PV adoption in Wallonia: The role of distribution tariffs under net metering*

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Abstract

The deployment of decentralized productions units (DPU) like rooftop solar panels is a major challenge for energy transition. Under a net metering system where the meter runs backward when there is excessive PV production, the electricity produced by a solar panel is valued at the retail price. Higher retail prices thus encourage the deployment of DPU. In this paper, we study the impact of tariffs on the decision to install residential solar installations. We analyze a panel data from Wallonia, where tariffs depend largely from volumetric charges. We exploit the presence of 13 different grid operators with non-uniform tariffs, to disentangle this relationship. Using various specifications, results suggest that in a municipality where the distribution tariff is one eurocent per kWh higher, the investment in solar PV is, all else equal, on a yearly basis around 5% higher.

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JEL codes: Q42, L51, D12

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1 Introduction

The traditional electricity system faces many challenges with the transition towards greener energy. New modes of production do not only have a tremendous impact at the production stage. A key issue for the distribution system operators (DSO) is to integrate distributed generation units (DPU), like residential solar panels, that are connected to the low voltage grid. By installing solar panels, households do not only produce green energy that they consume, they are also using the grid to make power exchanges. Indeed, a grid-connected DPU can import electricity when the production is insufficient to cover the consumption and export the excessive power when production exceeds consumption. There are thus a new kind of exchanges with the grid. There are different methods to price these power exchanges between a DPU and the grid and the financial return of a DPU is influenced by both the pricing structure and the price level (see Brown and Sappington (2017) and Gautier et al. (2018)). Consequently, we should observe a larger deployment of DPU in those regions offering a higher return on investment. In particular, if the electricity produced by a DPU is valued at the retail price, which includes network contributions, we should expect that in those regions where the retail price is higher, because the DSO applies higher network charges, the deployment of DPU is larger. Our objective is to test this relationship.

We use municipality-level data from 2008 to 2016 from the Walloon region, the southern region of Belgium. We focus on residential PV investments, which, as of today, have been made by close to 10% of the households. PV panels are connected to the grid and, when there is excessive production by the panels, the electricity is supplied to the grid. Under the net metering system used in Wallonia, the meter runs backward when electricity is supplied to the grid. Therefore, the electricity produced is valued at the retail price. One important component of the retail price is the grid tariff. Our estimation strategy takes advantage of the fact that tariffs are set by one of the 13 distribution system operators present on the territory, while energy policies, including those aimed at supporting the transition towards a green energy system, are set for the most at the regional and national levels. Key advantages of our setting are the wide variability across places and time of tariffs and the fact that, in Wallonia, tariffs are in large part dependent on the amount of electricity consumed, i.e. tariffs are volumetric. In addition to take advantage of cross sectional and inter-temporal variation in tariffs, we also control for various socioeconomic, housing and political factors. We believe that this approach allows us to obtain estimates reliable for policy purposes.

We find that higher consumption-based tariffs do provide incentives to invest in residential PVs, as net metering increases the returns on investment. Using various estimation approaches, we find that an increase in the distribution tariff by one eurocent per kWh leads to an increase of around 5% in the amount of new PVs installed yearly by households.

The determinants of the emergence of renewable energy sources in the energy system has already received much attention from the literature since the first analysis from Menz and Vachon (2006). Interests in investments in solar panels by residential households are much more recent. For example, the various factors behind PV adoption are studied in Vasseur and Kemp (2015) and De Groote et al. (2016). Using data at the household level or at the aggregated level such as the block, municipality or supra-municipality (county or utility), the literature has mostly focused on two issues. First, some authors have analyzed the role of social spillovers and the spatial diffusion of residential PVs as in Bollinger and Gillingham (2012), Muller and Rode (2013), Graziano and Gillingham (2014) or Balta-Ozkan et al. (2015). For example, Allan and McIntyre (2017) analyze a municipality-level data set from Great Britain. Using spatial econometrics techniques, they examine and confirm the presence of peer effects in the adoption of this solar technology. Second, more recently, other authors have also analyzed the effectiveness of policy incentives like upfront rebates, tax exemptions, tax credits or policies such as renewable portfolio standards (see Hughes and Podolesky (2015) and Crago and Chernyakhoskiy (2017)).

Empirical papers focusing on the link between grid-related factors and PV adoptions by residents are relatively scarce. They were mainly focused on the access to the power grid in the context of developing countries (see for example Smith and Urpelainen (2014)). Using U.S. state-level data, Matisoff and Johnson (2017) study the role played by net-metering policies, that allow residents to sell the over-supply of electricity to the energy grid at a price equal to the retail price. They find that net-metering policies, on a stand-alone base, are ineffective in encouraging households to invest in PVs. However, coupled with financial incentives, especially in the form of upfront cash incentives, this conclusion is reversed. Hence, financial incentives and net metering policies complement each others.

This work also relates to the theoretical literature interested in the regulation of natural monopolies (Joskow (2007)), and especially works looking at the regulation of DSO with a high diffusion rate of DPU (Jenkins and Perez-Arriaga (2017)). For example, Brown and Sappington (2017) study how the energy grid operator can break-even despite the emergence of distributed generation. To induce a desired level of decentralized production, fixed fee should be introduced in addition to volumetric charges, and if feasible additional fixed charges levied from decentralized producers should be introduced. Gautier et al. (2018) further on argue that volumetric charges are particularly problematic in settings where net-metering systems are implemented, as observed in Wallonia. Furthermore, the so-called prosumers have limited incentives to synchronize their local production with their consumption.

This paper attempts to measure the elasticity of investment in PV with respect to tariffs. We believe that our estimation will be of further use for the literature trying to quantify the impact of decentralized production units on the grid over time using numerical models like Cai et al. (2013), Darghouth et al. (2016) or Schittekatte et al. (2018). While many papers have used similar parameters to study this question, to our knowledge, none of them had precise empirical motivations for the parameter chosen. Overall, our results also highlight the problems faced by grid operators that are highly dependent on volumetric charges to recover their mostly fixed costs. Hence, it calls for a higher reliance on capacity payments (Borenstein (2016)), even though concerns about efficiency, redistribution and the consequences of usage-related externalities should not be overshadowed.

The paper is organized as follows. Section 2 provides a background of the energy sector in Wallonia, and more precisely about the policy context surrounding tariffs regulations and residential PV investments. Section 3 presents the data while Section 4 discusses our empirical strategy. Our results are presented in Section 5. In Section 6, we conclude and analyze some policy implications.

2 Residential PV in Wallonia

Belgium is composed of 3 regions: Brussels, Flanders and Wallonia. Wallonia is the largest in area and has more than 3.5 millions inhabitants. It is composed of 262 municipalities. In terms of energy policy, regions have the responsibilities to meet the targets about electricity production from renewable sources and to regulate the distribution of electricity. All other production as well as transmission issues are regulated at the national level.

2.1 Support to solar energy in Wallonia

Residential solar PV installations of less than 10 kWp are the focus of this paper. As shown on Figure 1, by the end of 2016, Wallonia had more than 130 000 households with PV installed in their residence, with a total capacity of 699 MWp. These installations produced 686 GWh of electricity in 2016. A striking fact described on this graph is that the most fruitful year in term of PV investments was the year 2012, even though the price of PV panels have continuously decreased since then. The main reason behind this shape is the very generous support system present in Wallonia and progressively discarded after 2012. Starting in 2008, Wallonia installed several mechanisms to support the deployment of small-scale solar panels by households. The supporting mechanism for residential installations (less than 10 kWp) is composed of several elements: a net metering system, a subsidy for the production of energy from renewable ressources, investment subsidies (mainly tax cuts) and, in some cases, additional grants from local government levels.

Net metering Households who install solar panels are making two types of exchange with the grid: imports from the grid when local production is insufficient to cover consumption and exports to the grid when production exceeds the consumption. To measure the exchanges with the grid, household are equipped with a single meter and the meter runs backwards when electricity is exported. This system is known as net metering. The meter measures net imports of energy, consumption minus production and net imports are used as the basis for the energy billing. With net metering, the energy produced by

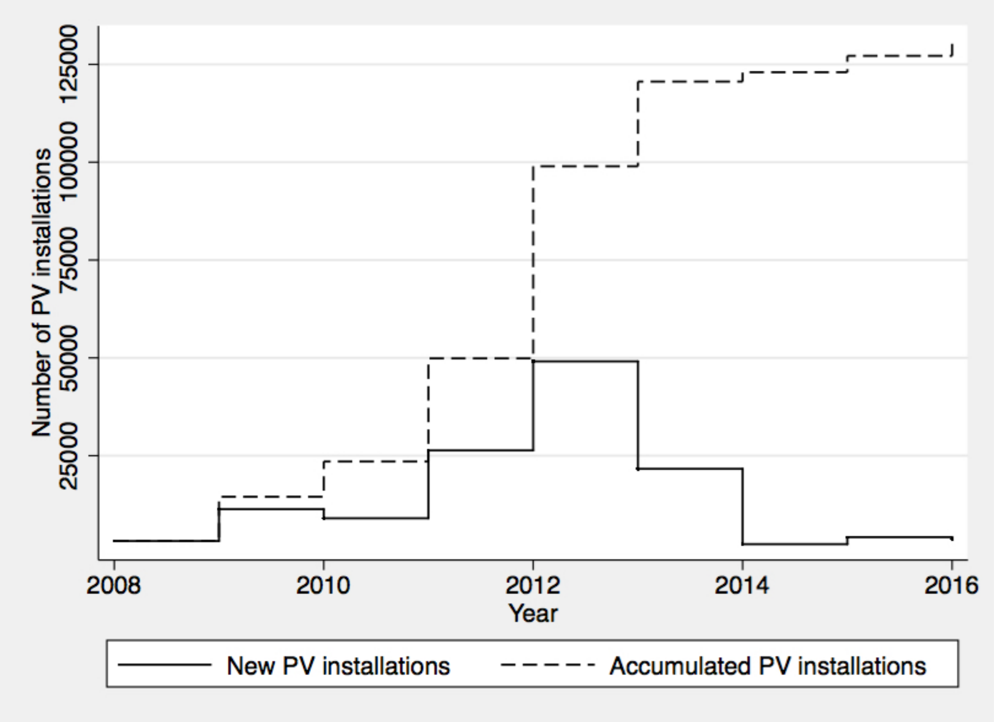

Figure 1: New and accumulated residential PV installations in Wallonia (2008-2016)

the solar panels is valued at its market value. In Wallonia, should the yearly production exceeds the yearly consumption (a negative index on the meter), there is no additional payment for these net exports and the electricity bill is equal to zero. With net metering, a higher grid tariff increases the return on PV investment. Hence, it can be seen as a implicit form of financial support for decentralized energy production.

Solwatt and Qualiwatt To support the production of green energy, Wallonia choose a tradable green certificate (GC) mechanism. Green certificates are awarded for the production from certified renewable sources at a rate of 1GC per MWh of green electricity produced. Energy retailers must use the GC to certify that a given percentage of their energy supply is green. To that end, GC are traded on a dedicated market and the regulator added a price floor at 65€ and a price ceiling at 100€. With a granting rate of 1GC per MWh, solar panels were not profitable. In 2008, the *Solwatt* plan changed this granting rate to 7 GC per MWh for solar PV installations of less than 10 kWp and extended the grant period. The technology started to spread quickly as the mechanism was quite generous with an estimated direct support of 588 € per MWh produced (Boccard and Gautier, 2015). As from 2011, the grant rate and the grant periods were modified (see table 1) but this change applied to new installations exclusively. The generous granting of GC to solar panels disequilibrated the GC market and the Solwatt system was replaced in March 2014 by a new supporting scheme named *Qualiwatt*. Installations supported by Qualiwatt have a guaranteed return on investment. The PV owner receives a yearly premium during 5 years. The premium is based on the installed capacity. As the net metering compensation is part of the return, a higher network fee implies a lower yearly premium to keep the return constant. Under Qualiwatt supporting scheme, the benefit of a higher grid tariff is partially offset by a lower premium. The Qualiwatt mechanism will be over in June 2018 and at this time new PV installations will no longer get a premium.

Grant rate (GC/MWh)	Grant period (years)	Application period
7	15 years	Jan. 2008 - Nov. 2011
7	10 years	Dec. 2011- Mar. 2012
6	10 years	Apr. 2012 - Aug. 2012
5	10 years	Sep. 2012 - Mar. 2013
1,5	10 years	Apr. 2013 - Feb. 2014

Table 1: Grant rate and grant period of GC, Solwatt mechanism

Investment subsidies During the period 2008-2011, investments in solar PV were eligible for an income tax rebate. The federal government supported investments in energy saving technologies, including solar panels, by allowing household to deduct installation expenses from their taxable incomes.

Different premia were offered to support investments in solar PV. The Walloon government offered an investment premium from 2008 to March 2010. The premium was calculated as a percentage of the investment and was capped. Some local governments (provinces and municipalities) decided to offer additional premium for the investment. In the timespan of our study, households in 80 municipalities have benefited from a local support mechanism at some point in time.

2.2 Distribution tariff

With the unbundling of the electricity system, the distribution of electricity is operated by local monopolies and 13 of them are now active on the territory of Wallonia covering from one municipality to about 60 of them, see Fig. 2. On average, as of 2017, distribution tariffs make 37% of the resident's final electricity bill (CWaPE (2017)). Distribution tariffs are regulated by the energy regulator active in Wallonia: The CWaPE. The regulator decides on a tariff methodology for a regulatory period of four years and the system in place is close to a cost-plus regime. Eligible costs were passed through consumers and the distribution tariff is adjusted yearly. Each DSO has its own tariff and there is no uniform pricing in Wallonia.

One particularity of the distribution bill in Wallonia is that it is for the most based on the volume of electricity consumed (Hinz et al. (2018)). For an average consumption of 3500 kWh per year, an average resident of Wallonia will have a bill related to the distribution of electricity that depends only at around 6% from fixed/capacity charges. The rest depends on the volume of electricity consumed. This reliance on the volumetric part is one of the highest observed in Europe, only equalled by the one observed in Hungary and the UK (European Commission (2015)).

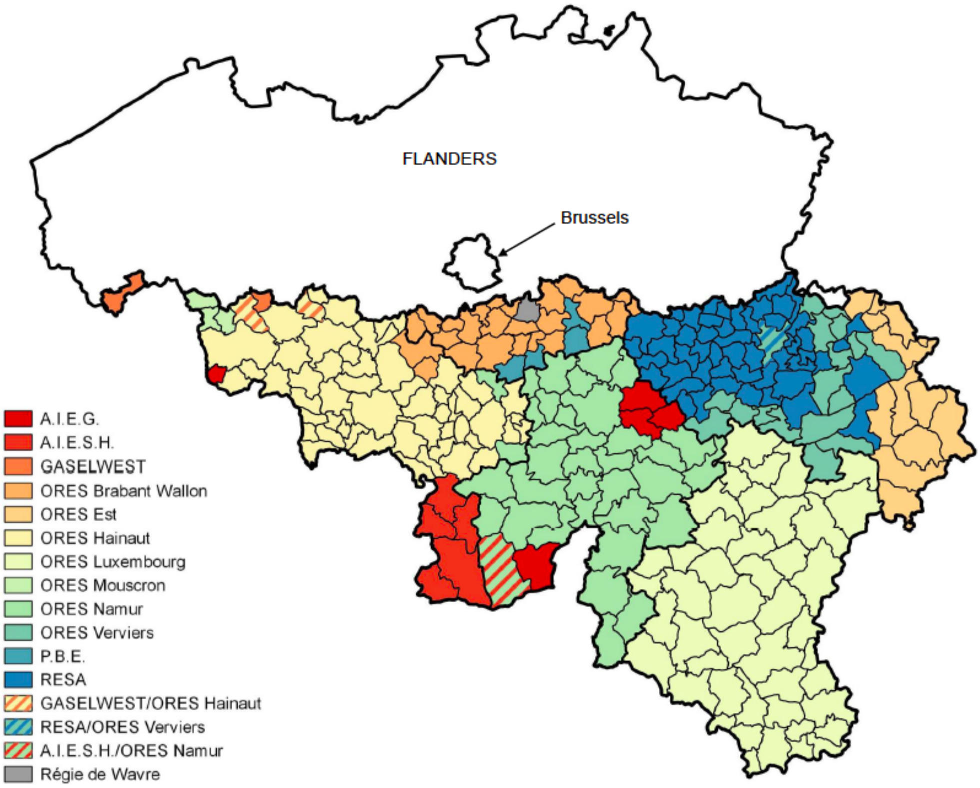

Figure 2: Map of Belgium with the 13 DSO active in Wallonia

Consumers have the choice between a single tariff or a dual tariff with a different rate for day and night consumptions (with the weekend being counted as night consumption). The following figure reports the single volumetric tariff (including VAT) for the 13 DSO for the period 2008-2016. As shown on Fig.3, distribution tariffs have been on the rise over the past 10 years, with the exception of the year 2014 where a transitory change in the VAT rate was applied. During our period of observations, the average tariff went from 7.8 to 10.5 eurocent/kWh. Although this rise has been heterogenous across Wallonia. Even if there is some within variation (0.92), most of the variation is between (1.39) our unit of analysis, the DSO. This heterogeneity reflects differences in local costs of distributing electricity and differences in the relative efficiency of the DSO, but the cost-plus system in place is not effective to disantangle the two. On average, the difference between the highest and the lowest tariff is equal to 8 eurocent/kWh.

For solar PV owner, a 1 eurocent difference in the distribution tariff translates into an additional saving of 10€ per MWh produced. This means that, in 2016, an installation producing 6 MWh has an *extra* yearly return of 442.8 € in the municipalities served by GASELWEST where the distribution tariff was the highest (14.60 eurocent/kWh) compared to municipalities served by AIEG where it was the lowest (7.22 eurocent/kWh). With a life time over 20 years for a solar panel, we expect that these substantial differences will have an impact on the decision to invest in solar PV installations.

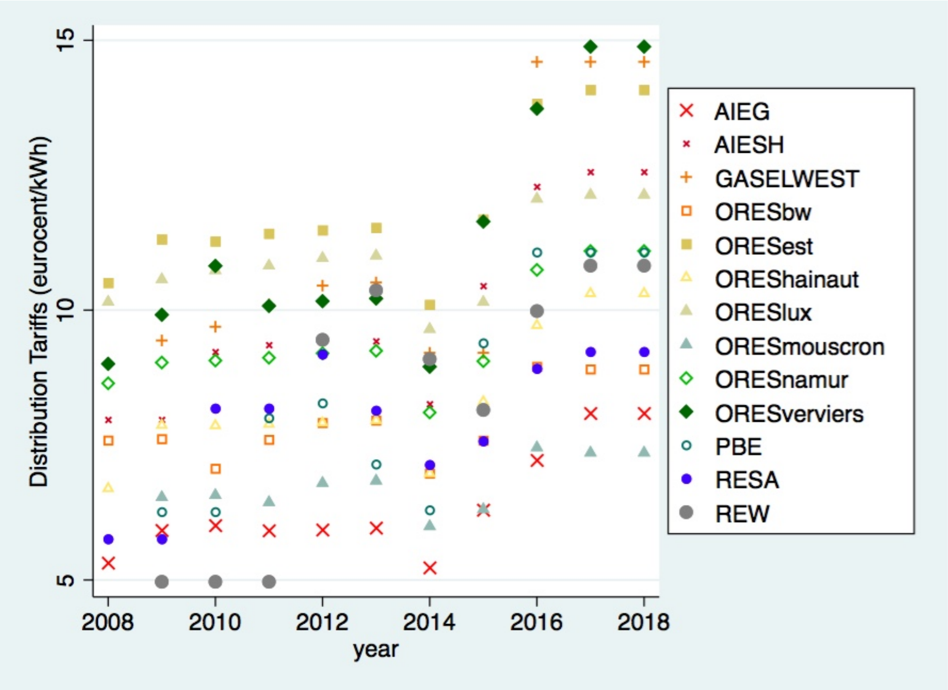

Figure 3: Evolution of the distribution tariff in the 13 DSO active in Wallonia (2008-2018)

3 Data

The CWaPE, the regulatory body responsible for the energy sector in Wallonia, collects information about the PV systems installed by residents. We have data since 2008, and PVs were scarce before then. Registration to the regulator is compulsory to be eligible for the subsidizing schemes. This information is aggregated at the municipality level for each years. The main reasons for this are because the information at the sub municipality level is imprecise and all our control variables are only available at the municipality/year level. We have information about both the number of installations and the production capacity of each installation in kilowatt-peak. There are two important things to note. First we have to drop six municipalities where two distribution system operators are active.[1] We end up with 256 municipalities remaining out of the 262 present in Wallonia. Second, the presence of municipalities where no PV panel were installed in a given year is very limited as it is only the case in 14 out of 2039 municipality/year observations.

Table 2: Descriptive statistics

Dependent variables	Mean	Std. Dev.	Min	Max	Source
Number of PV installations	59.977	85.487	0	1330	CWaPE
Capacity of PV installed	344.95	495.196	0	7527.21	CWaPE
Independent variables					
Tariff (eurocent/kWh)	8.81	1.67	4.967	14.602	CWaPE
% of houses	18.016	12.827	1	56.7	Walstat
% built after 81	21.74	7.01	5.4	40.3	Walstat
% unemployed	12.651	4.476	3.6	28.7	Walstat
Population (log of)	9.062	0.799	7.214	12.225	Walstat
Median income (log of)	10.26	0.152	9.885	10.809	Walstat
% foreigners	6.526	5.669	1.47	50.4	Walstat
Average age	40.303	1.573	35	46.7	Walstat
Local subsidies (log of)	0.176	2.827	-1.204	7.23	Self-collected
% vote green party	15.007	6.304	4.37	31.83	Federal Public Service

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[1] As we do not know the precise address of the investment and the distribution system operator frontier within the municipality, it is complicated to give a weight of the importance of the two DSOs or to use the same discontinuity as Ito (2014) with household level data.

Our explanatory variable is *tariff*. It is the distribution tariff (VAT included) paid for each kilowatt per hour of electricity consumed and is measured in eurocent. Tariffs are set by the CWaPE separately for each of the 13 distribution system operators covering the region.[2] This data was also provided by the CWAPE.[3]

We also control for various factors split into three categories: housing, socioeconomic and political factors. The two housing factors we control for are *% of houses* and *% built after 1981*. The former which is the share of buildings that are stand-alone houses is expected to positively impact the number of installations as it can be complex to install solar panels on buildings where multiple households live together like apartments building. The latter is the ratio of the number of buildings constructed after 1981 divided by the total supply of buildings. A priori it is unclear how this would impact our dependent variable. On the one hand more recent buildings might be more suitable for PV installations on the other hand most of the new buildings might be apartments rather than houses.[4]

We control for socioeconomic factors. *% unemployed* is the percentage of unemployed inhabitants. More unemployment is expected to negatively influence our dependent variable as investments in PV require a high up-front cost which is less likely to be available for unemployed people. *Population (log of)* is the number of inhabitants. We can expect that in municipalities with more inhabitants there will be more PV installations, as there will be more potential investors. *Median Income (log of)* is the median income net of taxes and

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[2] Remark that taking the log of the tariff, including the (comparatively small) fixed part of the tariff as a control variable or using the peak/off-peak tariffs in the case where there is a meter measuring these two flows separately does not impact our results.

[3] Note that the tariff data is missing for some DSO for the year 2008. We still analyse our data as if it was balanced.

[4] Unfortunately we do not have data about the share of households that rent instead have own the place where they live on a yearly base. However, we believe that this factor is rather stable over the years of our sample.

we expect that municipalities with wealthier inhabitants will invest more. *Average age* is the average age of the inhabitants and we expect that all else being equal younger people will be more aware of the PV investments possibilities than older people. Hence we anticipate a negative sign for this control variable. *% foreigners* measures the percentage of households with a foreign nationality. As foreigners are likely to come from a less well-off socioeconomic background and to be less aware of the subsidies available (due to linguistic issues and a more general lack of information), the coefficient of this variable is likely to be negative. All these control variables come from Walstat.

Finally we control for what we call political factors. *Local subsidies* is the level of the up-front subsidies granted to PV installers at the municipality and province level. We took the log and have added a small constant due to the presence of zero's. This information was collected by ourselves from various sources, including the administration of the municipalities/provinces themselves.[5] Remark that the level of these local subsidies is relatively small compared to what can be earned via the green certificate system. *% vote green party* is the percentage of votes received by the green party at the regional elections that took place in 2004, 2009 and 2014 at the canton level. We do not consider municipal election results as for those elections political parties do not always participate under their usual name and often form ad-hoc electoral list with other party members. We expect this variable to be a good proxy of the awareness of citizens towards renewable energy sources.

Descriptive statistics are available in Table 2.

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[5] When the subsidies were provided in the form of a percentage rebate of the up-front investment cost, we transformed this information in a lump sum subsidy approximated by the average capacity of the installation made in each municipality each year and the average cost per kWp that specific year.

4 Empirical strategy

Our objective is to study the impact of electricity tariffs on the decision to install PV using a closed-form approach. We take advantage of the panel nature of our municipality-level data in order to reach close to causal claims about this relationship. The specificity of the Wallonian context is also an advantage, as tariffs are set differently in the 13 distribution system operators while the rest of bill depends on market forces and policies set at the regional and national level.

Let $Y_{i,t}$ denote the number of PV installations in municipality i in year t. We model $Y_{i,t}$ as a function of our explanatory variable and control variables. A first specification can be written as follows:

$$Y_{i,t} = \alpha + \beta tariff_{i,t} + \gamma X_{i,t} + \mu_i + \phi_t + \epsilon_{i,t}$$

where α is a constant term, $tariff_{i,t}$ is our explanatory variable, $X_{i,t}$ is a vector of municipality-level covariates described earlier and $\epsilon_{i,t}$ is a mean-zero error term. We also include municipality fixed dummies μ_i and year dummies ϕ_t.

Taking advantage of the panel structure of our data allows us to control for various sources of unobserved heterogeneity. Municipality fixed-effects help us to implicitly consider municipality-specific omitted variables that are constant over time such as locational aspects (size of the area, solar radiation/orientation, geographic coordinate, etc.). Year fixed-effects control for broader trends in adoption of PV due to changes in tagged prices of panels, policies set at the regional and national level or an overall increase in awareness about solar energy. In addition to these fixed-effects, control variables will diminish the presence of the omitted variable bias by taking explicitly into consideration some form of heterogeneity evolving across time and place that is measurable.

One big issue when using a linear model is that it is not well-suited for our count data setting. For this purpose, we have fitted a Poisson model to take care of the non-linear nature of our data. As the data is not Poisson distributed and over dispersion of our dependent variable is an issue, the misspecified variance is corrected using a sandwich variance estimator. As shown in our robustness checks, these results are robust to the one obtained via negative binomial models which are more adequate to handle over dispersion but at the cost of stronger distributional assumptions (Cameron and Trivedi (2013)). Note finally that the presence of zero outcomes is limited in our sample.

One important thing to note is that in our preferred specification we have lagged by one year our explanatory variable. Hence, we use $tariff_{i,t-1}$ as an independent variable instead of $tariff_{i,t}$. There are a number of explanations for this assumption. First of all, one theoretical explanation is that households do not necessarily respond to contemporaneous tariffs but to lagged tariffs, as stipulated on their electricity bill which is received only later after the consumption of electricity. Households might find it difficult to evaluate how new tariffs might impact their returns to invest in solar panels as electricity consumption is only paid ex-post (Ito (2014)). As discussed in Jacqmin (2018), there might as well be delays due to administrative and installation reasons. Beside these explanations, using a one-year lag is also suggested using the Akaike Information Criterion (AIC) and the Schwartz Criterion (BIC), even though analyzing contemporaneous data does not change the quality of our results. A bi-product of the one-year lag between our explanatory and dependent variable is that it reduces the scope for reverse causality.

One final point to note is that, by looking at the impact of yesterday's tariff on tomorrow's investment, we implicitly assume that residents are myopic.

Table 3: Results

Dep. var. # of PV installations	(1)	(2)	(3)
Tariff (t)	0.026*		0.028**
	(0.0137)		(0.014)
Tariff (t-1)		0.058***	0.041***
		(0.015)	(0.015)
% of houses	0.021	0.013	0.014
	(0.02)	(0.022)	(0.025)
% built after 81	-0.122***	-0.147***	-0.16***
	(0.032)	(0.035)	(0.037)
% unemployed	-0.079***	-0.08***	-0.072***
	(0.022)	(0.022)	(0.022)
Median income (log of)	1.114	0.858	1.11
	(0.871)	(0.924)	(0.916)
Population (log of)	2.501*	2.599*	3.583**
	(1.49)	(1.558)	(1.605)
% foreigners	-0.053**	-0.046*	-0.039
	(0.027)	(0.027)	(0.03)
Average Age	-0.058	-0.016	0.021
	(0.064)	(0.066)	(0.065)
Local subsidies (log of)	0.008	0.005	0.005
	(0.006)	(0.006)	(0.006)
% vote green party	-0.003	-0.003	-0.003
	(0.008)	(0.009)	(0.009)
Year FE	yes	yes	yes
Municipality FE	yes	yes	yes
N	2031	1776	1776
log likelihood	-7216.93	-6359.13	-20530.22

Heteroskedasticity-consistent standard errors in parentheses.
Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In our context, this means that when optimizing, i.e. deciding to install PV or not, they do not anticipate the fact that their decision and the one of other consumers will have a subsequent impact on tariffs.

5 Results

Our main results are presented in Table 3. They all use the number of new PV installations as a dependant variable and a Poisson model. Regression (1) compares contemporaneous values of the number of PV installations and the distribution tariff. By taking advantage of the panel structure of our data, we are able to implicitly control for factors fixed over time and place using fixed effects.[6] Focusing on our variable of interest, we now find that an increase in one eurocent of the distribution tariff leads to an increase in 2.7% in the number of new PV installations.[7] The other coefficients estimated in this regression tend to be in adequacy with our predictions and stable across methodologies. We observe that having a larger share of recently constructed buildings leads to less PV installations. One explanation of this result is that recently constructed buildings tend to be apartment blocks, rented or owned by their inhabitants, where it is less suitable to make this kind of investments. Next, we find that a higher unemployment rate means that there will be less investments in solar panels, probably because unemployed inhabitants are less likely to be owners and to be able to finance this type of long term investments. As expected, we also find that municipalities with more inhabitants observe more installations. Finally, having more foreigners among its inhabitants leads to less installations as this part of the population might be less inclined to be aware of the large, though complex, subsidies available when installing solar panels. The other coefficients are not statistically different from zero.

The next regression reproduces regression (1), albeit one key change. Instead of comparing contemporaneously the dependent and explanatory variable, a one year of lag between them is introduced. As discussed, in the previous section, taking a one year lag can be defended on several grounds. First, a theoretical explanation lies in the fact that people optimize with respect to their bills rather than the tagged price, as one of the specificity of the elec-

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[6] When using random effect estimators, the quality of our results remains untouched. Following the results of the Hausman test, the null hypothesis of no systematic difference between fixed and random effects is rejected. Hence, the fixed effect estimator is more consistent.

[7] Note that when using a pooled Poisson regression we estimate that the increase will be of 28%. This overestimation confirms the importance of taking advantage of the panel dimension of our data to cure the omitted variable bias.

tricity market is that you pay your bill only much after you have consumed the good in question. Second, it mitigates contemporaneous feedback effects, that could bias our results. Finally, various information criteria (AIC and BIC) encourage us to use this approach rather than the one comparing contemporaneous data.[8] Comparing the coefficients of our variable of interest in regression (1) and (2), we see that taking a one year lag for our explanatory variable leads to a larger coefficient for our explanatory variable. The other coefficients tend, on the other hand, to be similar. In regression (2), with a coefficient of 0.058, we see that lagging our explanatory variable compared to our dependent variable, inflates our results compared to the one of regression (1). Hence, the impact of lagged tariffs on solar investments is more important than the one of contemporary tariffs. It means that an increase in one eurocent in the tariff leads to, all else being equal, an increase in between 5% and 6% in the number of PV installations the year after. Finally, including both lagged and contemporaneous values of tariffs in the same model, we observe that both have a significant and positive impact, although the one of $tariff_{i,t-1}$ is significant at the 1% threshold and the one of $tariff_{i,t}$ only at the 5% threshold. This last result comfort us in the idea that the impact of tariffs on the decision to install solar panels lies between the results obtained in regression (1) and (2) but is likely to lean more towards the one observed in the latter.

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[8] Note however that this leads to a reduction of our sample size, as due to missing tariff data, one year of observation has to be dropped.

Table 4: Robustness checks

	(4) years $\leq$ 2013	(5) years $>$ 2014	(6) capacity installed	(7) transm. tariff included	(8) OLS Fixed effects	(9) Negative Binomial
Tariff (t-1)	0.054***	-0.145	0.05***		0.038**	0.0503***
	(0.016)	(0.207)	(0.015)		(0.016)	(0.013)
Tariff + transport (t-1)				0.021		
				(0.012)		
% of houses	0.025	0.214	0.015	0.021	0.012	-0.007
	(0.024)	(0.223)	(0.024)	(0.047)	(0.028)	(0.007)
% built after 81	-0.166***	0.212	-0.16***	-0.193***	-0.076*	-0.026***
	(0.038)	(0.159)	(0.037)	(0.043)	(0.042)	(0.01)
% unemployed	-0.096***	-0.151	-0.074***	-0.048**	-0.042*	-0.022
	(0.026)	(0.094)	(0.022)	(0.022)	(0.025)	(0.014)
Median income (log of)	0.825	-1.769	0.983	0.191	-0.134	0.125
	(1.076)	(3.592)	(0.91)	(0.952)	(1.141)	(0.499)
Population (log of)	2.044	2.498	3.591**	3.738**	1.578	0.602***
	(1.799)	(6.856)	(1.604)	(1.737)	(1.953)	(0.083)
% foreigners	-0.064*	-0.432***	-0.039	-0.009	-0.03	-0.048***
	(0.037)	(0.166)	(0.03)	(0.031)	(0.036)	(0.011)
Average Age	-0.05	-0.006	0.024	0.108	-0.07	-0.119***
	(0.082)	(0.234)	(0.065)	(0.082)	(0.058)	(0.028)
Local rebates	0.005	0.031	0.006	0.009	0.006	0.007*
	(0.006)	(0.021)	(0.006)	(0.007)	(0.006)	(0.004)
% vote green party			-0.003	-0.001	-0.008	0.014**
			(0.009)	(0.009)	(0.011)	(0.006)
constant					-4.77	1.344
					(20.348)	(5.327)
Year FE	yes	yes	yes	yes	yes	yes
Municipality FE	yes	yes	yes	yes	yes	yes
N	1266	510	1776	1530	1776	1776
log likelihood	-4807.77	-590.11	-20570.8	-5145.11		-5403.05

Heteroskedasticity-consistent standard errors in parentheses.

Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

We provide additional robustness checks in Table 4 and use regression (2) as benchmark specification. In regression (4) and (5), we split our sample in two parts, before and after the major change in legislation supporting PV investments that took place in early 2014. On the one hand, focusing on the time period when the *Solwatt* system was in place, we observe no change compared to our previous results. On the other hand, focusing on the *Qualiwatt* system, we find that the tariff level has no significant impact on the PV investment decision. This does not come as a surprise as under the Qualiwatt supporting scheme the benefit for the consumer of a higher grid tariff is partially offset by a lower premium paid by the DSO. Therefore, the decision to invest should depend less on differences in the tariff. Furthermore, for regression (5), we have a limited amount of data available as only two years of data are at our disposal for the moment. Note in addition that in these two subsamples, there was no change in % *vote green party*, as no election took place.

In regression (6), we also take advantage of the availability of data concerning the capacity of each PV installations. For this purpose, we use the total capacity installed each year in each municipality as a dependent variable. In line with what we have observed so far, we see that an increase in one eurocent of the grid tariff leads to an increase of about 5% of the capacities installed.

From the investors' point of view, another aspect of the PV investment is differing from one DSO to the other: the transport tariff. This tariff, which is much smaller than the distribution tariff, about one fifth of the average tariff bill, also differs across DSO and time. However, as opposed to the distribution tariff, it differs mostly across time rather than across DSO, as only one tenth of its variation is explained by the variation between DSO. In regression (7), we add together the distribution and the transport tariffs in a single variable that we use as an explanatory variable. We find that this has an impact on our coefficient that now decreases to 0.02 as well as on the level of significance, as now the p-value is only 0.11, above conventional thresholds. We believe that this is due to the nature of the variation of the transport tariff. Now, much of the variation in our explanatory variable is taken away by our fixed effects. Note however, that considering separately the two tariffs or by using contemporary tariffs, leads us to qualitatively similar results as the ones observed in previous regressions that are as well significant. The fact that we also loose an additional year of observations reinforces our confidence in our main results.

Other estimation strategies are pursued in these last two regressions. The first one is presented in regression (8) and assumes a linear relationship. Before doing this OLS regression, we take the log of our dependent variable.[9] We observe that this does not change the significance nor the size of our coefficient. Finally in regression (9), we estimate a negative binomial regression. Again this more general approach leads us to results comparable to the one obtained in regression (2). Overall these results tend to confirm and further strengthen our initial claim that higher distribution tariffs do lead to more PV installed and that an increase of 1 eurocent leads to an increase in installation of around 5%.

6 Conclusions

In this paper we study the adoption of photovoltaic panels in a setting where both a net metering system, where the production of solar panels is valued at market price, is in place and distribution tariffs are in large part computed on a volumetric basis. We show that municipalities where the electricity is more expensive –due to higher grid tariffs– experience a larger deployment of

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[9] Beforehand, we have added a small positive constant to all our dependent variables, as some of them are equal to zero. Changing the constant in question does not influence the quality of our results.

decentralized production units. Using data from Wallonia, we measure that, all else being equal, an increase by one eurocent per kWh of the volumetric tariff leads to an increase in the number of investment in new installations by around 5%. Electricity users do react by installing more photovoltaic panels, as it helps them decrease their energy bill. Hence, a system with a net metering scheme and high volumetric tariffs highly subsidizes the development of residential PV installations and the theoretical literature (Brown and Sappington (2017) and Gautier et al. (2018)) has shown that net metering leads to an inefficient deployment of decentralized production units.

Furthermore, net metering decreases the registered consumption of the households equipped with PV installations and therefore translates in revenue losses for the DSO. To be able to cover the mostly fixed costs of the DSO, one policy response would be to further increase volumetric tariffs, worsening the sustainability of the DSO revenues, as residential users would again react by installing more PV, leading to the so-called death spiral of utilities (Costello and Hemphill (2014)). Hence, in this case, subsidies provided to become prosumer are not levied via the general tax system but via the grid system, i.e. the new, higher, bills paid by passive energy consumers. This work calls for two kinds of regulatory changes. First, a switch from the single/net metering system to a net purchasing/double metering system where energy imports and exports of prosumers can face a different tariff. Second, as discussed in Brown and Sappington (2018) or Schittekatte et al. (2018), regulators should set tariffs in order for the DSO to rely less on volumetric tariffs and more on fixed/maximum demand charges. However, they should have in mind the new redistributional issues that this change might create. In addition, the decreasing costs and increasing reliability of home batteries might create new problems, as the technological possibility to live off-grid might create a new threat to the DSO.

7 References

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