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A Panel Data Approach towards the Effectiveness of Energy Policies in Fostering the Implementation of Solar Photovoltaic Technology: Empirical Evidence for Asia-Pacific

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Abstract: Today, the growing Asia-Pacific population causes a dramatic growth in energy supply to meet energy demand. The rapid rise in energy demand is causing concern in the region. Thus, the present study scrutinizes the effect of energy policy involvement in steering-up renewable energy development by empirically assessing the role of policy instruments in encouraging residential-scale and commercial-scale photovoltaic (PV) systems. The analysis is performed using a fixed effects estimator on a selected range of policy approaches (market-pull policies and tax incentives) and a technology-push policy (capital grants) in selected Asia-Pacific countries between 1998 and 2015. The return on investment is estimated to measure the incentives of feed-in tariff (FIT) tariff policies for both residential-scale and commercial-scale PV systems. This study has shown the importance of a strategic combination between technology-push and market-pull policies as complementary to adopting technology and increasing renewable energy utilization for solar PV systems on a residential scale. Investigations into the effectiveness of regulatory support policies for solar PV systems indicate that energy policies are necessary to facilitate solar PV growth on a residential scale in the Asia-Pacific.

Keywords: renewable energy; solar photovoltaic; policy effectiveness; Asia-Pacific

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1. Introduction

An intensely growing Asia-Pacific population requires an equally dramatic growth in energy supply to meet energy demand [1]. As reported by the United Nations Population Fund [2], the region's population is estimated at 4 billion, and it is projected to increase to about 5 billion before leveling off in 2050. The supply of electricity more than doubled in Asia-Pacific countries between 2005 and 2015 [3]. The rapid rise in energy demand is causing concern in the region, as it is being met by increasing reliance on imported fossil fuels. Nearly 90% of their primary electricity comes from fossil fuels, 60% of which comes from Middle Eastern countries [4]. Using conventional energy sources to meet rising demand could jeopardize regional energy security. By broadening the energy mix and lowering carbon emissions, extensive deployment of renewable energy sources will help to tackle some of the nation's difficulties [3,5–11].

To recognize the effect of policy involvement in fostering the deployment of green energy sources, this study empirically assesses the role of environmental policies in RETs by focusing on residential-scale and commercial-scale PV systems. As part of its data collection, this study reviews in detail the design features of market-pull policies, namely, FIT and tax credit, and technology-push, namely, grants for selected Asia-Pacific countries between 1998 and 2015. One of the rationales for choosing these countries is that they have experienced a substantially higher growth rate in solar PV compared to other countries in the region. For instance, Japan pioneered other countries with the highest solar PV installed since 2000. The capacity installed for 2015 was 9379 MW [12]. Meanwhile, other countries have started adopting the PV system at a rapid pace in recent years. For instance, PV development in Malaysia grew 32 percent from 2000, with its installed capacity standing at 60 MW in 2015 [12]. Although China is the region's leading consumer of solar PV, it was removed from the research owing to a lack of data on FIT for each province. The good development prospects of solar PV deployment in countries are projected to continue in the foreseeable future since it decreases reliance on conventional energy supplies while fulfilling the world's constant energy needs.

This study contributes to the current investigation in two ways. First, although the impact of the government intervention on investments in clean-energy sectors has gained substantial consideration in the environmental economies area until now the literature has stressed the regulatory support in RETs and focuses nearly exclusively on developed countries (e.g., Nicolli and Vona [13]; Crago and Chernyakhovskiy [14]). In contrast, this study explicitly categorizes the policy instruments into the following two types: market-pull and technology-push, and also investigates their impact on the adoption of solar PV across countries and states in the selected Asia-Pacific countries. Moreover, for policy variables, this study applies other important explanatory variables that may influence solar PV development, such as net import ratio, CO_2 intensity, fossil share, and income on PV uptake.

Second, some of the important quantitative studies addressing the effect of energy policy on technological changes in the RET sector include e.g., Pfeiffer and Mulder [15], Nesta et al. [16], and Romano et al. [17]. Nevertheless, many studies tend to reduce sector heterogeneity by using aggregate statistics to show the direction of low-carbon growth. For instance, certain RETs (such as hydroelectric and wind) are well-developed financially and technically, while others (such as solar PV) are still developing. Thus, there may be a differential regulatory support impact across various industries.

Therefore, building on the results of Jenner, Groba and Indvik [18], this study exploits their taxonomy to investigate how the role of energy policies differs across solar PV systems. This study is important to extricate the heterogeneous elements underlying the aggregate RET deployment. Moreover, it assists in enacting personalized regulatory support interference for each specific technology. The novelty of this paper lies in the distinction the analysis makes between FIT policies based on two solar PV technologies, namely, residential-scale installations and commercial-scale installations, and their effect on PV growth. To see if the variation in tariff amount influences solar PV development, two alternative rates for PV installations were implemented.

The paper structure starts with the introductory related growth in energy supply to meet energy demand and the effect of policy involvement in fostering the deployment of green energy sources in Section 1. In the next section, this study reviews several previous studies that focus on the role of technology-push and market-pull policies in promoting renewable energy use. Moreover, policy combinations between technology-push and market-pull. Section 3 presents the methodological approach, which consists of research design and data sources, variables, and measurements (e.g., Measuring the Deployment Level of Solar PV, Measuring ROI for FIT Schemes, Other Market-Pull and Technology-Push Instruments and Other Determinants of Solar PV Development), and econometric model specification. The empirical results of the study are reported in Section 4, and the Outcome discussion in Section 5. Finally, Section 6 concludes the remarks and policy implications of the study. It discusses the policy implications of the current study, provides a recommendation for future research, and elaborates on the limitations that exist in this study.

2. Literature Review

When RETs arrive on the market, they have not yet reached their optimum performance regarding reliability and cost [6]. The optimum realization will be attained steadily through learning by using or learning-by-doing [19]. Policy instruments are hence needed so that these low-carbon technologies can potentially be accepted above narrow market niches and so that they develop their learning curves [20]. The next part emphasizes that a mixed policy design is crucial in the situation of technological change, especially in green energy sources.

2.1. The Role of Technology-Push Policy in Promoting Renewable Energy Use

In the absence of policy support, corporations tend to underinvest in green technology, unable to avoid indirect impacts on rivals who have not invested in development. In the absence of policy support, corporations tend to underinvest in green technology, unable to avoid indirect impacts on rivals who have not invested in development. Firms tend to minimize risk if the technological achievement is uncertain and market growth is expected to be endless. Thus, technology-push policies are vital for internalizing clean-energy advantages [21].

Several empirical analyses show the positive impact of a technology-push approach on clean-energy technologies' innovation. For instance, Watanabe et al. [22] revealed that green energy grants had a positive impact on innovation in PV capacity in Japan. They suggest that the funding opens an ethical phase between innovation, cost reduction, market expansion, and complementary grant funding and expenses. In addition, Del Rio and Bleda [23] highlight that another strategy of assistance is also needed in encouraging private R&D, as this is mutual to the effect of grants. Meanwhile, Klaassen et al. [24] investigated the impact of R&D expenditure on wind capacity in Denmark, Germany, and the United Kingdom. They analyzed technology innovation using a learning curve approach where the reduction in capital expenditure is due to R&D-ground knowledge stock and cumulative capacity. They discovered that the learning rates caused by using wind capacity were lower than the learning rates caused by R&D.

As indicated above, technology-push policies have been shown to positively internalize the benefits of clean-energy technologies. Nonetheless, as RETs develop, more potential investors are willing to invest in the technologies but are hesitant because of revenue uncertainty. The next section reviews the impact of market-pull policies on creating demand for RETs.

2.2. The Role of Market-Pull Policy in Stimulating Renewable Energy Use

Once the RET achieves the mature stage, firms may underinvest in the sector provided that the green technologies are vulnerable to competition with the conventional energy sector. This is likely because they are hesitant about the profitability, technical progress, or overall future costs of the technologies. Market-pull approaches may support investment incentives for renewable capacity or directly increase renewable generation through price-driven measures [20,25]. FIT is a form of the price-based market-pull instrument under which electricity producers using RETs adopted RETs authorize an agreement that earns incentives, which is subject to the amount of kWh they generate. On the other hand, the tax credit is intended to encourage individuals and firms to invest in clean-energy technologies by allowing investments in RETs to be fully or partially deducted from tax obligations or the income of the business.

Previous literature highlights that FIT is better for lessening investment and price issues along with promoting learning-by-using [26,27]. Butler and Neuhoff [28] made a comparison between policy support schemes in Germany (e.g., FIT) and the U.K (e.g., tendering and quota). They revealed that FIT may alleviate costs to firms regardless of similar levels of competition and policy costs. They debate that financing uncertainty under tendering and quotas reduces the investment in RETs activity. Further, fiscal incentive, for instance, rebates and encouraging tax policies lessen the clean-energy technology costs and the risk of the investment by reducing upfront investment costs [29,30]. Nevertheless, there is also literature that outlines there are technological discrepancies pertaining to the innovation impact of instruments. For example, Johnstone, Haščič, and Popp [31] found that significant policy support, such as renewable energy credits, can encourage innovation in the energy industry that is competitive with conventional energy sources, such as wind energy. However, specific subsidies, such as FIT and tax credits, are essential to encourage innovation in high-cost technologies, such as PV.

2.3. Policy Combination between Technology-Push and Market-Pull

Few authors, for instance, Grubb, Chapuis and Duong [32,33] and Dowlatabadi [34], emphasized the significance of market-pull supports to boost market technological diffusion. On the other hand, Hoffert et al. [35] asserted that technology-push instruments are necessary for creating new technologies to convey to market readiness, e.g., at a competitive expenditure degree. Nevertheless, both the case and theoretical research accept that technological change affluence in RETs needs a combination of market-pull and technology-push measures for innovation generation and increased alternative source exploitation [31,36,37]. Fischer [38] created a theoretical model demonstrating that grant assistance for emission control technologies is successful when market-pull policies are included to accelerate technology adoption. This theory is supported by Johnstone et al. [31] with an empirical analysis that highlights that a policy combination of technology-push and market-pull is necessary for the development of RETs.

Nicolli and Vona [16] explored the role of market regulations and various dummy renewable energy policies on innovation performance in various RETs. They found the inducement effect of policy instruments is diverse throughout sectors and depends on their level of maturity. Furthermore, it is found that FIT is encouraging solar PV development in EU countries. On the other hand, technology-push policies—grants and government R&D expenditure—are positive and significant in the premature stages of technological progress, for instance, in the context of marine energy and PV markets in 19 EU countries. In a recent study, Romano et al. [17] explored various renewable policy enactments (e.g., dummy policy variables of FIT, tax incentives, RPS, and capital subsidies) and their effects on the share of non-hydroelectricity generation in developed and developing countries from 2004 to 2011. The findings confirm that not all renewable policies contribute to a growth in the proportion of non-hydro generation and that their effectiveness varies depending on the phase of output performance of the countries. In another study [39] emphasized the importance of the development of an energy enactment policy and the efficient provision of hydroelectricity generation to encourage output performance in Malaysia.

The main limitation of the previous research is the insufficiency of focus given to the stringency of the policies, although the strategy formulation and market features might impact policy potency. To address this issue, Jenner, Groba, and Indvik [18] introduced a new indicator for quantifying the stringency of FIT strategies on wind and solar PV capacity of 26 EU countries from 1992 to 2008. They used a fixed effects regression to measure the efficacy of environmental policies by including an indicator to measure the strength of FIT along with other dummy variables of tax incentives and grants. The study reinforces the importance of including a statistical representation of ROI for FIT policies. In detail, FIT policies, measured by ROI, are necessary for solar PV and wind development, a finding that is masked when design heterogeneity among FIT policies is ignored. Jenner, Groba, and Indvik [18] also stress that policy design, power pricing, the cost of electricity generation, and natural resource endowments are more essential than policy existence in developing renewable energy deployments. However, the analysis does not explicitly account for changes in FIT tariff amounts received by power producers and their influence on RET capacity.

Previous studies have discussed various aspects of regulatory support that might influence the development of RETs. Thus, this study intends to contribute to the literature by recognizing the various policy instruments to promote the technological change of RETs in the context of solar PV growth. Unlike previous work, this study analyses in detail the role of energy policies, namely, market-pull (FIT and tax credit) and technology-push (grants) in the utilization of solar PV capacity. In addition, since the FIT policies may differ in how each one is designed and the market in which they operate, this study analyses in detail the effectiveness of FIT in two PV sectors, namely, residential-PV systems and commercial-PV systems.

3. Quantitative Research Methodology

3.1. Research Design and Data Sources

This study uses balanced panel data to estimate the linkages between energy policies and solar PV growth in a few Asia-Pacific countries, including Australia, India, Japan, Malaysia, South Korea, and Thailand, between 1998 and 2015. Since the FIT incentives given by the government vary on the basis of PV capacity, this study uses a separate sample of the FIT based on solar PV, namely, residential-scale (4 kW), and commercial-scale (100 kW) installations. Furthermore, the FIT schemes enacted in Australia and India vary across the states; thus, this study captures the state policy enactments in these studied countries to be implemented in the analysis.

Information on the annual added installed solar PV capacity for Japan, Malaysia, South Korea, and Thailand was obtained through the Bloomberg New Energy Finance terminal. The terminal provides the average PV capacity value for the countries comprised of residential (4–10 kW) and commercial installations (50–100 kW). Next, figures on solar installation for the states in India were retrieved and purchased from the Indian Ministry of Renewable Energy annual report and the Indiastat agency. Lastly, figures on solar installation for states in Australia were obtained from the Australian PV Institute.

Besides that, the information on solar PV investment costs was obtained from the Photovoltaic Power System Programme survey reports. These reports provide investment costs for small-scales and large-scales installation per watt. Then, the investment of solar PV for 4 kW and 100 kW were obtained by multiplying the investment value by 1000 watts.

The following several control variables are used in this study to indicate an influence on solar PV growth: CO_2 intensity, energy import dependency, fossils share, and income. These control variables are obtained from respective countries'/states' statistics departments, including the Australian Bureau of Statistics, Indiastat, the Statistics Bureau of Japan, the Australian Bureau of Statistics, National Statistical Office of Thailand, Statistics Korea, and Department of Statistics Malaysia. Table A1 (in Appendix A) provides a definition and summary statistics of the variables.

3.2. Description of Variable and Measurement

3.2.1. Measuring the Deployment Level of Solar PV

This study follows a similar approach to Jenner, Groba and Indvik [18] and Crago and Chernyakhovskiy [14], who used the renewable annual added capacity to estimate the effect of policy incentives on RET adoption. The natural logarithm for the capacity installation is applied to decrease the effect of outliers on the dataset over country/state-year was adopted by previous studies (e.g., Marques, Fuinhas and Pires Manso [40], Marques and Fuinhas [41], and Jenner, Groba and Indvik [18]). Jenner, Groba and Indvik [18] proposed the annual added capacity is preferable as it reflects the adoption decision as purely as possible. Besides, this indicator is also acceptable for yearly cumulative installation since it distinguishes the impact of regulatory support involvement on the current period from capacity development in the prior period. It is assumed that for solar PV, a higher degree of capacity installation reflects a high level of deployment in the sector.

3.2.2. Measuring ROI for FIT Schemes

Previous literature has implemented several techniques in assessing the financial profitability of solar adoption over time, including payback period (e.g., Robinson, Stringer, Rai and Tondon [42] and Schelly [43]), net present value [44], internal rate of return [45] or return on investment (e.g., Cherrington et al. [46], Liu et al. [47] and Jenner, Groba and Indvik [18]. This research conjectures that the main measurement for assessing the financial return of the solar system is the return on investment (ROI). The measurement serves as the leading aspect that influences the investor when deciding whether to adopt the technology. It does not thoroughly capture all the criteria that affect the investment judgment. The ROI reflects the crucial element that affects earnings (income earned through selling electricity during the presence of FIT or at the market rate) and expenditure. Besides, it is frequently accepted in economics that investors explore to maximize gains relative to losses. Nevertheless, this study also includes a binary policy variable of a FIT to check the robustness of ROI results. The inclusion of the dummy variable is important to verify whether the impact of policy enactment alone is significant or not to accelerate solar PV capacity. It is expected that the ROI indicator is positive for solar PV development since it strengthens the significance of integrating details regarding the heterogeneity of the policy elements into the econometric analysis [18].

To ease the calculations for the FIT incentives, the following few presumptions are formed: (i) each location is retrofitted with PV systems either with 4 kW capacity for residential-scale or 100 kW for commercial-scale installations; (ii) the inauguration outlay is total remunerated at the commencement date of the project-no borrowings to finance the project; (iii) the PV system preserves 100 percent operation during the contract period [48,49]. However, many researches have shown that the financeable life of the PV system is likely to be extended beyond 25 years [50–53]; (iv) all the electricity produced is exported back to the grid [35,36].

$$ROI_{ijt} = \frac{\left(\left(FIT_{ijt} \times N_{ijt}\right) + \left[\left(P_{ijt}\left(SL_{it} - N_{ijt}\right)\right) - \left(LCOE_{ijt} \times SL_{it}\right)\right]\right.}{LCOE_{ijt} \times SL_{it}} \quad (1)$$

where FIT_{ijt} is the incentive earned by the solar PV investors for each electricity marketed to the grid under a FIT scheme in residential or commercial PV installation (in USD/kWh); N_{ijt} is the number of years of a FIT agreement; P_{ijt} is the average market electricity rate sold (in USD/kWh); SL_{it} is the anticipated shelf life of a PV panel device; $LCOE_{ijt}$ is the levelized cost of electricity generation for PV (in USD/kWh). The LCOE of a solar PV system i in country/state j in a given year t and can be calculated as follows:

$$LCOE_{ijt} = \frac{I_{it} + \sum_{t=1}^{SL} \frac{M_{it}}{(1+r)^t}}{\sum_{t=1}^{SL} \frac{E_{ijt}}{(1+r)^t}} \quad (2)$$

where I_{it} is the installation outlay of a PV system, M_{it} is the yearly maintenance cost; r is the risk-free rate of return; E_{ijt} is the amount of electricity generated from the PV system (kWh). The LCOE is applied since it is most often applied for electricity generation comparisons for emerging technologies such as solar PV [54–56]. Following Branker et al. [50], the amount of electricity generated from a solar PV system i (kWh) in a country/state j in a given year t can be calculated as follows:

$$E_{ijt} = IC_{it} \times SI_{ijt} \quad (3)$$

where IC_{it} is the installed capacity of solar PV depending on the size; SI_{ijt} is the average yearly local solar radiation in country/state j (in kWh/m^2).

For the aim of this study, ROI and LCOE are evaluated utilizing the assumption of optimality concerning technical conditions and operational specifications. The calculation of the financial profitability of FIT is restricted to the above measurement, which can be deemed the most critical element for any investment decision. Nevertheless, there is a possibility that the real investment decision is not only affected by investment, maintenance, and operation expenditure but also through transaction outlay, for instance, duration expended on negotiating an agreement with a PV inauguration [57]. Intuitively, the ROI indicator represents the ROI received by the investors for solar PV capacity inaugurated in year t in the country/states j. The numerator equals the revenue minus expenditure earned by the solar PV generators for producing a kWh per annual over the lifespan of a panel inaugurated during a FIT. Likewise, the denominator equals the cost of electricity generated from producing a kWh of solar energy annually. In the presence of FIT, the individual/firm earns a generation tariff of the incentives. As soon as the contract expires, the producer receives the electricity savings (average electricity price minus the cost of electricity generated from solar panels) until the end of the capacity lifespan.

To differentiate the impact of FIT policies from the impact of non-policy elements, this study follows the approach of Jenner, Groba and Indvik [18] by splitting the ROI indicator into two components. ROI_1_{ijt} measures the ROI during the FIT enactment. This approach is similar to the standard ROI, but it gives a value of zero for a country/state when a FIT is not enacted. The formula for ROI_1_{ijt} of a solar PV system i in a country/state j in a given year t can be calculated as follows:

$$ROI\_1_{ijt} = \begin{cases} \frac{\left(FIT_{ijt} \times N_{ijt}\right) + \left[\left(P_{ijt}\left(SL_{it} - N_{ijt}\right)\right) - \left(LCOE_{ijt} \times SL_{it}\right)\right]}{LCOE_{ijt} \times SL_{it}} & if\ FIT_{ijt} > 0 \\ 0 & if\ FIT_{ijt} = 0 \end{cases} \quad (4)$$

Meanwhile, ROI_0_{ijt} measures the ROI when the FIT is not enacted. This approach is similar to the market ROI, which takes the value of zero in the presence of FIT policies. The formula of ROI_0_{ijt} for a solar PV system i country/state j in a given year t can be calculated as follows:

$$ROI\_0_{ijt} = \begin{cases} \frac{\left[\left(P_{ijt} \times SL_{it}\right) - \left(LCOE_{ijt} \times SL_{it}\right)\right]}{LCOE_{ijt} \times SL_{it}} & if\ FIT_{ijt} = 0 \\ 0 & if\ FIT_{ijt} > 0 \end{cases} \quad (5)$$

The rationale for including these measurements is to investigate separately any country/state in which the FIT policies are enacted or are absent within the same model specification. The reason is that the ROI indicated during the FIT policies is driven by the policy-related attributes in comparison to the market ROI during the absence of FIT, which is driven by the non-policy attributes.

3.2.3. Other Market-Pull and Technology-Push Instruments

Apart from the FIT, this study also accounts for another market-pull policy, namely, tax credits for PV development. The tax credit is intended to encourage individuals and firms to invest in clean-energy technologies by allowing the investment in RETs to be fully or partially deducted from tax obligations or the income of the business. For the technology-push policy, this study applies to grants for solar PV uptake. This instrument is monetary assistance that does not need to be repaid and is given by the government for lessening investment costs corresponding to the preparation, purchase, or construction of RETs equipment. In addition, this incentive may also be associated with the establishment of a new RET market through the R&D phase. The availability of tax credits and grants is deciphered as a binary number, representing the digit of one to imply the existence of a support policy for the specific year and zero otherwise. It is expected that the presence of tax credits and grants will encourage greater solar PV capacity for the country.

3.2.4. Other Determinants of Solar PV Development

Besides the role of energy policies, the success of solar PV deployment also depends on several conditioning factors. Several control variables are transformed into natural logarithms (ln) to reduce any outliers that can potentially skew or bias any analysis performed in the estimation.

First, this study includes CO_2 intensity, which is evaluated by CO_2 emissions per GDP. The postulated influence of CO_2 intensity on the growth of renewables is ambiguous. First, it is possible that higher CO_2 emissions led to greater clean-energy technology investment. On the other hand, it is also possible that greater pollution reflects the higher demand for energy, and thus the inclination to commit the renewable energy sources will be reduced [40,58].

Second, this study includes the proportion of net energy imports to aggregate energy consumption to account for dependence on energy from foreign markets. Earlier literature (e.g., Gan et al. [59] and Dong, [60]) proposes that the major substitution of foreign energy dependence can be coped with by locally generated means. It is expected that the higher the foreign energy imports for a country, the higher the possibility of the country's searching for alternative energy, which eventually spurs RET adoption.

Third, this study considers the contribution of fossil fuel energy sources to total electricity generation compared to solar PV capacity. Fossil fuel generation can be a barrier to green energy development through the regular benefits of stakeholders in these sectors. Several studies (e.g., Huang et al. [61] and Sovacool, [62]) support the conjecture that the potency of fossil fuels derives from the effect of strong lobbying activities.

Meanwhile, the effect of income in the renewable literature has been tested several times (e.g., Chang et al. [63], Narayan and Smyth [64], and Sadorsky [65]). Generally, income can be measured in the following two forms: by GDP or by GDP per capita. This study measures income by using an absolute economic size measure (real GDP) and not the standard of living of a population as the explanatory variable. The inclusion of income as measured by real GDP will control for the possibility of wealthier countries having a higher rate of investment in renewable energy.

3.3. Econometric Model Specification

This study uses a fixed effects estimator to control any time-invariant variables that might be correlated with the dependent variable. The application of the fixed effects estimator assumes individual-specific effects that are permitted to be correlated with the exogenous variables. Based on the policy inducement, there are four countries that enact the FIT scheme at the country level, namely, Japan, Malaysia, South Korea, and Thailand. Meanwhile, FIT schemes in Australia and India vary across state levels. For a PV capacity i in country/state j, in year t, the fixed effects regression is stated as follows:

$$PV\ capacity_{ijt} = a_i + \beta_2 ROI_{ijt} + \beta_X Y_{ijt} + \beta_Y Z_{ijt} + \gamma_t + \sigma_i + \mu_{ijt} \quad (6)$$

where ROI_{ijt} is the return on investment of FIT incentives, measured by ROI (the numerical variable is also exchanged for a dummy FIT policy to indicate any impact on the presence of policy on the solar PV uptake or for ROI_1_{ijt} and ROI_0_{ijt} to parse out the impact of FIT incentive against non-policy attributes on ROI); Y_{ijt} is the binary variables of other renewable policy instruments to encourage solar PV growth; Z_{ijt} is other explanatory variables that might influence solar PV capacity; γ_t is year fixed effects that capture any variation over time that is not linked to other independent variables that are common to all countries/states j (e.g., global changes in energy prices, international political tension, and federal policy effects); σ_i is country/state fixed effects that takes account for time-invariant characteristics of country/state j (e.g., weather conditions, land area, and solar insolation) that might affect the solar PV development; μ_{jt} is the error term. The robust standard errors by year level are applied to control any heteroscedasticity and autocorrelation in the residuals. The advantages of applying the robust standard errors are that the p-values will be more accurate and the robust standard errors will not impact the coefficients of the variables.

To guarantee the accuracy of the findings, the validity of the fixed effects estimation is first evaluated by employing the following set of tests: (i) the Wooldridge test for serial correlation (e.g., Drukker [66]); (ii) the modified Wald statistics for group-wise heteroskedasticity (e.g., Greene [67]); (iii) the Pesaran test to check contemporaneous correlation (e.g., Pesaran [68]) and (iv) the Sargan–Hansen test to check for the presence of individual effects against random effects (e.g., Sargan [69] and Hansen [70]). In panel data, the most common approach to estimate the series is by fixed effects and random effects models. The application of these approaches is subjected to diagnostic checks such as serial correlation, heteroscedasticity, and cross-sectional dependence. From the Wooldridge test in Tables 1 and 2, the null hypothesis of no first-order autocorrelation is rejected at a 5 percent significance level, indicating that the residuals exhibit serial correlation. Next, from the modified Wald test in Tables 1 and 2, it is shown that the null hypothesis of the non-significance of the whole coefficient explanatory variables is rejected at a 5 percent significance level, indicating that the residuals exhibit group-wise heteroscedasticity. Third, from the Pesaran test in Tables 1 and 2, the null hypothesis of no cross-sectional correlation is not rejected at a 5 percent significance level, indicating that the residuals do not exhibit a cross-sectional correlation. Lastly, the Sargan–Hansen test in Tables A3 and A4 (Appendix A) shows the null hypothesis of non-observed individual effects is rejected at a 5 percent significance level, confirming there is a requirement for controlling the unrecognized heterogeneity between countries/states with the fixed effects model. Therefore, the robust standard errors are applied to account for heteroscedasticity and autocorrelation in the residuals. For the main analysis, the country/state fixed effects regressions are presented using three different sets of FIT variables to illustrate the effect of the FIT instrument on solar PV residential and commercial scales, namely, (i) binary FIT; (ii) ROI; (iii) a mix of ROI_0 and ROI_1. The following section explains the results from the estimations from the fixed effects specification in Equation (6).

Table 1. Fixed effects estimation results for solar PV on the residential scales.

Dependent Variable: Added_4 kW, ln								
Independent Variable	**Robust Standard Error**				**Conventional Standard Error**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
FIT	0.343 (0.256)				0.343 ** (0.156)			
ROI		0.145 ** (0.062)				0.145 *** (0.0561)		
ROI_4 kW_1			0.164 * (0.081)	0.149 (0.089)			0.164 *** (0.062)	0.149 ** (0.067)
ROI_4 kW_0			0.103 (0.082)	0.072 (0.059)			0.103 (0.071)	0.0721 (0.075)
Tax	0.058 (0.210)	−0.0005 (0.191)	−0.003 (0.196)	0.077 (0.251)	0.0579 (0.160)	−0.0005 (0.163)	−0.003 (0.163)	0.078 (0.189)
Grant	−0.732 *** (0.209)	−0.758 *** (0.215)	−0.761 *** (0.213)	−0.761 *** (0.215)	−0.732 *** (0.164)	−0.758 *** (0.161)	−0.761 *** (0.161)	−0.761 *** (0.163)
FIT × Tax				−0.226 (0.257)				−0.226 (0.253)
FIT × Grant				0.342 * (0.188)				0.342 (0.221)
Net import ratio	−2.234 *** (0.730)	−2.184 *** (0.722)	−2.224 *** (0.701)	−2.229 *** (0.732)	−2.234 *** (0.590)	−2.184 *** (0.587)	−2.224 *** (0.589)	−2.229 *** (0.591)
Fossil share, ln	1.734 (1.009)	1.777 * (0.994)	1.789 * (1.015)	1.763 * (0.965)	1.734 *** (0.431)	1.777 *** (0.430)	1.789 *** (0.430)	1.763 *** (0.430)
CO_2 intensity, ln	−0.150 (0.117)	−0.124 (0.112)	−0.117 (0.120)	−0.092 (0.103)	−0.150 (0.126)	−0.124 (0.126)	−0.117 (0.127)	−0.0918 (0.128)
GDP, ln	0.881 * (0.477)	1.087 ** (0.412)	1.119 ** (0.424)	1.180 ** (0.422)	0.881 *** (0.265)	1.087 *** (0.281)	1.119 *** (0.286)	1.180 *** (0.302)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country/state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 1. *Cont.*

Dependent Variable: Added_4 kW, ln								
Observations	342	342	342	342	342	342	342	342
R-squared	0.815	0.816	0.817	0.818	0.811	0.812	0.812	0.816
Wald (χ^2)					77.14 ***	81.30 ***	88.48 ***	98.67 ***
Wooldridge test F(N (0,1))					10.93 **	11.59 **	11.25 **	11.70 **
Pesaran test					−2.557	−2.613	−2.531	−2.658

Notes: (1) Numbers in parentheses are standard errors; (2) *** Statistically significant at $p < 1$ percent; (3) ** Statistically significant at $p < 5$ percent; (4) * Statistically significant at $p < 10$ percent; (5) The modified Wald test has χ^2 distribution and test the null hypothesis: $\sigma_c^2 = \sigma^2$, for $c = 1, \ldots N$; (6) The Wooldridge test the null hypothesis of no serial correlation and is normally distributed N (0,1); (7) The Pesaran test the null hypothesis of no contemporaneous correlation in residuals.

Table 2. Fixed effects estimation results for solar PV on the commercial scales.

Dependent Variable: Added_100 kW, ln								
Independent Variable	Robust Standard Error				Conventional Standard Error			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FIT	0.374 (0.365)				0.374 * (0.195)			
ROI		−0.268 * (0.140)				−0.268 *** (0.0997)		
ROI_100 kW_1			−0.220 (0.137)	−0.216 (0.164)			−0.220 ** (0.106)	−0.216 * (0.119)
ROI_100 kW_0			−0.338 (0.247)	−0.360 (0.246)			−0.338 ** (0.133)	−0.360 *** (0.137)
Tax	−0.355 (0.485)	−0.248 (0.512)	−0.239 (0.494)	−0.095 (0.650)	−0.355 (0.272)	−0.248 (0.270)	−0.239 (0.271)	−0.095 (0.343)
Grant	−0.259 (0.336)	−0.307 (0.332)	−0.287 (0.316)	−0.321 (0.313)	−0.259 (0.203)	−0.307 (0.198)	−0.287 (0.200)	−0.321 (0.207)
FIT × Tax				−0.273 (0.622)				−0.273 (0.388)
FIT× Grant				0.181 (0.442)				0.181 (0.317)
Net import ratio	0.393 (1.009)	0.432 (1.023)	0.447 (1.045)	0.513 (1.004)	0.393 (0.750)	0.432 (0.746)	0.447 (0.747)	0.513 (0.754)
Fossil share, ln	1.024 (1.287)	1.016 (1.403)	1.151 (1.412)	1.100 (1.460)	1.024 * (0.549)	1.016 * (0.546)	1.151 ** (0.555)	1.100 * (0.564)
CO_2 intensity, ln	0.025 (0.121)	−0.028 (0.113)	−0.015 (0.106)	−0.019 (0.109)	0.025 (0.160)	−0.028 (0.159)	−0.015 (0.160)	−0.019 (0.161)
GDP, ln	1.477 * (0.797)	1.095 (0.755)	1.154 (0.759)	1.087 (0.671)	1.477 *** (0.337)	1.095 *** (0.356)	1.154 *** (0.355)	1.087 *** (0.389)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country/state fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	342	342	342	342	342	342	342	342
R-squared	0.672	0.676	0.676	0.674	0.617	0.619	0.619	0.620
Wald (χ^2)					164.38 ***	106.23 ***	107.39 ***	109.96 ***
Wooldridge test F(N (0,1))					0.766	0.663	0.873	2.498
Pesaran test					−2.639	−2.629	−2.627	−2.622

Notes: (1) Numbers in parentheses are standard errors; (2) *** Statistically significant at $p < 1$ percent; (3) ** Statistically significant at $p < 5$ percent; (4) * Statistically significant at $p < 10$ percent; (5) The modified Wald test has χ^2 distribution and test the null hypothesis: $\sigma_c^2 = \sigma^2$, for $c = 1, \ldots N$; (6) The Wooldridge test the null hypothesis of no serial correlation and is normally distributed N (0,1); (7) The Pesaran test the null hypothesis of no contemporaneous correlation in residuals.

4. Empirical Results

This section reports the empirical results of the study. Tables 1 and 2 display that the binary dummy variable representing FIT policies (Column 1) is positive, but the effect has not been significant enough to drive solar PV capacity for both sectors since 1998. Interestingly, when the effect of the binary dummy FIT is replaced with an ROI indicator (Column 2), it is shown that it has a strong relationship with solar PV uptake for residential PV. For instance, the fixed effects regression in Table 1 (Column 2) implies that for a 10-percentage point rise in ROI, countries/states will initiate 1.5 percent PV capacity in the residential areas. Hence, the findings indicated a crucial relationship between FIT policies and solar PV growth by considering the heterogeneity of the policy in each country/state. Among the factors related to policy heterogeneity are the amount of the tariff compensated to the generators, the contract duration, and the digression rate, which decreases over time and is subject to the duration of the time after policy endorsement. Meanwhile, the non-policy factors are the cost of PV panels, wholesale electricity prices, LCOE, and shelf life of the PV systems.

Further, the result of the analysis for ROI revealed that the residential-scale PV capacity is affected by related policy attributes. Table 1 in Column 3 implies that for a 10-percentage point rise in ROI_4 kW_1, countries/states will initiate 1.64 percent more PV capacity per year on average from the residential PV sector. Interestingly, this study found that when the FIT policies are not in place, there is no relationship between ROI and PV growth for both PV systems. This finding of the study implies that additional ROI incentivized by FIT policies rather than market ROI may be the driver of PV growth for residential scales.

Table 2 shows worth noting that the effect of ROI on the PV commercial scale is negative and significant on PV growth. Table 2 in Column 3 implied that for a 10-percentage point rise in ROI_100 kW_1, countries/states will reduce 2.68 percent PV capacity per year on average from the commercial PV sector. However, dissimilar findings are found for the coefficients of ROI_100 kW_1 and ROI_100 kW_0 during the presence and absence of FIT policies. Table 2 (Column 7) shows that the effects of ROI_100 kW_1 and ROI_100 kW_0 are negative and significant for the conventional standard errors but that they become non-significant when robust clustered standard errors are applied to the regression to accommodate the presence of heteroskedasticity in the model. This evidence implies that additional ROI incentivized by FIT policies is not likely sufficient to impulse the deployment of commercial PV in the countries.

Besides the successful role of FIT on PV development on the residential scale, the results also revealed that the effect of capital grants on solar PV on the residential scale is negative and significant (see Table 1, Columns 1–4). Further, their effect becomes noticeably lower when the binary FIT is replaced with the ROI indicator. Table 2 captures the effect of capital grants on solar PV on the residential scale (Column 1) is negative and significant by 76 percent, and it becomes lower during the market ROI and ROI incentivized by FIT (Columns 3–4). On the other hand, it is noted that there is no relationship between tax credits or capital grants and PV commercial systems, although their effect is negative across regression specifications.

In addition to the individual policy treatment, this study also investigates whether any impact on PV growth arises from a policy mix of renewable instruments. For instance, the interaction between FIT and tax credit is positive but insignificant in Table 1 (Column 4), implying that the effect of a policy mix of tax credits and FIT does not benefit PV growth in the residential sector. In contrast, the results of the policy mix of FIT and capital grants are found to be successful in driving PV growth for the residential sector. For instance, the combination between FIT and capital grants is encouraging, implying that the effect of a policy mix of grants and FIT on PV growth in the residential scale is 34.2 percent on average per year. Nevertheless, it is found that the policy mix of FIT and tax credits and FIT and grants does not successfully influence PV growth on a commercial scale during the sample period of analysis.

This study also incorporated the country/state fixed effects to control for any country/state heterogeneity, which is likely to affect FITs stability and solar PV development (e.g., solar insolation, regulatory stability, previous and current design command) to the degree that these heterogeneities are time-invariant. Nonetheless, it might be in the interest of a researcher to compare the results of fixed effects with those of a random effects estimator. Tables A3 and A4 (Appendix A) provide the results of the random effects estimations. The tables reveal that the parameter estimates of policy variables are noticeably lower and less significant in the random effects regressions in comparison with fixed effects models, signifying that the impact of policy instruments on solar PV growth is negatively biased (e.g., understated) without controlling the country/state-level characteristics.

5. Outcomes' Discussion

The relative contribution of two types of factors, usually characterized as "technology-push" and "demand-pull", to the timeliness of new technology adoption has been the subject of continuous discussion. The availability of new technology, its maturity, and its relative benefit are among the first variables, while the degree of unmet need and awareness of the new technology are among the second. China began a revolution in energy production and consumption in late 2012. The country's leading economic planning organization revealed a tremendous increase in domestic renewable energy from wind, sun, and water in May 2014. China installed more new wind power in 2013 than the rest of the world combined and more solar PV than the United States over the previous decade. In the coming years, new goals will overshadow past accomplishments. China is also showing indications of weaning itself off coal, which presently generates three-quarters of the country's electricity. A growing number of Chinese provinces have imposed coal use caps as of the beginning of 2014.

Over the last two years, Chinese policymakers have made reforms aimed at accelerating the implementation of decentralized solar power and allowing people to generate their own electricity. The State Grid Corporation's action plan and new government laws mean that distributed solar projects under 6 MW might join the grid for no additional cost. New targets have been set for small-scale solar power to account for up to 50% of China's total solar power by 2015. Furthermore, the government has set fixed payments for the energy generated and has stated that low-cost financing would be encouraged to aid uptake. These precautions appear to be effective. In 2013, an estimated 3 GW of small-scale solar PV was installed, with an additional 8 GW predicted in 2014, equating to 32 million typical solar panels found on hundreds of thousands of British houses. At this rate, China will soon surpass Germany in solar energy production.

In conjunction with the China achievement-related PV systems, the study's results indicated that market-pull policies are important for increased solar PV deployment on a residential scale. Specifically, FIT is necessary for residential solar PV deployment, irrespective of whether other policy supports are incorporated or isolated. The FIT measures have probably been the most applied policy intervention in stimulating the renewable expansion; they are principally a form of price regulation under which the renewable electricity producer is granted a price for each kWh generated. Hence, price-driven measures represented by FIT provide financial incentives for direct expansion and capacity expansion for the technology. As noted by Mendoça [26] and Toke and Lauber [27], the FIT mechanism is better at lessening prices and investment risk, along with supporting learning-by-using, compared to quantity-based mechanisms. The quantity-based approach is a market-pull policy that obliges electricity companies to produce a fraction of their power from alternative sources. Examples of a quantity-based approach are energy portfolio standards and tradable green certificates.

More in-depth analysis reveals the importance of incorporating the unique policy design of FIT for accelerating solar PV on the residential scale. This is because the FIT is a unique instrument in which the investment incentives provided by the scheme vary depending on the market in which it operates and how each policy is designed. Therefore, policy-related (e.g., contract duration and tariff amount) and non-policy-related information (e.g., wholesale electricity price, solar insolation, and panel lifespan) are more necessary than the existence of a single policy for deciding on solar PV growth. Correspondingly, the fixed effects model shows that FIT is insignificant for solar PV in both domestic and commercial sectors when the binary policy variable is used. This result is consistent with that achieved by Jenner, Groba and Indvik [18], who revealed that incorporating a statistical representation of ROI into the model specification produces a significantly different result rather than relying on a binary policy variable. They found that FIT, represented by ROI, was significant for encouraging PV and wind growth for 26 EU countries between 1992 and 2008. Therefore, the intricacies of the specific design in FIT are important rather than focusing on the correctness of a policy category.

The findings also show the comparison between the impacts of market ROI and additional ROI in the presence of a FIT scheme. For residential-scale PV capacity, comparing ROI_4 kW_1 and ROI_4 kW_0 in fixed effects regression confirm that market ROI is not adequate to drive small-scale PV installation. In Table 1 (Column 3), the effect of a 10-percentage point rise in ROI leads from 1.03 percent in the country/state when the FIT is absent (ROI_4 kW_0) to a significant 1.64 percent in country/state years with a FIT implementation (ROI_4 kW_1). The paucity of FIT implies that ROI for the installation is minimum, and, consequently, any solar PV growth that arises is determined by other criteria, for instance, cultural and political environment (which have been captured by the fixed effects model). Consequently, when FIT is in place, ROI is capable of providing additional incentives for investors to invest in PV systems above that specified by other criteria during the presence of market ROI.

One unpredicted finding in this study is the substantial yet opposing impact of capital grants on solar PV installation for residential PV systems. A possible explanation for this is the lack of coordination in the implementation of both policy programs at the country/state level. In the case of insignificant coefficients of policy variables, for instance, tax credits for both PV installations, these may be insignificant because the tax credits were only recently adopted at the country/state level, and their weight in the sample is small. For instance, tax credits were implemented only for Japan, Malaysia, and Thailand at the end of 2009. The findings are validated by Jenner, Groba and Indvik [18], who found that tax incentives did not affect the solar PV and wind inaugurations in EU countries from 1992 to 2008.

Besides the positive and significant role of the market-pull policy represented by FIT, the finding also reinforces the importance of incorporating more than one policy variable to drive solar PV deployment. In other words, many policy interventions have overlapping goals and cooperate up to a certain extent. For instance, the findings show that capital grants for the early phase of the renewable energy market may be accompanied by FIT when the RETs become mature. This explanation can be found in the residential PV installations when they are then positive and significant for solar PV on the residential scales. The finding highlights the importance of having regulatory policy support in a combination between technology-push and market-pull policies as they are complimentary for adopting the technology and increasing renewable energy utilization (e.g., Grübler, Nakićenović and Victor, [71]; Bürer and Wüstenhagen, [37]; Johnstone, Haščič and Popp, [31]).

Although the success of a green energy strategy will be improved by a reciprocal approach, it will be decreased by uncoordinated overlapping policies. For instance, there is an insignificant effect of the combination of FIT and tax credits on both scale PV systems. This finding signifies those policies do not represent the various phases of technology growth and the process of introducing the technology into the market for solar PV deployment. Accordingly, renewables deployment will increase faster when there are complementary policies, and one may observe that renewables deployment is decreased if there is policy conflict as more policies are launched.

In contrast, despite commercial-scale PV systems generally having greater economies of scale than residential-scale PV systems, the finding established evidence that FIT has no effect on the development of solar PV on a commercial scale. This could be for a few reasons. First, this may be since the FIT received for commercial-scale PV is lower than for the residential sector, meaning that the ROI is not as attractive as for residential PV. For instance, in 2015, the FIT rates for residential-scale PV in Japan were approximately USD 0.22/kWh, compared to commercial-scale PV, where the FIT rates were lower at USD 0.17/kWh [72]. Therefore, the added revenue from the FITs is not adequate to drive PV projects into cost-competitiveness and encourage investment in commercial PV sectors. Second, the insignificant result of FIT regarding solar PV growth on a commercial scale is likely because the size of the panel system is larger, which makes its installation more difficult compared to residential-scale PV systems. For instance, in 2015, the net additional installed capacity of solar PV on a residential scale in Japan stood at 952.155 MW, compared to solar PV on a commercial scale, which was only 285.372 MW. In 2015, the net additional installed capacity of solar PV in South Australia on the residential scale stood at 545 MW, compared to solar PV on the commercial scale, which was only 1.25 MW. This finding establishes evidence that investors in residential-scale PV reap the benefit of FIT since these systems require less diligent work.

This study also provides robust evidence that the effect of renewable policies on solar PV growth is understated in the absence of fixed effects analysis. Huang et al. [61] and Chandler [73] highlighted the economic, geological, and political factors that affect policymakers' decisions to deploy renewable electricity generation. In detail, the factors that influence energy policy implementation and development in solar PV include the abundance of solar resources, a reliable planning regime favoring clean-energy technologies, strong lobbying for renewable development, and finally, a political and cultural environment favorable to renewables. Hence, the robust finding from the fixed effects regression verifies that these factors must be controlled to accurately assess policy effectiveness.

6. Concluding Remarks and Policy Implications

In conclusion, this study has successfully identified the effectiveness of energy policies in encouraging the adoption of solar PV technology. In contrast to most studies on RETs, they consider exclusively developed countries. However, this study focused on solar PV adoption in selected Asia-Pacific countries in the period of 1998–2015. This study addresses the differential impact of various policies on two types of solar PV scales—residential PV systems and commercial PV systems. This study's findings indicated that market-pull policies and policy interaction between technology-push and market-pull are necessary for determining the adoption of solar PV capacity on a residential scale. Solar energy adoption is one example of a larger class of technology adoption issues that can be influenced by both technical push and demand-pull variables. Policies to boost solar adoption, like other kinds of technological adoption, have addressed both technical hazards (technology-push) and adopter objections (demand-pull). Prior studies on innovation as it relates to the debate over technology-push vs. demand-pull, as well as previously recognized barriers to renewable energy adoption (RE). In addition, the presence of an ROI indicator to measure the effectiveness of FIT shows that the intricacies of a specific design in FIT are crucial for the deployment of residential-scale PV capacity.

The findings of this study have few policy implications. Considering policy interventions are a significant thrust of solar PV growth, it is possible that other countries can study and adopt the best strategy routines from successful economies to encourage the deployment of RET. In the field of solar PV development, the policy strength, represented by the ROI provided by FIT, has the greatest benefit for residential-scale PV systems. Therefore, policymakers should maximize the benefits of the FIT scheme since small-scale PV systems are able to accommodate the power supply for many households and can be installed with low investment costs. In addition, it is undoubtedly true that at some sites, residential-scale PV systems will have system and cost gains over large-scale PV.

The study presents three limitations. First, the low coefficients of regulatory support variables in the findings propose that renewable energy has been initiated to a greater degree in more advanced economies, for instance, Japan and South Korea, and currently in emerging economies, for instance, Malaysia and Thailand. Second, precise information on PV capacity for small-scale (4 kW) and commercial-scale (100 kW) installations in selected countries/states cannot be obtained due to data unavailability. Thus, the average value of solar PV installation for each capacity was applied to construct the ROI value. Nevertheless, this study also applied a binary policy variable of a FIT to check the robustness of ROI results. Third, although there are already several commercially and economically viable RETs, the sector only accounts for a modest proportion of global energy generation. Accordingly, there might be other factors that hinder the market penetration of RETs besides the presence of effective energy policies noted in this chapter. Therefore, the effect of finance on the growth of RETs is worth investigating since the energy field demands a large initial outlay due to the sector requiring more heavy capital than other sectors.

Future studies are suggested to extend the analysis of solar power plants demographically and economically. It is a very diverse and wide geographical area that should be taken to express the discontinuity of solar energy and the impact of expanding electricity storage on the overall economic and environmental parameters. Moreover, the condition in 2015 was far different from that in 2020 when China, India, and Vietnam had been accelerating their PV development much faster than Japan. The changes in the policies that happened between 2015 and 2020 have been shaping the current PV market in the region and will influence its future direction. Thus, the future study recommends considering the current year of the dataset, e.g., from 2015 to 2022.

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Appendix A

Table A1. Definition of variables and summary statistics.

Variable	Definition	Mean	Std. Dev.	Min	Max
Added_4 kW	Annual added capacity for residential PV installation	71.106	202.645	0	1497.172
Added_100 kW	Annual added capacity for commercial PV installation	49.158	169.404	0	1304.8
ROI_4 kW	Return on investment for residential PV installation	0.396	1.608	−0.9	7.43
ROI_100 kW	Return on investment for commercial PV installation	0.365	1.056	−0.89	6.66
ROI_4 kW _1	Return on investment for residential PV installation when FIT is enacted	0.453	1.233	−0.82	8.09
ROI_100 kW _1	Return on investment for commercial PV installation when FIT is enacted	0.388	0.989	−0.69	6.66

Table A1. *Cont.*

Variable	Definition	Mean	Std. Dev.	Min	Max
ROI_4 kW _0	Return on investment for residential PV installation when FIT is not present	−0.058	1.008	−0.9	8.43
ROI_100 kW _0	Return on investment for commercial PV installation when FIT is not present	−0.08	0.744	−0.91	5.66
FIT_4 kW	Dummy variable, encoded as 1 if FIT is awarded to residential PV installation, 0 otherwise	0.234	0.424	0	1
FIT_100 kW	Dummy variable, encoded as 1 if FIT is awarded to commercial PV installation, 0 otherwise	0.228	0.420	0	1
Tax_4 kW	Dummy variable, encoded as 1 if tax credits are awarded to domestic PV installation, 0 otherwise	0.529	0.499	0	1
Tax_100 kW	Dummy variable, encoded as 1 if tax credits are awarded to commercial PV installation, 0 otherwise	0.312	0.464	0	1
Grant_4 kW	Binary variable, coded as 1 if the capital grant is awarded to residential PV installation, 0 otherwise	0.549	0.498	0	1
Grant _100 kW	Binary variable, coded as 1 if capital grant is awarded to commercial PV installation, 0 otherwise	0.616	0.486	0	1
Net import ratio	Net energy imports ratio to total energy consumption	0.118	0.293	−0.774	0.939
CO_2 Intensity	CO_2 emission per GDP	26.486	7.757	11	44.3
Fossil Share	Importance of fossil fuels ratio to total electricity generation	62.382	23.772	4.498	98.845
GDP	Real GDP in billion, constant USD (2000 prices)	426	1250	9.79	5990

Table A2. Correlation matrix.

	Added Capacity_4 kW, ln	**Added Capacity_100 kW, ln**	**ROI_4 kW**	**ROI_100 kW**	**ROI_4 kW_1**	**ROI_4 kW_0**
Added capacity_4 kW,ln	1					
Added capacity_100 kW,ln	0.527	1				
ROI_4 kW	0.504	0.213	1			
ROI_100 kW	0.578	0.416	0.867	1		
ROI_4 kW_1	0.389	0.148	0.78	0.704	1	
ROI_4 kW_0	0.328	0.159	0.643	0.525	0.0231	1
ROI_100 kW_1	0.425	0.317	0.668	0.804	0.823	0.062
ROI_100 kW_0	0.422	0.284	0.551	0.616	0.063	0.801
FIT_4 kW	0.48	0.401	0.53	0.626	0.666	0.026
FIT_100 kW	0.479	0.424	0.543	0.603	0.644	0.074
Tax _4 kW	0.538	0.349	0.229	0.325	0.176	0.153
Tax_100 kW	0.705	0.593	0.481	0.571	0.346	0.346
Grant_4 kW	0.021	−0.158	−0.148	−0.24	−0.151	−0.049
Grant_100 kW	0.41	0.179	0.144	0.143	0.059	0.161
FIT_4 kW × Tax_4 kW	0.33	0.236	0.479	0.504	0.607	0.023
FIT_4 kW × Grant_4 kW	0.406	0.213	0.607	0.523	0.56	0.283
FIT_4 kW × Tax_100 kW	0.377	0.217	0.537	0.533	0.644	0.069
FIT_4Kw ×Grant_100 kW	0.302	0.129	0.482	0.394	0.572	0.070
GDP, ln	0.169	0.084	0.393	0.283	0.283	0.278
Net import ratio	0.195	0.188	−0.046	−0.016	0.009	−0.087
Fossil share, ln	0.111	0.118	0.036	0.017	0.024	0.027
CO_2 intensity, ln	−0.131	0.032	−0.245	−0.233	−0.096	−0.271

Table A2. *Cont.*

	ROI_100 kW_1	ROI_100 kW_0	FIT_4 kW	FIT_100 kW	Tax _4 kW	Tax_100 kW
ROI_100 kW_1	1					
ROI_100 kW_0	0.042	1				
FIT_4 kW	0.669	0.16	1			
FIT_100 kW	0.722	0.059	0.901	1		
Tax _4 kW	0.256	0.223	0.286	0.303	1	
Tax_100 kW	0.429	0.396	0.461	0.475	0.636	1
Grant_4 kW	−0.254	−0.052	−0.180	−0.194	−0.018	−0.201
Grant_100 kW	0.033	0.2	0.094	0.056	0.365	0.272
FIT_4 kW × Tax_4 kW	0.607	0.042	0.704	0.716	0.367	0.446
FIT_4 kW × Grant_4 kW	0.51	0.227	0.624	0.654	0.202	0.341
FIT_4 kW × Tax_100 kW	0.643	0.039	0.628	0.66	0.338	0.532
FIT_4 kW × Grant_100 kW	0.473	0.0376	0.608	0.641	0.196	0.273
GDP, ln	0.23	0.142	0.312	0.313	−0.252	0.047
Net import ratio	0.075	−0.11	0.194	0.201	0.117	0.039
Fossil share, ln	0.043	0.008	0.091	0.119	−0.064	−0.023
CO_2 intensity, ln	−0.067	−0.26	−0.07	−0.041	0.056	−0.174

	Grant_4 kW	Grant_100 kW	FIT_4 kW × Tax_4 kW	FIT_4 kW × Grant_4 kW	FIT_100 kW × Tax_100 kW	FIT_100 kW × Tax_100 kW	GDP, ln	Net import ratio	Fossil share, ln	CO_2 intensity, ln
Grant_4 kW	1									
Grant_100 kW	0.593	1								
FIT_4 kW × Tax_4 kW	−0.135	0.022	1							
FIT_4kW × Grant_4 kW	−0.005	0.126	0.638	1						
FIT_100 kW × Tax_100 kW	−0.175	0.017	0.894	0.605	1					
FIT_100 kW × Grant_100 kW	0.031	0.274	0.672	0.728	0.615	1				
GDP, ln	0.121	0.004	0.401	0.4	0.347	0.318	1			
Net import ratio	0.039	−0.015	0.313	0.233	0.172	0.215	0.371	1		
Fossil share, ln	0.019	−0.141	0.186	0.207	0.09	0.124	0.417	0.267	1	
CO_2 intensity, ln	−0.043	−0.195	0.001	0.01	−0.13	−0.023	−0.23	0.168	0.209	1

Table A3. Random effects estimation results for solar PV on the residential scales.

Independent Variable	Dependent Variable: Added_4 kW, ln							
	Robust Standard Error				Conventional Standard Error			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FIT	0.287 (0.260)				0.287 * (0.167)			
ROI		0.077 (0.070)				0.077 (0.0563)		
ROI_4 kW_1			0.069 (0.093)	0.090 (0.122)			0.069 (0.062)	0.090 (0.072)
ROI_4 kW_0			0.073 (0.053)	0.034 (0.054)			0.073 (0.075)	0.034 (0.079)
Tax	0.170 (0.220)	0.158 (0.224)	0.159 (0.223)	0.344 (0.239)	0.170 (0.170)	0.158 (0.173)	0.159 (0.173)	0.344 * (0.200)
Grant	−0.558 ** (0.218)	−0.570 *** (0.200)	−0.579 *** (0.202)	−0.585 *** (0.192)	−0.558 *** (0.169)	−0.570 *** (0.169)	−0.579 *** (0.169)	−0.585 *** (0.175)
FIT × Tax				−0.513 *** (0.110)				−0.513 * (0.276)
FIT × Grant				0.317 (0.415)				0.317 (0.238)
Net import ratio	−0.931 * (0.545)	−0.769 (0.559)	−0.822 (0.551)	−0.562 (0.662)	−0.931 ** (0.456)	−0.769 * (0.446)	−0.822 * (0.455)	−0.562 (0.439)
Fossil share, ln	0.738 (0.623)	0.678 (0.593)	0.720 (0.608)	0.511 (0.517)	0.738 *** (0.281)	0.678 ** (0.273)	0.720 *** (0.279)	0.511 ** (0.259)
CO_2 intensity, ln	0.118 (0.181)	0.139 (0.181)	0.131 (0.180)	0.158 (0.170)	0.118 (0.081)	0.139 * (0.082)	0.131 (0.083)	0.158 ** (0.079)
GDP, ln	0.194 (0.166)	0.199 (0.163)	0.198 (0.163)	0.217 (0.154)	0.194 *** (0.072)	0.199 *** (0.069)	0.198 *** (0.072)	0.217 *** (0.067)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	342	342	342	342	342	342	342	342
Sargan–Hansen test	329.279 ***	252.314 ***	251.380 ***	425.867 ***				

Notes: (1) Numbers in parentheses are standard errors; (2) *** Statistically significant at $p < 1$ percent; (3) ** Statistically significant at $p < 5$ percent; (4) * Statistically significant at $p < 10$ percent; (5) Sargan–Hansen is the test of overidentifying restrictions of fixed effects vs. random effects. The joint null hypothesis is that the instruments are valid instrument; (i) no correlation between the vector of regressor and error term; (ii) no correlation between the vector of regressors and group-specific error.

Table A4. Random effects estimation results for solar PV on the commercial scales.

Independent Variables	Dependent Variable: Added_100 kW, ln							
	Robust Standard Error				Conventional Standard Error			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FIT	0.342 (0.406)				0.342 * (0.199)			
ROI		−0.396 *** (0.149)				−0.396 *** (0.093)		
ROI_4 kW_1			−0.360 ** (0.162)	−0.310 (0.190)			−0.360 *** (0.100)	−0.310 *** (0.118)
ROI_4 kW_0			−0.409 (0.254)	−0.468 ** (0.233)			−0.409 *** (0.128)	−0.468 *** (0.127)
Tax	−0.198 (0.444)	−0.107 (0.498)	−0.085 (0.480)	0.340 (0.635)	−0.198 (0.274)	−0.107 (0.267)	−0.085 (0.269)	0.340 (0.328)
Grant	0.073 (0.311)	−0.049 (0.314)	−0.023 (0.300)	−0.152 (0.282)	0.073 (0.187)	−0.049 (0.180)	−0.023 (0.182)	−0.152 (0.186)
FIT × Tax				−0.937 (0.694)				−0.937 ** (0.366)
FIT × Grant				0.445 (0.490)				0.445 (0.314)
Net import ratio	0.357 (0.660)	0.509 (0.543)	0.522 (0.598)	0.616 (0.521)	0.357 (0.438)	0.509 (0.431)	0.522 (0.444)	0.616 * (0.326)

Table A4. *Cont.*

Independent Variables	Dependent Variable: Added_100 kW, ln							
	Robust Standard Error				Conventional Standard Error			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Fossil share, ln	0.033 (0.274)	0.135 (0.267)	0.184 (0.268)	0.043 (0.219)	0.033 (0.253)	0.135 (0.251)	0.184 (0.258)	0.043 (0.180)
CO_2 intensity, ln	0.167 * (0.099)	0.077 (0.087)	0.073 (0.089)	0.077 (0.062)	0.167 ** (0.0770)	0.077 (0.0774)	0.073 (0.079)	0.077 (0.059)
GDP, ln	0.114 (0.072)	0.092 (0.067)	0.085 (0.068)	0.092 * (0.054)	0.114 * (0.065)	0.0921 (0.064)	0.085 (0.066)	0.092 * (0.047)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	342	342	342	342	342	342	342	342
Sargan-Hansen test	156.681 ***	92.298 ***	157.312 ***	158.107 ***				

Notes: (1) Numbers in parentheses are standard errors; (2) *** Statistically significant at $p < 1$ percent; (3) ** Statistically significant at $p < 5$ percent; (4) * Statistically significant at $p < 10$ percent; (5) Sargan-Hansen is the test of overidentifying restrictions of fixed effects vs. random effects. The joint null hypothesis is that the instruments are valid instrument; (i) no correlation between the vector of regressor and error term; (ii) no correlation between the vector of regressors and group-specific error.

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