 30 OECD member countries included in this study 22 have implemented a FIT. In 20% of the observations a FIT was in place; in the last decade of our data-period (2002-2011) even 43% of the years include a FIT-policy.

To measure the strength of a FIT we distinguish four strength measures (see Table 2): tariff amount (split into three parts; tariffs for small, commercial and utility scale systems), contract duration, limitation on cost or capacity and average cost of generating one solar kWh for each panel observation (taking solar irradiation and PV-system price into account).

To be able to combine the four measures we reward each of them with points on a pre-defined scale. The sum of the rewarded points forms the FIT-strength indicator. This is a transparent alternative for the ROI indicator that is composed by Jenner et al. (2013). By rewarding the four FIT design characteristics individually we are able to test the effectiveness of these characteristics separately as well as combined as one FIT-strength indicator.

Table 2
Points classification of FIT strength measures.

Nr.	FIT strength measure	Points
1a	FIT-Tariff amount: small systems	[0,25]
1b	FIT-Tariff amount: commercial systems	[0,25]
1c	FIT-Tariff amount: utility scale systems	[0,25]
2	FIT-Duration contract	[-20,20]
3	FIT-Cap on cost or capacity	Yes = -15, No = 0
4	FIT-Cost of generation	[-20,20]

Table 3
Descriptive statistics for FIT measures.

	Mean	Std.Dev.	Minimum	Maximum
FIT-Tariff Small	11.87	5.26	1.00	20.00
FIT-Tariff Commercial	10.98	5.31	0.00	20.00
FIT-Tariff Utility	7.00	7.39	0.00	22.00
FIT-Tariff	9.95	4.98	0.67	20.33
FIT-Duration	4.03	8.84	-10.00	20.00
FIT-Cap	-4.03	6.68	-15.00	0.00
FIT-Cost	13.12	3.57	5.00	19.00
FITSTRENGTH	42.94	20.65	0.00	82.00

Note: descriptive statistics are given for subsample of observations with a FIT (130).

Rewarding each of the four measures properly is crucial; both knowledge of actual data and a reasonable division of points are required to obtain a well-balanced and correct FIT-strength indicator. Table 2 gives an overview of the scales on which points are assigned to each measure.[1] The chosen points ratio between one measure and the other is based on personal calculations and in-depth market knowledge. Table 3 displays the descriptive statistics of the involved measures. Data on the FIT policies have been obtained from a variety of sources including PV Grid, Wind-works.org, IEA Policies & Measures Databases, RES Legal and Europe's Energy Portal. A detailed database on FIT policies does not exist but is composed by the authors. We have categorized the data such that they could reasonably be compared between countries and years. The following illustrates our approach.

Since all measures have only values in the years that a FIT was in place, in Table 3 the descriptive statistics for only these 130 observations are shown. The minimum-maximum ranges of points that are actually rewarded, shown in Table 3, deviate somewhat from the classification in Table 2 for some of the measures. This is mainly the case for the measures contract duration (FIT-DURATION) and Average Cost of Generation (ACG) of one kWh (FIT-COST). The reason for these deviations is that countries in our data panel did not implement FITs with a contract of less than 10 years[2] and that no country implemented a FIT when the average cost of generation was above 25.4 eurocent.[3]

The division of points is linear and based on the actual minimum and maximum values of each measure. Let's illustrate this with respect to the tariff amount measure. The lowest tariff amount for small PV-systems (Measure 1a in Table 2) is 5.2 eurocent, the highest is 60 eurocent. Points are divided linearly between 0 eurocent (0 points) and 75 eurocent (25 points) (see Table A1 in Appendix A). A tariff amount between 3 and 6 eurocent is rewarded 1 point, a tariff amount between 60 and 63 eurocent is rewarded 20 points. Thus points are assigned in the range 1-20. The same method is applied for tariff amounts of commercial and utility scale systems. For FIT-DURATION and FIT-COST we have awarded points in the range of

[1] Table A1 in Appendix A shows a more detailed overview of how the points are assigned.
[2] A contract of 10 years corresponds with -10 points in Table A1 in Appendix A.
[3] An average cost of generation of 25.4 eurocent corresponds with 5 points in Table A1 in Appendix A.

-20 points (5 year) to 20 points (25 year) respectively 5 points (25.4 eurocent) to 19 points (3.8 eurocent).

As we have mentioned above, the tariff amount measure is split into three different categories. Since we expect the tariff amount to be more effective for larger systems (due to the fact that the life cost of energy of larger systems is lower), we have rewarded the tariff amount of larger systems with more points. We assumed that small systems need to have on average 10% higher tariff than commercial systems and 20% higher than utility scale systems to be equally effective.

FIT-DURATION has been rewarded with both negative and positive points. A FIT that includes a contract of more than 15 year is generally considered as attractive since tariffs are paid over a period more comparable with the lifetime of a PV-system. A balanced trade-off between contract duration and tariff amount is important to retain a profitable ROI. As not many investors have been able to obtain a good ROI with a short contract, a contract of less than 15 years has been rewarded with negative points.

A limitation on cost or capacity, also known as a cap (FIT-CAP), is a pre-defined maximum on either the budget or the installed capacity during a fixed period of time. A cap can cause uncertainty to potential investors as they are no longer sure whether pre-investment costs can be earned back. As a cap has a negative impact on the effectiveness of a FIT, negative points are awarded if a cap is included. We use a binary valuation for this specific design characteristic since – due to the high variability in caps – it is hard to classify the caps and since there are relatively few FIT policies that include a cap. The inclusion of a cap (no matter which one) is rewarded with -15 points.

As shown in Table 2, a fourth measure is included: the average cost of generation (FIT-COST). Two countries that implement FITs with equal tariff amount and contract duration will not necessarily have a comparable development; ROI is based on more factors than these two alone. ROI varies primarily because of the difference in insolation[4] between countries. Purely

[4] The intensity of incoming solar radiation incident on a square meter horizontal surface.

based on solar irradiation, generation in Israel is about 70% higher than the generation of a PV-system in the average country in our panel. But price, lifetime and efficiency of a PV-system also contribute to its variation. By keeping all other factors constant (lifetime = 25 years, PV-system efficiency = 15% and one sq. meter of solar panels consist of 150 Watt peak (Wp)), we have calculated the average number of kWh's that is generated by a system per Wp for each country-year. Dividing the prevailing PV-system price per Wp by that number, gives us the average cost of generating one kWh of solar electricity over the lifetime of a PV-system. The lower this number, the higher the reward in points is.

The unweighted sum of the rewards forms the strength of the FIT (FITSTRENGTH) in our main analysis. In sensitivity analyses we give subsequently more weight to each underlying characteristic to test whether our results are robust.

The dots in Figure 3 are showing all FITSTRENGTH observations through the years. FITs become on average stronger through the years. Part of this increase is of course explained by decreasing system prices which makes PV more and more attractive. As an example, the development of FITSTRENGTH is highlighted for Germany (solid line), Spain (line with small dots) and Italy (line with bars). The development is very consistent over the years in Germany, but far less so in Italy (big jump in 2008) and Spain (jump in 2008, but sharp decline in 2009 and 2011). This indicates that variation in the panel is available, not only with respect to FITSTRENGTH levels between countries, but also to changes over time.

We are not only interested in the effects of FIT and its design characteristics, but also in the effects of policy consistency. The hypothesis is that the effects of a FIT are larger when a country has a more consistent policy over time. If potential investors gain confidence in the continuity of a policy, the effectiveness of a FIT is expected to increase. So the higher and more constant tariffs over several years are, the higher the level of consistency, the higher the expected effectiveness.

We measure consistency by two variables. First, we replace FITSTRENGTH by the average FIT over the past 5 years (FITSTRENGTH(5)). As a sensitivity analysis we do also estimations with the average over the last 2, 4, 6, 8 and 10 years. Second, we add to the FITSTRENGTH variable the standard deviation of FITSTRENGTH (FITSTRENGTH(SD)) over the past 5 years.

Descriptive statistics of the FIT variables are shown in Table 4.

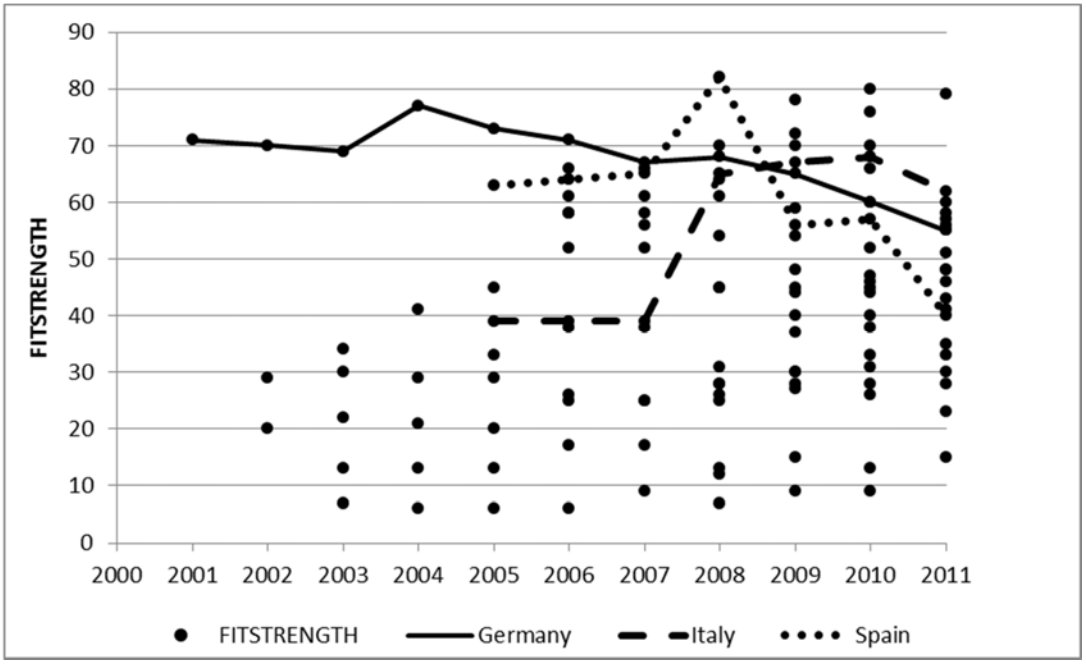

Figure 3. Overview FITSTRENGTH observations and development three countries.

Table 4

Descriptive statistics FIT-policy variables.

	Mean	Std.Dev.	Minimum	Maximum
FITSTRENGTH	8.46	19.38	0.00	82.00
FITSTRENGTH(5)	4.39	12.92	0.00	72.00
FITSTRENGTH(SD)	2.95	7.45	0.00	42.46

2.5 Other policy variables

As a sensitivity analysis we also include the following other policy variables:

- RD&D budgets for (governments) investments in the PV sector (RDENDBUDGET);
- investment and tax incentives (POLINVEST);
- net metering policies (POLNETMET);
- calls for tender (POLTEN).

We measure RD&D budgets in million US$ and the other three policies simply through binary variables, by counting whether a certain policy is present or not. We include these policies only in a sensitivity analysis since there are not many observations per policy available and since three of these policies have an imprecise binary measure. We leave a more robust analysis of these policies for further research.

Descriptive statistics of the other policy variables are shown in Table 5.

Table 5
Descriptive statistics other policy variables.

	Mean	Std.Dev.	Minimum	Maximum
RDENDBUGDET	9.49	24.21	0.00	225.74
POLINVEST	0.29	0.45	0.00	1.00
POLNETMET	0.06	0.24	0.00	1.00
POLTEN	0.01	0.09	0.00	1.00

2.6 Exogenous and control variables

The following exogenous variables are included to control for differences between countries and in time:

- wealth (both GDPcap and $GDPcap^2$) to account for a possible U-shaped curve analogous to the Environmental Kuznets Curve (see Grossman and Krueger, 1991, Panayotou, 1993);[5]
- trade openness of a country (OPENNESS) measured as the percentage of export and import of GDP as more open countries might easier import new PV technologies and profit more from PV export, making national investments more profitable;
- population density (POPDENS) measured as the number of inhabitants per squared kilometer as PV is a land intensive energy technology;
- energy import (ENERGYIMPORT) measured as share of total energy as a higher share might give more incentives to decrease this share by investing in PV;

[5] The Environmental Kuznets Curve hypothesis postulates an inverted-U-shaped relationship between income levels and negative environmental effects, which might implicate a U-shaped relationship between income levels and PV.

- the capacity of the electricity plants (ELECCAPACITY) as a higher capacity results in more replacement investments and thus a higher chance of investments in PV;
- the price of electricity (ELECPRICEHH) as a higher price makes it more likely that the business case for PV becomes profitable. We do not include industrial electricity prices because this would cause collinearity and would not contribute to the explanatory power of the model. We have chosen for the household electricity price variable because it is less correlated with the other variables in the model.

Data for GDPcap, OPENNESS, and POPDENS are obtained from the World Bank. ENERGYIMPORT, ELECCAPACITY, and ELECPRICEHH data are all derived from the OECD-iLibrary. Descriptive statistics of both exogenous and control variables are given in Table 6.

Table 6
Descriptive statistics control variables.

	Mean	Std.Dev.	Minimum	Maximum
GDPcap	18.20	11.46	1.65	56.39
OPENNESS	87.66	48.44	15.92	319.55
POPDENS	149.05	125.74	13.09	511.37
ENERGYIMPORT	25.90	135.74	-842.00	99.00
ELECCAPACITY	1.65	1.22	0.00	7.17
ELECPRICEHH	137.46	64.38	10.32	409.17

3. Results

This section discusses the empirical results.[6] First we discuss the effectiveness of the general FIT measure and the impact of the consistency of FITs. Next, we delve into the relation between effectiveness and design characteristics of the FIT. Finally, we present some sensitivity analyses.

3.1. Effectiveness of FIT

Table 7 presents the estimation results for the base models. In all cases FITSTRENGTH has a positive and significant (at 1%) effect on the production of PV, measured as share of produced electricity. If a country introduces a FIT with a strength of 82 (the maximum in the sample) the effect is +0.2% on the PV share in electricity production. Compared with the mean PV share of 0.06% this is a relative large effect. The effect becomes 5.5 times higher if the indicator is changed to the average of FITSTRENGTH in the preceding 5 years. Estimations with other averages (2, 4, 6, 8, 10 years) show that the effectiveness is linearly increasing in the lag period (see Table 8 and 9). For 10 years the effectiveness is more than 10 times as high with an effect of 2.14% on the production of PV. This means that effectiveness increases considerably if over a longer period of time FITSTRENGTH is high. If the standard deviation is included in the estimations, the effect of FITSTRENGTH is also much higher, but decreases if the standard deviation increases. Again, this indicates that consistency is very important for the effect of FIT on the production of PV.

These effects are reproduced if added capacity per capita is taken as endogenous variable. The effect of FITSTRENGTH is positive and significant and increasing if it is higher over a longer period and decreasing if the standard deviation is larger. The effect of consistency measured as average over the previous 5 years for produced solar electricity is twice the effect for added capacity. This is not only the case for 5 years, but also for 2, 4, 6, 8 and 10 years. On the other hand, if the standard deviation is used as measure for consistency the effect of this variable is larger for added capacity than for produced solar electricity.

[6] As the Breusch Pagan test is rejected for all variables on 1%, standard errors are White corrected.

The result for GDP per capita results in a non-linear relation with the production electricity share of PV. The effect of GDP growth is negative until a level of 37.000 dollars per inhabitant and positive above that level. For added capacity the results are quantitative comparable, but they are less significant. Openness has no influence on the production or added capacity of PV. Population density has a negative influence in most estimations. This is not surprising as PV is a land intensive way of producing electricity. The influence of energy imports is not significant. For the electricity capacity and the price of electricity we find clearly a positive effect. With a high capacity more new investments are needed, giving space to the choice of PV. A higher price of electricity clearly stimulates relative expensive solutions like PV as the business case of PV will be more often positive.

Table 7
Estimation results base model.

	PVSHARE			ADDCAPC		
	Current	5 yr	St dev	Current	5 yr	St dev
FITSTRENGTH	0.002***	-	0.011***	0.183***	-	0.557***
	(0.20)		(0.87)	(14.98)		(45.65)
FITSTRENGTH(5)	-	0.013***	-	-	0.483***	-
		(1.10)			(39.57)	
FITSTRENGTH(SD)	-	-	-0.022***	-	-	-1.027***
			(-0.33)			(-15.27)
GDPcap	-0.064***	-0.052***	-0.056***	-1.475*	-1.172*	-1.068
$GDPcap^2$	0.001***	0.001***	0.001***	0.017**	0.016**	0.015
OPENNESS	0.001	0.000	0.001	0.020	0.003	0.013
POPDENS	-0.001***	-0.001*	0.000	-0.051**	-0.031*	-0.007
ENERGYIMPORT	-0.001	0.000	0.000	-0.016	-0.004	-0.006
ELECCAPACITY	0.016***	0.010***	0.014***	0.348**	0.190*	0.266**
ELECPRICEHH	0.002**	0.001*	0.002*	0.057***	0.029*	0.039*
TREND	-0.006	-0.008	-0.006	-0.166	-0.125	-0.191*
Constant	0.198	0.316*	0.047	7.670	8.951	0.746
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	660	660	660	660	660	660
R^2	0.39	0.57	0.50	0.30	0.42	0.46

Notes: */**/*** means significance at 10%/5%/1%. Marginal effects based on maximum FITSTRENGTH (82) and average standard deviation FITSTRENGTH (14.86) between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

Table 8

Estimation results 2, 4, 6, 8 and 10 years PVSHARE.

	2 yr	4 yr	6 yr	8 yr	10 yr
FITSTRENGTH(5)	0.007***	0.011***	0.016***	0.021***	0.026***
	(0.58)	(0.91)	(1.32)	(1.69)	(2.14)
GDPcap	-0.057***	-0.053***	-0.051***	-0.052***	-0.052***
$GDPcap^2$	0.001***	0.001***	0.001***	0.001***	0.001***
OPENNESS	0.001	0.001	0.000	0.000	0.000
POPDENS	-0.002*	-0.002	-0.001	-0.001	-0.001
ENERGYIMPORT	0.000	0.000	0.000	0.000	0.000
ELECCAPACITY	0.013***	0.011***	0.009***	0.009***	0.008***
ELECPRICEHH	0.002***	0.001***	0.001***	0.001***	0.001**
TREND	-0.008*	-0.008**	-0.007*	-0.006*	-0.005
Constant	0.293	0.303	0.324	0.330*	0.354*
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	660	660	660	660	660
R^2	0.46	0.52	0.58	0.59	0.61

Table 9

Estimation results 2, 4, 6, 8 and 10 years ADDCAPC.

	2 yr	4 yr	6 yr	8 yr	10 yr
FITSTRENGTH(5)	0.304***	0.419***	0.571***	0.763***	0.958***
	(24.95)	(34.33)	(46.81)	(62.56)	(78.55)
GDPcap	-1.285**	-1.195**	-1.143**	-1.133**	-1.164**
$GDPcap^2$	0.017**	0.017**	0.016**	0.016**	0.016***
OPENNESS	0.011	0.007	0.000	-0.005	-0.008
POPDENS	-0.052	-0.038	-0.025	-0.014	-0.008
ENERGYIMPORT	-0.009	-0.005	-0.003	-0.001	0.000
ELECCAPACITY	0.271***	0.214***	0.163***	0.125***	0.101**
ELECPRICEHH	0.043***	0.034***	0.023**	0.015	0.011
TREND	-0.164	-0.149	-0.102	-0.064	-0.028
Constant	9.311	8.818	9.165	9.698	10.504
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	660	660	660	660	660
R^2	0.36	0.40	0.44	0.47	0.49

3.2. Effectiveness of separate FIT design characteristics

Table 10 presents the estimation results for the FIT design characteristics. Nearly all characteristics are positive and significant. Only for the effect of capacity restriction on the production share of PV no effect is found. The largest effect is found for the tariff. With the highest available tariff in our sample, the marginal effect of FIT is 0.5% on the production share. For this share the second most effective characteristic is cost, followed by duration. For added capacity tariff is also the most effective characteristic. The other three characteristics have comparable effects. We can conclude that tariff is the most important design characteristic, but that the effectiveness is largest when all characteristics are optimized.

Table 10

Estimation results FIT design characteristics.

	PVSHARE	ADDCAPC
FITSTRENGTH(SD)	-0.018***	-0.820***
	(-0.27)	(-12.19)
FIT-TARIFF	0.024***	1.785***
	(0.50)	(36.30)
FIT-COST	0.018***	0.629***
	(0.37)	(12.57)
FIT-DURATION	0.013*	0.788***
	(0.25)	(14.98)
FIT-CAP	0.001	0.753***
	(0.01)	(11.29)
GDPcap	-0.059***	-1.390
$GDPcap^2$	0.001***	0.014
OPENNESS	0.001	0.020
POPDENS	0.000	0.071*
ENERGYIMPORT	0.000	-0.007
ELECCAPACITY	0.014**	0.320*
ELECPRICEHH	0.002**	0.056**
TREND	-0.015**	-0.824***
Constant	0.069	-7.785*
Fixed effects	Yes	Yes
Observations	660	660
R^2	0.49	0.45

Notes: */**/*** means significance at 10%/5%/1%. Marginal effects based on average standard deviation FITSTRENGTH (14.86), maximum for TARIFF (20.33), COST (20), DURATION (19), and minimum (in absolute value) for CAP between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

3.3. Sensitivity analyses

In Section 3.1 and 3.2 we have found that the FIT is effective in stimulating the production and capacity of PV and that all design characteristics are important if the goal is to increase the effectiveness of the FIT. In this section we show whether these conclusions are affected when we change several assumptions.

First, we changed the weighting schemes of the underlying parts of FITSTRENGTH. The underlying characteristics of the FITs are weighted differently compared with the base model (the model with FITSTRENGTH and its standard deviation). In each sensitivity analysis the weight of respectively tariff, cost, duration and cap is doubled. In all cases FITSTRENGTH and its standard deviation are significant and the sign is the same as in the base model (see Table 11 and 12). Marginal effects are comparable.

Table 11

Estimation results PVSHARE: different weighting schemes FIT.

		Double weight for:			
	Base	Tariffs	Cost	Duration	Cap
FITSTRENGTH	0.011***	0.005***	0.009***	0.010***	0.007***
	(0.87)	(0.67)	(0.85)	(0.98)	(0.57)
FITSTRENGTH(SD)	-0.022***	-0.011***	-0.018***	-0.020***	-0.013***
	(-0.33)	(-0.26)	(-0.34)	(-0.33)	(-0.19)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	660	660	660	660	660
R^2	0.50	0.44	0.49	0.48	0.42

Notes: */**/*** means significance at 10%/5%/1%. Estimation results for other variables (models are comparable with Table 7 and 10) available on request. Marginal effects based on maximum FITSTRENGTH and average standard deviation FITSTRENGTH between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

Table 12

Estimation results ADDCAPC: different weighting schemes FIT.

		Double weight for:			
	Base	Tariff	Cost	Duration	Cap
FITSTRENGTH	0.557***	0.283***	0.400***	0.430***	0.525***
	(45.65)	(38.43)	(38.83)	(43.86)	(43.08)
FITSTRENGTH(SD)	-1.027***	-0.522***	-0.721***	-0.759***	-0.947***
	(-15.27)	(-13.01)	(-13.47)	(-12.27)	(-13.53)
Fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	660	660	660	660	660
R^2	0.50	0.44	0.49	0.48	0.42

Notes: */**/*** means significance at 10%/5%/1%. Estimation results for other variables (models are comparable with Table 7 and 10) available on request. Marginal effects based on maximum FITSTRENGTH and average standard deviation FITSTRENGTH between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

Second, we replaced PV as share of electricity production by produced electricity per capita. Again we find that the effect of FIT is significant, positive and increasing in consistency (see Table 13). The results for the design characteristics are also comparable, although cost and duration do have different significance levels now.

Table 13

Estimation results FIT production electricity per capita.

	Current	5 years	St.dev.	Design
FITSTRENGTH	1.892**	-	7.596***	-
	(155.12)		(622.83)	
FITSTRENGTH(5)	-	9.353***	-	-
		(766.99)		
FITSTRENGTH(SD)	-	-	-15.666***	-12.342***
			(-232.80)	(-183.40)
FIT-TARIFF				18.064***
				(367.24)
FIT- COST				12.252*
				(245.04)
FIT-DURATION				10.634***
				(202.04)
FIT-CAP				1.084
				(16.25)
Fixed effects	Yes	Yes	Yes	Yes
Observations	660	660	660	660
R^2	0.40	0.57	0.49	0.47

Notes: */**/*** means significance at 10%/5%/1%. Estimation results for other variables (models are comparable with Table 7 and 10) available on request. Marginal effects based on maximum FITSTRENGTH (82) and average standard deviation FITSTRENGTH (14.86) between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

Third, we estimated the effect of FIT including variables for other policy instruments (RD&D budgets for investments in the PV sector, investment and tax incentives, net metering policies, calls for tender). As these instruments are less often used, resulting in few observations, and are measured in a rough manner (based only on a simple count of available instruments), we do not include these results in our base models. Most important is that including the four other policy instruments does not influence our main conclusions (see Table 14). The effects of the other instruments are in all cases insignificant, while the coefficients for FITSTRENGTH and its standard deviation are highly comparable.

Table 14

Estimation results other instruments

	PVSHARE	ADDCAPC
FITSTRENGTH	0.011***	0.555***
	(0.89)	(45.51)
FITSTRENGTH(SD)	-0.023***	-1.029***
	(-0.34)	(-15.29)
POLINVEST	-0.022	0.729
POLNETMET	-0.026	1.821
POLTEN	-0.063	-0.879
RDENDBUDGET	-0.001	-0.027
GDPcap	-0.054**	-1.128
$GDPcap^2$	0.001***	0.015*
OPENNESS	0.001	0.010
POPDENS	0.000	-0.006
ENERGYIMPORT	0.000	-0.005
ELECCAPACITY	0.014***	0.271**
ELECPRICEHH	0.002*	0.039*
TREND	-0.006	-0.198*
Constant	0.000	1.600
Fixed effects	Yes	Yes
Observations	660	660
R^2	0.47	0.42

Notes: */**/*** means significance at 10%/5%/1%..Marginal effects based on maximum FITSTRENGTH (82) and average standard deviation FITSTRENGTH (14.86) between brackets below coefficients. To correct for heteroscedasticity standard errors are White corrected.

4. Conclusions

This paper has empirically analyzed whether FIT policies have been effective in the development of solar PV. In contrast to the existing literature FIT-structure and policy-consistency were explicitly taken into account.

We have found a strong positive relation between the presence of a FIT and the development of a country's share of PV in the electricity-mix. This effect is increasing if the FIT policy is more consistent. The tariff of the FIT is the most important design characteristic; the other characteristics (cost levels, duration of contracts and caps w.r.t. capacity or costs) are important too though. If the goal is to maximize the effectiveness of FITs the design characteristics should be consistent in time and optimized for each relevant aspect.

We have indications that our results are robust. Measuring FIT policies in other ways, (by changing the weighting schemes of the underlying characteristics), changing the endogenous variable, varying the time scale of measuring, and including other policy instruments did not change our results. Especially with respect to the sensitivity analysis with non-FIT policy instruments included, we feel that it might be interesting to invest in new research as our non-FIT policy variables are based on rough measures only.

Appendix A

Table A1

Detailed overview of points per FIT measure.

FIT-TARIFF

Points	**Small (€)**	**Comm (€)**	**Utility (€)**
0	0	0	0
1	0.03	0.027	0.024
2	0.06	0.054	0.048
3	0.09	0.081	0.072
4	0.12	0.108	0.096
5	0.15	0.135	0.12
6	0.18	0.162	0.144
7	0.21	0.189	0.168
8	0.24	0.216	0.192
9	0.27	0.243	0.216
10	0.3	0.27	0.24
11	0.33	0.297	0.264
12	0.36	0.324	0.288
13	0.39	0.351	0.312
14	0.42	0.378	0.336
15	0.45	0.405	0.36
16	0.48	0.432	0.384
17	0.51	0.459	0.408
18	0.54	0.486	0.432
19	0.57	0.513	0.456
20	0.6	0.54	0.48
21	0.63	0.567	0.504
22	0.66	0.594	0.528
23	0.69	0.621	0.552
24	0.72	0.648	0.576
25	0.75	0.675	0.6

FIT-DURATION

Years	*Points*
5	-20
6	-18
7	-16
8	-14
9	-12
10	-10
11	-8
12	-6
13	-4
14	-2
15	0
16	2
17	4
18	6
19	8
20	10
21	12
22	14
23	16
24	18
25	20

FIT-CAP

Cap?	*Points*
Yes	-15
No	0

FIT-COST

ACG (€)	*Points*
0.62	-20
0.605	-19
0.59	-18
0.575	-17
0.56	-16
0.545	-15
0.53	-14
0.515	-13
0.5	-12
0.485	-11
0.47	-10
0.455	-9
0.44	-8
0.425	-7
0.41	-6
0.395	-5
0.38	-4
0.365	-3
0.35	-2
0.335	-1
0.32	0
0.305	1
0.29	2
0.275	3
0.26	4
0.245	5
0.23	6
0.215	7
0.2	8
0.185	9
0.17	10
0.155	11
0.14	12
0.125	13
0.11	14
0.095	15
0.08	16
0.065	17
0.05	18
0.035	19
0.02	20

Table A2. List of variables

PVSHARE	Share of electricity generated with PV in total generated electricity	%
ADDCAPC	This year installed new capacity for PV per capita	MWp
FITSTRENGTH	Measure for strength feed-in tariff this year	Points
FITSTRENGTH(5)	Measure for strength feed-in tariff average of last five years	Points
FITSTRENGTH(SD)	Measure for strength feed-in tariff: standard deviation of last five years of FITSTRENGTH	Points
RDENDBUDGET	Government investment in PV Research	Million US$ (2010 prices +exchange rates)
POLINVEST	Binary for presence of investment/tax policies	Binary 0/1
POLNETMET	Binary for presence of net metering policies	Binary 0/1
POLTEN	Binary for presence of tender policies	Binary 0/1
FIT-Tariff Small	Measure for strength feed-in tariff this year related to height tariff for small producers	Points
FIT-Tariff Commercial	Measure for strength feed-in tariff this year related to height tariff for commercial producers	Points
FIT-Tariff Utility	Measure for strength feed-in tariff this year related to height tariff for utilities	Points
FIT-Tariff	Measure for strength feed-in tariff this year related to height tariff for all users	Points
FIT-Duration	Measure for strength feed-in tariff this year related to duration of contract	Points
FIT-Cap	Measure for strength feed-in tariff this year related to a cap on capacity or cost	Points
FIT-Cost	Measure for strength feed-in tariff this year related to system costs	Points
GDPcap	GDP per capita	Dollars (in constant prices of 2000) per inhabitant
OPENNESS	Exports plus imports as share GDP	%
POPDENS	Population density	Capita per sq. km
ENERGYIMPORT	Share of imports in energy use	%
ELECCAPACITY	Electricity generation capacity	MWe per capita
ELECPRICEHH	Electricity price households	Dollars per MWhe

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