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The political economy of financing climate policy — Evidence from the solar PV subsidy programs[☆]

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ABSTRACT

We analyze the political impact of a generous solar panel subsidization program. Subsidies far exceeded their social benefit and were partly financed by new taxes on adopters and by electricity surcharges for all consumers. We use local panel data from Belgium and find a decrease in votes for government parties in municipalities with high adoption rates. This shows that the voters' punishment for a costly policy exceeded the potential reward by adopters who received generous subsidies. Further analysis indicates that punishment mainly comes from non-adopters, who change their vote towards anti-establishment parties.

1. Introduction

There is now a broad consensus among scientists that the massive increase in CO_2 emissions has been responsible for climate change. There is also a growing awareness that drastic policies are required to reduce emissions and prevent a further acceleration of global warming. However, there is much less consensus on the type of policies that are required. Economists often favor Pigouvian taxes to correct for externalities.[1] Yet, several authors argue that both the design and the implementation of such taxes might be politically complicated for a variety of reasons: distributional concerns, industry pressure, aversion to taxes, lack of coordination, ideology, or fiscal competition between countries (Marron and Toder, 2014; Jenkins, 2014; Anderson et al., 2023; Dolphin et al., 2020). As a result, politicians have often favored subsidy programs to promote renewable energy sources (RES), such as solar, wind or biofuel. This, in turn, has led to wide-ranging costs for technologies and interventions that aim to reduce CO_2 emissions (Gillingham and Stock, 2018).

Despite the political arguments behind the choice for technology-specific subsidies, there is little evidence on their electoral impact. This is particularly relevant for new green technologies, which may involve considerable uncertainty regarding their

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[1] See, for example, the Economists' Statement on Carbon Dividends (https://clcouncil.org/economists-statement), written in January 2019, and signed by 27 Nobel laureates and 15 former chairs of the US Council of Economic Advisers.

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potential for development (De Groote and Verboven, 2019). As such, there can be substantial scope for miscalculations and voters responses. We aim to fill this gap by looking at the impact of subsidies for solar photovoltaic systems (PV) on votes for the parties that introduced them.

PV is one of the green technologies that received the largest support in many countries. The California Solar Initiative (Hughes and Podolefsky, 2015) and the German feed-in tariff are the most prominent examples. The solar subsidy programs often combined different support measures, including feed-in-tariffs, green certificates, capital subsidies, tax credits and net metering.[2] In many countries this support was considerable, especially for small-scale rooftop systems installed by households. For Germany, Marcantonini and Ellerman (2015) estimate the support corresponds to an implicit carbon price for solar energy of 552€per ton for the period 2006–2010, far above the perceived optimal carbon price.[3] As a result, the high support created a group of PV adopters that benefit from the policy, while also creating a cost for the rest of society that likely outweighs the social gains.

For our analysis, we exploit the generous subsidy programs for residential solar photovoltaic systems in Belgium. Starting in Flanders in 2006, each of the country's three regions (Flanders, Wallonia and Brussels) offered subsidies for residential solar installations. Each program combined production subsidies in the form of tradable green certificates, net metering[4] and investment subsidies. The magnitude and the timing of these programs differ across regions, but in all cases subsidies were initially very generous and adoption by the households was massive. At the end of 2012 small-scale installations accounted for 1550 MW or 0.14 kW per capita in Belgium, compared with 4370 MW or only 0.05 kW per capita in Germany.[5]

The combination of high subsidies and high adoption rapidly created both a financial and a political problem. Subsidies were mainly linked to solar production and they were granted for a long period (up to 20 years). As a result, governments created a solar debt as they committed to paying a large amount of subsidies to PV adopters. We estimate that the total amount of production subsidies promised to solar during the 2006–2016 period amounted to 9.19 billion €, or 811 €/capita, with important differences across regions. This corresponds to a subsidy of 303 €/MWh or an implicit carbon price of 671 €/ton CO_2.[6] It is well documented that PV adoption is increasing with income (De Groote et al., 2016) and funding solar subsidies through surcharges on the electricity bill could be regressive (Feger et al., 2022; Winter and Schlesewsky, 2019). The financing of these costs and the associated redistributive aspects was, therefore, one of the most important and contentious political debates during the last years, both in Flanders and in Wallonia, similar to the recent debate in California (see, for example, Borenstein, 2022).

To cover the cost of the rapidly increasing solar debt, the regional governments introduced a dedicated surcharge on the electricity bill, which led to an important increase in the price of electricity. In addition, the regions decided to tax the adopters for their role as "prosumers", i.e. electricity consumers who installed solar PV and receive payments for the electricity they produce. While adoption was large in most of the country, the extent to which the costs were spread out over time differs greatly between the regions, leading to substantial variation in electricity prices in recent years.

Against this background, our objective is to test the retrospective voting hypothesis. Accordingly, citizens use their votes to discipline politicians, rewarding those who performed well and punishing those who did not. Regional governments are appointed for a term of five years after the regional election. The main policies were designed during the legislation of 2004–2009, which at that time were center or center-left coalitions in the three regions. Retrospective voting may apply to both non-adopters and adopters of PVs, who may respond in opposite ways. On the one hand, the non-adopters, who did not benefit from the subsidies may punish the government when it becomes apparent that they end up paying a high subsidy cost for only limited (environmental) benefits. Indeed, the solar debt led to substantial increases in the energy price, impacting mainly the non-adopters who end up paying higher surcharges per kWh consumed.[7] On the other hand, the adopters themselves may either reward the government for the high subsidies they get or they may punish the government if they see that some of their benefits are taken away by the imposition of new fees that reduce their return on investment. The imposition of a dedicated fee for solar producers indeed reduces their benefit and it has been challenged in court by some prosumers, both in Flanders and in Wallonia.

Our setting is particularly suitable to investigate how voters hold politicians accountable. First, information on policies needs to adjust the priors voters have about policymakers (Arias et al., 2022). At the time, climate policy was new, suggesting voters likely did not have strong priors on the ability of the incumbents to do it well.[8] Second, the policy impact needs to be salient (Chetty et al., 2009; Huet-Vaughn, 2019). Investments in rooftop solar by households are very visible where people reside, and adoption rates were high. At the municipality level, they average 10% and can go up to 29%. The policies also received large attention in the media and the financial impact further enforce the salience. All electricity consumers were regularly reminded about the costs

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[2] Campoccia et al. (2009), Dusonchet and Telaretti (2010, 2015) detail the main instruments used in several EU countries and estimate their relative importance by calculating the financial return of an investment in a small-scale (residential) PV installations. Rodrigues et al. (2016) also includes non-EU countries in their comparisons.

[3] To give an idea, Nordhaus (2014) estimates a social cost of carbon equal to $22.1 (in 2005 $) per ton of CO_2 for the year 2020. In Europe, the carbon price on the EU ECTS markets was close to this number but recently increased up to almost 100€ by the start of 2022, which is also more in line with recent estimates, see e.g. Carleton and Greenstone (2021) who estimate a social cost of carbon for 2020 of $125.

[4] With net metering, solar production is valued at the electricity retail rate (Brown and Sappington, 2017; Gautier et al., 2018).

[5] Data from Germany are retrieved from Prol (2018).

[6] Assuming solar production replaces production by gas power plants, emitting 450 grams of CO_2/MWh.

[7] The net metering system limits the impact on adopters as their bill is based on their net consumption, i.e. their total consumption minus their solar production.

[8] The Kyoto Protocol was formally adopted by the EU in 2002 and came into force in 2004. This was the start of several policies and debates at the regional and national levels.

because of surcharges for green energy that appeared on their electricity bills. Adopters were regularly reminded of the benefits as most of the subsidy was paid out by a government agency, each time a certain level of electricity production was reached.

To evaluate these hypotheses, we exploit local municipality-level variation in the solar PV adoption rate across the country. Since individual-level data is unavailable, we specify a micro-founded model for the election outcomes at the municipality-level of the parties that introduced the policies. We compare the parties' election outcomes during the regional election years 2009, 2014 and 2019 with the pre-program election years 1995, 1999 and 2004. We ask whether the election outcomes were more or less favorable to the incumbent parties in those municipalities where solar PV adoption had been higher. By including fixed effects for each municipality and election year, our model can be interpreted as a difference-in-differences framework with the local adoption rate measuring the treatment intensity (Callaway et al., 2021). Additionally, we relax the common trend assumption by allowing for changes in votes that can be explained by a large set of local demographics, including homeownership rates and income. We also test the common trend assumption using the pre-program election years.

Our main finding is that the incumbent parties received *fewer* votes in municipalities where PV adoption has been more successful, consistent with the retrospective voting hypothesis. Voters punished the incumbent parties, once it became apparent that the financing costs would be high and be paid to a large extent by non-beneficiaries.[9] We also find that the punishment tends to be more severe in Flanders and grows over time, consistent with the periods and regions in which more costs were passed on to consumers through substantially higher electricity prices and to adopters through a dedicated prosumer fee. Both non-adopters and adopters may lie at the base of punishing the government. To distinguish between both groups, we add the share of PV adoption in neighboring municipalities to our model of election outcomes. We find an effect that is at least as negative as for the share of PV adoption in the municipality itself, suggesting punishment is mainly driven by adopters' neighbors, i.e. the non-adopters.

Finally, we consider which political parties were most affected. Among the incumbent parties, mainly the socialist parties were negatively affected. This is intuitive as they were part of the government and most associated with the subsidy policies in the public debate. Moreover, their voters are expected to attach more weight to the issue of subsidies going to more wealthy households. The parties that gained votes were on the most extreme sides of the political spectrum (both on the left and the right). As they were never in government, it could point to voters attaching blame on all (traditional) parties or reflect an increase in anti-establishment sentiment following a failed policy.

Related literature. We contribute to three strands of literature. A first strand investigates the impact of solar panel policies on household behavior. Hughes and Podolefsky (2015) focus on the impact of investment subsidies on adoption in California. Matisoff and Johnson (2017) and Gautier and Jacqmin (2020) focus on the role of net metering policies. Crago and Chernyakhovskiy (2017) show that investment subsidies have relatively more impact than factors affecting future benefits like energy prices or solar irradiation. De Groote and Verboven (2019) show that households discount the future benefits heavily and confirm that investment subsidies are more effective than production subsidies to promote PV adoption. Feger et al. (2022) investigate optimal subsidy and tariff design in terms of efficiency and equity and Langer and Lemoine (2022) investigate the optimal timing. We contribute to this literature by investigating the electoral impact of solar panel policies. Closest to our work is Comin and Rode (2023). They do not focus on incumbent parties, but instead show that PV adopters vote more for the green party because of increased awareness of environmental issues.

A second strand of literature discusses the impact of green energy policy on voting behavior. More specifically, we contribute to the literature on respective voting, which studies how voters respond to good or bad policies.[10] While most of this literature has focused on general economic performance[11] (GDP growth, employment, etc.), a recent literature considers the impact of environmental policies both at the national (Obradovich, 2017) and at the local level (for instance the policy response to a natural disaster as in Neugart and Rode, 2021). These later studies build upon the fact that the costs and benefits of environmental policies are not equally spread across the territory. Stokes (2016) considers the example of wind turbines. While in terms of climate they benefit all, the residents living close to the windmills may suffer additional costs because of their proximity. Using data from Ontario (Canada), she identifies a loss for the incumbent party/candidate from voters located at a short distance from the mills (up to 3 km). On the contrary, Umit and Schaffer (2022) do not find a significant effect in Switzerland.

Even with substantial costs, environmental policies can receive public support. An important example is GermanyÕs nuclear phase-out. The antinuclear sentiment after the Fukushima disaster led to the support of a large majority of the population (Goebel et al., 2015), even though social costs largely outweigh the benefits (Jarvis et al., 2022). Pani and Perroni (2018) show that politicians have incentives to maintain inefficiently high energy subsidies instead of phasing them out to secure their re-election. Similarly, a pro-solar sentiment could prevent voters from punishing politicians.

We contribute to this literature by empirically investigating the impact of green technology subsidies on votes in a setting where the theoretical impact is ambiguous as voters have reasons to both reward and punish the government.

Finally, we contribute to the recent and growing empirical political economy literature to evaluate the impact of spending on voting behavior. Several papers look at the impact on votes by beneficiaries of cash transfers in developing countries. For example,

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[9] Furthermore, the costs and benefits for non-adopters and adopters might not be correctly perceived by the citizens. In Douenne and Fabre (2022), it is shown that most of the respondents to their survey have pessimistic beliefs regarding the redistributive aspects of the carbon tax. Pessimistic beliefs may exacerbate the votersÕ response to the policy.

[10] This is distinct from another literature on "buying votes", according to which politicians develop investment policies to attach future voters. Biais and Perotti (2002) provide a seminal paper in the context of privatizing. Several papers apply their hypothesis to pro-environmental policies: Urpelainen (2012), Alkin and Urpelainen (2013) and, in the context of solar subsidies, Ovaere and Proost (2015).

[11] See Healy and Malhotra (2013) for a survey.

Labonne (2013) exploits the variation created by the gradual roll-out of the program. Manacorda et al. (2011) make use of a discontinuity in the assignment rule. Recent literature has also looked at the impact of spending in developed countries using quasi-experimental variation. Compared to cash transfers, these policies are often more difficult to assign to a specific group or area. Therefore, researchers resort to a measure of treatment intensity to investigate their effect. Acemoglu et al. (2021) show how voters rewarded the Labor Party in Norway for national schooling reforms by exploiting local differences in the intensity of the policy. Huet-Vaughn (2019) finds positive effects on votes for the US democratic party in areas where investments in public goods were more salient. We adopt a similar strategy by exploiting the local salience of the policy, measured by the PV adoption rate. In contrast to these papers, we show that voters are able to look beyond the initial impact of increased spending and punish governments for policies of which the costs outweigh the social gains.

The rest of this paper is structured as follows. Section 2 discusses the subsidy programs and how they influenced the investment benefits and the public debt. Section 3 discusses how the debt was financed. Section 4 describes our empirical approach and results and Section 5 concludes.

2. Subsidy programs to promote residential PV installations

2.1. Specific subsidies to solar energy for residential installations

The promotion of green energy is a responsibility of the three regions in Belgium (Flanders, Wallonia and Brussels). Since 2003 each region implemented its own system of so-called green certificates (GCs) to support renewable energy sources (RES), such as wind, solar and biomass. The GCs are production subsidies, awarded for a given period and specific to each type of RES. The costs of the subsidies are initially borne by the retailers as they need to comply to green energy quota obligations by producing green energy or buying GCs. Ultimately, they are paid by the consumers through higher electricity prices.

Starting in 2006, the regions wanted to encourage the installation of small-scale solar PV on the rooftop by households, which was not profitable under the GC mechanisms in place. Interestingly, the regions distinguish residential and commercial solar installations, the former receiving much higher support. A residential installation is made by a household on its rooftop and there is a power limit of 10 kWp to be eligible. Flanders was the first region to have a dedicated program for residential solar PV installations in 2006, Brussels and Wallonia followed in 2007 and 2008. These initially very generous programs remained in place until 2012 in Flanders and 2014 in Wallonia, when major reforms took place.

In the three regions, the solar programs combined the same three subsidy types: green certificates, net metering and investment subsidies. But the timing and the magnitudes of the subsidies differ between regions.

First, the three regions introduced green certificate subsidies that were considerably higher than the general GC system. In Flanders, this was done by increasing the minimum guaranteed price for the solar producers, with the obligation for the grid operator to cover the difference between the guaranteed price and the market price. In Wallonia and Brussels, the increase was implemented by giving more GC per MWh produced, with the obligation for the grid operator to buy all the GC in excess supply on the market at the floor price. In both Flanders and Wallonia, the granting period was also extended.

Second, households received benefits through net metering. Prosumers withdraw electricity from the grid when their consumption exceeds their production and inject electricity when their production exceeds their consumption. With net metering, the two flows are valued at the same price. It implies that energy produced by the solar installation is valued at the retail price, which includes not only the electricity price but also all extra charges for distribution and taxes.[12]

Third, at the start of the programs, all regions offered tax rebates, specified as a percentage of the PV investment with a cap. Some municipalities also provided investment subsidies.[13] In addition, for the years 2006–2011, the federal government supported investments in energy-saving technologies, including solar panels, by granting a tax credit.

Reforms of the GC mechanism. The granting mechanisms for GC lack the flexibility to adapt to rapidly changing market conditions with decreasing module prices. There was no automatic adjustment mechanism as in Germany for its feed-in tariff (Grau, 2014). The adaptations were instead made by the regional governments who took time before making decisions.

The system of GCs was profoundly reformed in 2013 (Flanders) and 2014 (Wallonia) to be more flexible and better adapt to the market conditions. Instead of committing to a mechanism, governments commit to a rate of return and adjust their support accordingly. As a result, subsidies were gradually phased out. GCs are no longer offered to residential PV installations since July 2014 in Flanders, and since July 2018 in Wallonia. Nowadays, only the region of Brussels continues to offer GCs for solar installations.

Magnitude and success of the subsidies. The subsidy schemes provided huge support to residential PV installations. Fig. 1(a) reports our estimates of the present value of the subsidy benefits of a 4 kWp installation in three regions during January 2006–December 2016. It compares it to the investment cost, showing a very high net present value (NPV) in all regions in most periods.[14] Fig. 4 in Appendix A decomposes the NPV to show the relative importance of the three instruments (GCs, net metering and investment subsidies) in each region. A comparison of panels (a) and (b) of Fig. 1 shows that subsidies have been the main driver of adoption (as studied in more detail in De Groote and Verboven, 2019 and Gautier and Jacqmin, 2020).

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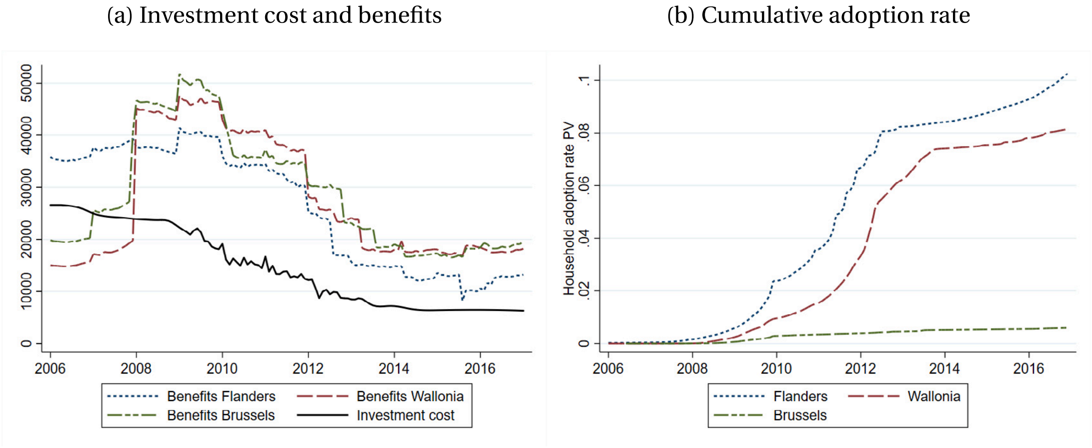
[12] But there is no payment if the production exceeds the consumption over the billing period of one year.

[13] For Flanders, this was the case in about 40% of municipalities but the magnitude of the support was small (De Groote et al., 2016).

[14] Fig. 1(a) extends the information provided for subsets of regions and periods in De Groote et al. (2016), De Groote and Verboven (2019) and Boccard and Gautier (2015, 2021). Appendix A provides details on the data sources and methodology.


(a) Investment cost and benefits

(b) Cumulative adoption rate

Fig. 1. Net present value and adoption rates in each region,2006–2016.
Notes: Panel (a) shows the annual evolution of the investment cost and the present value of all financial benefits of a 4 kWp installation. The amounts are adjusted for inflation (in 2013 prices). The present values are computed based on the lifetime of the solar PV, the duration of the financial benefits, and an interest rate of 3% (as in Fig. 4). Panel (b) shows the annual evolution of the total adoption rate, i.e. the cumulative number of all PV installations per household.

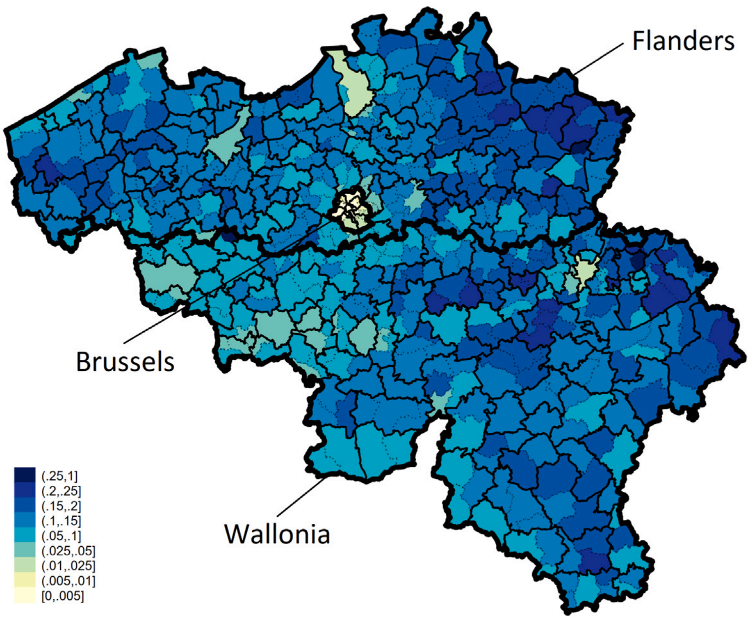


Fig. 2. Map of adoption rates, 2006–2016.
Notes: This map shows the household adoption rates in different municipalities. Thick solid lines denote the three regions, thin solid lines denote different cantons.

The generous subsidies combined with rapidly declining investment costs resulted in a massive PV adoption in Flanders and Wallonia, while adoption remained limited in urban Brussels, as shown in Fig. 1(b).[15] New adoptions were especially high when the NPV of investment peaked before the GC reforms in Flanders (2013) and Wallonia (2014). Fig. 2 shows that adoption rates also vary substantially within the regions, for reasons not related to the general subsidies. This cross-sectional variation will be useful in the empirical analysis.

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[15] Throughout this paper, we make use of data from the Census of 2011 (https://census2011.fgov.be/) to obtain demographic information (at the municipality level). The data on adoptions were provided by regional government agencies: Brugel (Brussels), CWAPE (Wallonia) and VREG (Flanders).

Table 1
Total subsidy costs per region, 2006–2016 .

	Flanders	Wallonia	Brussels	Total
Total subsidy (in billion EUR2013)	5.85	3.29	0.05	9.19
- Green certificates (in billion EUR2013)	3.84	2.14	0.04	6.01
- Net metering (in billion EUR2013)	2.01	1.15	0.02	3.18
Expected production (in million MWh)	19.9	10.3	0.2	30.3
Subsidy EUR2013/MWh	293.6	320.4	322.8	302.8
Subsidy EUR2013/household	2198.9	2158.2	93.2	1943.3

Notes: The first row of this table shows the total subsidy costs over 2006–2016, i.e. the present value of all commitments to adopters, covering both green certificates and net metering (from Appendix A) and discounted/compounded to 2013 using a yearly discount factor of 0.97. The amounts are expressed in billion euros, adjusted for inflation (in 2013 prices). The second row shows the expected production, in million MWh, the third row the implied subsidy per MWh and the fourth row the implied subsidy per household.

2.2. The cost of subsidies

The combination of generous subsidies and high adoption generated a huge cost for society. The main cost overrun came from the cost of the GC mechanism. GCs are granted for a given period and linked to solar production. Consequently, governments committed to paying high subsidies for a long time, creating a *green certificate debt*. Furthermore, net metering resulted in a lost income for grid operators who need to be compensated. Only the investment and tax subsidies that were paid from the general budget, did not create any long-term financing problems.

We measure the green certificate debt and the cost of net metering as, respectively, the value of GC the government *committed* to pay during the granting period and the lost income for the grid operator over the granting period. We express the total subsidies in 2013 euros. We detail our computations and our hypothesis in Appendix A and we present the results in Table 1.

We estimate that the total subsidies (GC plus net metering) during the period 2006–2016 amounted to 9.2 billion€. This covers an expected solar production equal to 30.3 million MWh, which corresponds to a subsidy of 302.8 €/MWh. Table 1 provides a breakdown per region. On average, each household is expected to pay a total of 1943 euros to finance the subsidies for residential solar production.

3. Financing solar subsidies

The generous subsidies and the massive PV adoption implied substantial and increasing financial costs to society, which were largely unanticipated by the governments in charge.[16] Furthermore, there was no cap on the eligible solar capacity. Around 2012, it became apparent that the GC mechanism was extremely costly and that this cost would eventually be passed through to consumers. This subsequently led to an intense political debate, and subsidies to solar PVs became a political issue.

There were two main controversies in the political debate. First, there was a debate on the magnitude of the GC subsidies, which were considered too generous, and needed to be revised downwards several times. Second, there was a debate on the allocation of the cost of the subsidies to the different categories of consumers as it created important distributional issues.

3.1. Financing and reducing the GC debt

To finance the debt, the regions imposed additional surcharges on the electricity bill but the two main regions adopted different solutions. In Flanders, the debt burden was shared more or less equally among all the households through a flat tax on each electricity household in 2015. The tax was substantial. Consumers with a consumption level less than 5MWh/year had to pay an additional 100€ per year.[17]

In Wallonia, the government imposed a dedicated volumetric surcharge to finance the GC debt in 2013. The amount was insufficient to cover the full cost of the debt, but the government decided to cap the surcharge at 13.82€/MWh and did not want an immediate full pass-through of the cost. Part of the cost will be paid later by *future* consumers. The region also reduced the GC debt by modifying the GC mechanism ex-post and reducing the granting period from 15 to 10 years.[18]

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[16] In Flanders, the bill that introduced the policy stated an expected total capacity of 16,500 kWP by 2010 (Source: Flemish Parliament, piece 2188 (2003–2004)). By the end of 2009, and only looking at PVs < 10 kW, total capacity had already reached 260,398 kWp (15 times higher than the initial estimate). By the end of 2012, the end of the first phase of the GC policy, it had reached 1,046,164 kWp (63 times higher). Similarly in Wallonia, the energy regulator had in 2007, a forecast of 12,000 solar installations for the period 2008–2012 with a cumulated power of 41 MW. At the end of 2012, there were 98,000 installations in Wallonia (8 times more) with a cumulative power of 556 MW (13 times more) (Source: CWAPE, 2007 and 2012, Annual report on green certificates).

[17] The amount of the tax increased with the level of consumption, but only to a small extent, which was the main critique in the public debate. The tax was abolished in January 2018 after a Court decision and replaced by a low fee of about 9€ per year.

[18] This retrospective change in the rules generated a lot of anger among prosumers who organized themselves in a lobby group and launched a class action against this decision. Despite several attempts by successive governments to find a negotiated solution, the case was brought to Court. The Court validated the government's decision, but the case is still under appeal.

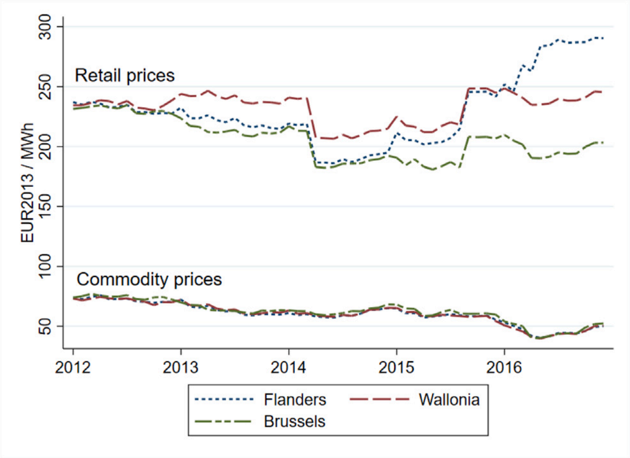

Fig. 3. Electricity prices per region,2012–2016.
Notes: This graph shows the evolution of the electricity price in the three regions. The retail price is the sum of the commodity price of electricity and the different taxes and surcharges.
Source: Hindriks and Serse (2021).

3.2. Financing net metering

Both the governments in Flanders (in 2013) and Wallonia (in 2014) decided to impose a prosumer fee. This prosumer fee is based on the PV capacity (in kWp) and serves as a contribution of the prosumers to the grid costs, i.e. it is designed to reduce the net metering subsidy. Brussels instead decided to stop net metering in 2020, also for PVs that were installed before.

The imposition of new fees on prosumers was an extremely contentious issue. It was seen by prosumers as an attempt by the governments to renegotiate their promises and lower the return on their investment ex-post. For this reason, earlier attempts to impose such a fee were successfully challenged in courts by some prosumers. Later, the fees were effectively implemented in 2015 in Flanders and in 2020 in Wallonia.

3.3. Evolution of electricity prices

The cost of the subsidies and the way they were financed translated into changes in electricity prices. Fig. 3 shows the evolution of the commodity and retail prices of electricity for a representative consumer in the three regions. Retail prices started to diverge in 2013, reflecting the different policy choices made by the regions. Since the commodity price is almost the same in the three regions, the price differences mainly come from the extra taxes and surcharges to support green energy. The difference between Flanders and Wallonia partially reflects the choice made in Wallonia to transfer a part of the GC debt to future consumers, while Flanders decided to pass most of the debt to current consumers. In Brussels, where there is almost no GC debt, the electricity price is the lowest.

Although Fig. 3 is suggestive that the subsidy costs translated to some extent into higher electricity prices, this pass-through was neither complete nor automatic. Furthermore, part of the increased electricity prices materialized through extra fixed fees (i.e., the flat surcharge in Flanders), and not through variable price increases (per KWh) that would directly affect electricity consumption. Hence, only part of the electricity price increase observed in Fig. 3 after 2013 may be viewed as an implicit carbon tax.

3.4. Political responsibility

The support for green energy is a regional competence and each region has a minister in charge of energy. The regional governments are appointed for five years, following the regional elections that took place in 2004, 2009, 2014 and 2019. The electoral system is one of proportional representation and the political spectrum is highly fragmented. Regional governments consist of a coalition of parties, usually at least two in Wallonia and three in Flanders, formed after the election.

The generous subsidy programs were implemented by the government during the legislature of 2004–2009. The government acting during the 2009–2014 legislature had to adapt and later suppress the GC mechanism. During this term, it became apparent that the PV adopters benefited from a very high return and the subsidy costs would be passed through to consumers. Furthermore, earlier unsuccessful attempts to impose a prosumer fee were discussed during this term. The government appointed for the 2014–2019 term had to impose further corrective measures to finance the GC debt and the net metering.

These controversies were part of the political debate and largely echoed in the press. To illustrate, in Flanders, parliamentary questions concerning energy policy that included a reference to solar panels accounted for 12% in 2004–2009, 11% in 2009–2014 and further increased to 19% in 2014–2019. In Wallonia, among the parliamentary questions addressed to the Minister in charge of energy, 16% included a reference to solar panels or green certificates in 2009–2014 and 9% in 2014–2019.[19] These figures document an intense parliamentary activity around solar panels, especially during the 2014–2019 legislature in Flanders, and they received large press coverage. Other topics that were discussed were usually more technical in nature and did not directly impact the finances of all households.[20]

The issues have been important in the public debate because they relate to the energy transition and the policies to address climate change. The debate focused on the magnitude of both the subsidies and the subsequent surcharges and electricity price increases. In addition, the debate was concerned with the distributional implications, as the benefits and costs were shared unequally among citizens. The discussions put much less emphasis on how tax policies may raise efficiency, as evident from the limited pass-on of the subsidy costs in the variable part of the electricity bill (Section 3.3).

It should finally be noted that the green parties were not necessarily the main advocates for those policies. In Flanders, the green party did not approve the policy in parliament and had not been part of the regional government since 2004. In Wallonia, the green party was part of the majority only for the period 2009–2014. Table 6 in Appendix B details the composition of regional each government.

4. Voters' responses to the subsidy programs

The previous sections discussed how generous subsidies led to the massive adoption of PVs, which in turn implied substantial financial costs and an intense political debate. In this section, we provide evidence on the impact of the policies on voters' responses. We will first discuss the hypotheses, and the empirical model to evaluate them. Next, we discuss our findings.

4.1. Hypotheses

We consider the impact of the subsidy programs on voters' responses. According to the retrospective voting hypothesis, citizens-voters reward politicians for good policies and punish them for bad ones. In the context of PV subsidies, we should distinguish between the consequences for adopters and non-adopters. The latter may punish the government because they end up with much higher (electricity) costs, while hardly experiencing environmental benefits. The expected impact is more ambiguous for the adopters. On the one hand, they benefited from high subsidies and they may want to reward the government parties that designed the generous subsidy scheme (Ovaere and Proost, 2015). On the other hand, as prosumers they may also punish them because of the corrective measures that reduced their return on investment. This punishment may become stronger over time when new corrective measures are taken.

In this empirical analysis, we will first compare voting patterns between areas with high and low adoption rates to test for an overall impact on votes. This strategy is motivated by the fact that the policy is more salient in these areas, which is crucial to expect effects on behavior (Chetty et al., 2009). Adopters are likely to be more aware of the policy as they are strongly affected, but we can also expect non-adopters to be more aware of the policy in these areas because it is more visible to them (Huet-Vaughn, 2019). After establishing the overall effect, we will provide extensions to distinguish between adopters and non-adopters.

4.2. Model

Since individual voting data is unavailable, we specify a micro-founded model for the election outcomes at the municipality level for all the regional election years (1995, 1999, 2004, 2009, 2014 and 2019).

Base model and identification. We start with the following aggregate regression model, as derived from individual voting behavior in Appendix E:

$$Y_{mt} = \gamma PV_m \times I(t \geq 2009) + \beta X_m \times I(t \geq 2009) + FE_m + FE_{rt} + e_{mt} \tag{1}$$

where Y_{mt} denotes the vote share of the 2004–2009 government parties in municipality m and election year t, PV_m is the cumulative adoption rate in municipality m at the end of the first (most generous) phase of the GC policy, X_m are local demographics, $I(t \geq 2009)$ is an indicator for elections since 2009, and FE_m and FE_{rt} are fixed effects per municipality m and per region r and election time t ($r = \{Flanders, Wallonia, Brussels\}$).[21] Note that we observe data at the municipality level only since 2014. Appendix C explains how we combine this with data at the (more aggregate) "canton" level during the earlier periods.[22]

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[19] We searched in the parliamentary archives accessible via https://www.vlaamsparlement.be (Flanders) and https://www.parlement-wallonie.be/ (Wallonia). For Flanders, we searched for all the parliamentary questions in the domain ÔEnergyÕ and we selected those containing the keyword 'solar panel'. For Wallonia, we collected all the parliamentary questions addressed to the Minister in charge of energy and we selected those with the keyword 'solar panel' or 'green certificates' in the title.

[20] While we can expect these topics to matter less for votes, we will suggest an identification strategy that isolates the impact of the solar panel policy. We will also find the strongest effects in Flanders in 2014–2019, consistent with the higher share of parliamentary questions.

[21] The first phase of the policy ended after 2012 in Flanders and in 2014 in Wallonia. Brussels did not make major adjustments in our sample period so we include all adoptions. We define government parties by region: in Flanders, we use all votes for CVP/CD&V, VU, NV-A, SP.a, SLP/Spirit and (Open) VLD, including cartels formed among them. For Wallonia, we use PS and PSC/CDH. For Brussels we use PS, PSC/CDH, ECOLO, (Open) VLD, SP.a, SLP/Spirit, CVP/CD&V and the cartel votes CD&V-NV-A (we do not include VU/NV-A separately as they never had a minister in the government of Brussels).

[22] We use public information provided by the Belgian government. For the years 1995–1999 the information was obtained from http://www.ibzdgip.fgov.be/. For 2004–2019, we obtain the data from https://verkiezingenXXXX.belgium.be/ with XXXX referring to the election year. We use data from 208 cantons and 589 municipalities, but we drop 15 municipalities in 2019 because mergers gave rise to a new composition.

Table 2
Summary statistics, vote and PV adoption.

	Mean	SD	Min	Max
Vote share 2004–2009 government	0.601	0.171	0.093	0.904
Vote share radical left	0.035	0.043	0.000	0.268
Vote share green	0.100	0.049	0.027	0.318
Vote share left	0.206	0.111	0.024	0.564
Vote share center	0.304	0.166	0.030	0.783
Vote share liberal	0.227	0.102	0.054	0.727
Vote share radical right	0.092	0.077	0.000	0.397
Local PV adoption rate	0.097	0.042	0.002	0.287
Neighbor PV adoption rate	0.099	0.033	0.000	0.191
Flanders	0.508	0.500	0.000	1.000
Wallonia	0.457	0.498	0.000	1.000
Brussels	0.035	0.184	0.000	1.000

Notes: This table provides summary statistics of our main variables, i.e. the vote shares, local and neighbor adoption rates and region dummies. The unit of observation is an election year (1995, 1999, 2004, 2009, 2014, 2019) and canton (or municipality for the last two election years). The total number of observations is 1995, amounting to on average 332.5 canton/municipality per election year. Neighbor PV adoption rate calculated using row-standardized contiguity matrix.

Our identification strategy is similar to that of a difference-in-differences estimator where we consider the treatment intensity. See for example Acemoglu et al. (2021) for a related recent example in a voting context. The parameter γ is our estimate of interest. It captures how votes changed differently in areas with more PVs. Eq. (1) assumes the treatment effect γ is homogeneous. Nevertheless, if treatment effects are heterogeneous, the estimate can still be interpreted as an average causal response (ACR) (Callaway et al., 2021).[23] Note that the two-way fixed estimator we use estimates a weighted version of the ACR with positive weights that sum to 1. The weights are close to the population weights when the distribution of the adoption rates is symmetric and close to normal. We verified this is the case here, see Appendix D Fig. 6.[24]

The inclusion of fixed effects allows us to capture time-invariant differences between municipalities and aggregate trends over time in each region. This is important as, for example, adoption is more likely in rural areas, while certain political parties experience large differences in votes between rural and urban areas. Moreover, by controlling for $X_m \times I(t \geq 2009)$ we can make weaker assumptions than the usual difference-in-differences estimator would require. The common trend assumption requires that votes would have changed in the same way in different municipalities if there had not been any PV adoption. We still allow for votes to change through a rich list of observable characteristics that are important for adoption behavior (see De Groote et al., 2016 in this context). We include the local distribution of housing and geographic characteristics (population density, home ownership, number of rooms, year of construction), as well as individual and household characteristics (income, household size, gender, nationality, education). For example, if parties are rewarded for pro-urban policies and we see less adoption in urban areas, it will not bias our results as it will be captured by the interaction of population density with the indicator of elections in 2009 or later. An alternative strategy would have been to instrument the adoption rates by exogenous shifters such as solar radiation. Comin and Rode (2023) do this for Germany, but this variation is small in Belgium.

Despite our rich controls, there remains a possibility that people change their vote for unobserved reasons that are correlated with adoption rates. In particular, high adoption in an area might be the result of a local trend in increased environmental preferences that is not fully explained by X_m. Such environmental preferences could also directly affect the type of households that invest in solar. As explained below, we estimate event studies that show that there was no such trend before the policy change. A remaining concern is that such an increase only took place recently. However, we will show that this is unlikely to be the case as we find no effects for the green party, which was not in government, but is expected to benefit the most from an increase in environmental preferences. Moreover, the implied possible bias of γ would be upward, while we find a negative effect for the parties in government. This suggests that our estimate is conservative.

Extensions. We also discuss the results of richer specifications. First, to provide robustness on the total effect on votes, we allow for year-specific effects γ_t (and β_t) instead of using the indicator $I(t \geq 2009)$. This allows us to discuss dynamic effects and to test for a pre-trend in the data. We then discuss specifications with regional effects (γ_r and γ_{rt}) to see if the difference in policies within the country also led to different voting patterns. In Appendix D, we also show robustness for adding time-varying income variables, for aggregating at the canton level and for effects that might be driven by subsidies at the municipality level.

Next, we extend the main model to better understand the sources of the net impact on votes by separately identifying the impact of neighbors of PV adopters. Since we do not have data at the individual level, we look instead at how households are affected by

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[23] This interpretation for continuous treatment effects holds under a strong parallel trends assumption: for all adoption rates, the average change in votes across all municipalities if they had experienced the same adoption rate, is the same as the average change in votes for the municipalities that experienced that adoption rate. This rules out selection on gains, but we do not expect that in this context.

[24] In Appendix D Table 9 we also estimate piece-wise linear effects and show that there is little heterogeneity over different "dosages" (i.e. adoption rates).

Table 3
Regression results, Model (1).

	(1) Base	(2) + demo	(3) Yearly effects	(4) Regional effects
Local PV adoption rate				
$\times I(year \geq 2009)$	−0.373 (0.132)	−0.793 (0.226)		−0.569 (0.271)
$\times I(year = 1995)$			0.148 (0.128)	
$\times I(year = 1999)$			0.132 (0.095)	
$\times I(year = 2009)$			−0.667 (0.227)	
$\times I(year = 2014)$			−0.605 (0.205)	
$\times I(year = 2019)$			−0.813 (0.221)	
$\times I(year \geq 2009) \times Flanders$				−0.578 (0.259)
$\times I(year \geq 2009) \times Brussels$				3.974 (6.893)
Municipality FE	YES	YES	YES	YES
Year × region FE	YES	YES	YES	YES
Demographics $\times I(year \geq 2009)$	NO	YES	YES	YES
Observations	1,995	1,995	1,995	1,995
R-squared	0.968	0.971	0.971	0.971
P-value no pre-trend			0.373	
P-value same effect after 2004			0.013	

Notes: Linear regression on vote share of 2004–2009 government parties. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

adoptions in neighboring municipalities, while controlling for the own adoption rate:

$$\begin{aligned} Y_{mt} &= \gamma_1 PV_m \times I(t \geq 2009) + \beta_1 X_m \times I(t \geq 2009) \\ &\quad + \gamma_2 \widetilde{PV_m} \times I(t \geq 2009) + \beta_2 \widetilde{X_m} \times I(t \geq 2009) \ + FE_m + FE_{rt} + e_{mt} \end{aligned} \tag{2}$$

where $\widetilde{PV_m}$ and $\widetilde{X_m}$ are the adoption rate and characteristics of neighboring municipalities of m.[25] The parameter γ_1 still captures the total effect of adopters and their closest (within-municipality) neighbors, while γ_2 now only captures a neighbor effect (between adjacent municipalities).

Finally, we will analyze which parties lost and gained votes. To study this, we repeat the main analysis with different outcome variables Y_{mt}. Instead of the vote share of the incumbent parties, the outcome variables become the vote shares of different (groups of) political parties. The composition of these groups can be found in Table 7 in Appendix B.

4.3. Results

Summary statistics on votes and adoption can be found in Table 2 and statistics on local demographics are in Table 8 in Appendix D.

Base model. Table 3 presents the results from our main model (Eq. (1)). In Regression 1 we control for local fixed effects, as well different time fixed effects for each of the three regions. The adoption rate coefficient of −0.373 in Column (1) implies that a 10 percentage point increase in the local adoption rate decreases the 2004–2009 government vote share by 3.7 percentage points. In Regression 2 we additionally control for a set of local demographics, interacted with a dummy equal to one from 2009 on. This controls for vote changes that can be attributed to voter characteristics rather than adoption. We find that this cannot explain the negative impact. Adopter characteristics are rather related to an increase in votes for the incumbent parties, making the decrease due to adoption raise to 7.9 percentage points.

Regression 3 shows the impact by election year, with the election year before the policy change (2004) as the base. The non-significant effects in 1995 and 1999 confirm that there was no pre-trend in the votes, providing confidence in the identification strategy.[26] Furthermore, the effect is present in every election after 2004 and significantly larger in 2019. This is consistent with

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[25] We use a row-normalized contiguity matrix.

[26] As stressed by Roth (2022), non-significant effects can also be the result of a lack of power. We follow his approach and calculate the linear trend we can detect at a 5% significance level with 50% (80%) power. This provides further confidence in our results as we can detect trends of .12 (.18) in absolute value per election, which is too low to explain our treatment effects, especially in the first years. We also found no pre-trend in a specification without control variables, but the smaller effect sizes make it more difficult to exclude that they could come from non-detected linear trends.

the more recent increases in surcharges on the electricity bill for non-adopters (see Fig. 3) and the introduction of the prosumer fee for some of the adopters. Finally, Regression 4 shows a more negative effect in Flanders. This stronger punishment effect is consistent with the larger electricity surcharges in that region, as well as with the introduction of the prosumer fee for adopters of PVs. In Appendix D Table 10, we show the interaction effects with Flanders for each year. Consistent with the above explanation, punishment is intensifying over time in Flanders only. For Brussels, the results are too imprecise to draw conclusions, due to its small number of cantons and municipalities.

Appendix D shows that our conclusions are robust to various changes in our specifications. First, we find no impact of controlling for time-varying local income (source: STATBEL). This is the only control variable we observe every year and by adding it this way, we control for changes in economic conditions that could be related to both votes and adoption (Table 11). Second, we show that there is no concern following the different levels of aggregation used in the paper by estimating the model at the level of the canton in all years (Table 12). Third, we show that municipalities in Flanders that provided local subsidies for solar panels experienced the same effects (Table 13). Finally, we re-estimate the regression with yearly effects. We remove the control variables from the model and show that the common trend assumption is also not rejected in this case. We also add them in more flexible ways and similarly find no change in our conclusions (Table 14).

In sum, the main finding is that the incumbent parties received *fewer* votes in municipalities where the subsidization policy was more successful. We now provide a further analysis to gain additional insights about the mechanisms behind this effect.

Extension: prosumers versus non-adopters. The "net punishment" found in Table 3 may come through two different channels. first channel comes through the voters who did not adopt PVs and hence did not directly benefit from the programs. They would punish the incumbent parties because they realize that the financing costs would be high and be paid to a large extent by non-beneficiaries. Although the increase in the electricity price affects all consumers, the punishment effect is expected to be more important for the non-adopters who live in municipalities where many people adopted. There are two reasons for this. First, voters have many motives to choose one party over another. The visibility of PVs in the neighborhood can make the PV policy more salient in these areas and therefore have a larger impact on the votes. Second, households might be envious that the subsidy is used to transfer wealth to their direct neighbors. In places where there are few PVs, the beneficiaries of this policy are less visible than in places where there are a lot of PVs. Furthermore, there is more adoption in richer places (De Groote et al., 2016). Therefore, this policy may generate a Matthew effect, which may be more visible in places where there are more PVs. All these reasons may explain why the punishment is stronger in places where adoption is more important. An alternative channel of the retrospective voting hypothesis is that the prosumers themselves punish the government because they feel deceived after having to pay a new prosumer fee.

To distinguish between the behavior of prosumers and their neighbors, we run the model specified in Eq. (2) (see Table 4). Regression 5 starts from Regression 2 but adds the adoption rate of neighboring municipalities. We then allow for time-varying effects of the demographics of neighboring municipalities in Regression 6. As we show more formally in Appendix E, if a negative effect is explained by punishment by prosumers only, we should not see any impact on the local vote share by the adoption rate in the neighboring municipalities. However, we find a negative impact in both specifications, with effect sizes that are close to our main estimates of interest. This shows that neighbors of prosumers are punishing the government.

In regression 6 we even see that the negative effect is large for the adoption rate of neighboring municipalities, and close to 0 for the local adoption rate. As only the local adoption rate captures voters in the municipality that adopted themselves, this suggests that prosumers are counteracting the negative effect of their (within-municipality) neighbors by rewarding the government. However, this result should be interpreted with caution. In the last row of Table 4, we show that our estimates are not sufficiently precise to be able to reject the hypothesis that the local adoption rate has the same effect as the adoption rate of neighboring municipalities. This implies that we cannot confirm that prosumers indeed reward the government.

Since exposure might be different in rural and urban areas, we also investigate heterogeneous effects along this dimension. As shown in Appendix D Table 15, we do not find significant differences.

Extension: party-specific votes. Finally, Table 5 estimates the main model (Eq. (1)), but replaces the outcome variable with the vote share of different (groups of) political parties. As there are very few cantons and municipalities in Brussels, we only do this for the two other regions.[27] The pattern in the two regions is quite similar with votes going to the radical left and radical right, and coming from the socialist parties. In both regions, these parties had important competencies in environmental policies and are likely more affected by concerns related to the Matthew effect as subsidies for solar panels are a transfer to more wealthy households (De Groote et al., 2016).[28] Note also that the effects of the liberal parties are different in both regions (p-value of 0.066). This is consistent with the fact that liberals were part of the government that introduced the subsidization policy in Flanders, but not in Wallonia. We do not find important effects for the green party. This suggests that environmental preferences did not increase more in high-adoption areas which was a potential concern for our identification strategy (see Section 4.2).

Note that we cannot exclude that other parties involved in the government over the past years experienced strong negative effects too. We only detect significantly positive effects for parties that were never in government, both on the left and the right

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[27] We also estimated a model that included the effects for Brussels. These estimated effects were all insignificant and imprecise, and there was almost no change in the estimates for the other regions

[28] Policies that conflict with the party's ideology can influence their electoral effect. In the context of fiscal spending in the US, Huet-Vaughn (2019) suggests that their positive effect of road spending might not hold if the responsible party was the Republican party instead of the democratic party as they generally favor smaller budgets. Indeed, Lowry et al. (1998) show that voters hold politicians accountable in a partisan way as they punish Republicans and reward Democrats for increases in the fiscal scale.

Table 4
Regression results, Model (2).

	(5) Neighbor effect	(6) + controls
Local PV adoption rate		
$\times I(year \geq 2009)$	−0.505	−0.088
	(0.299)	(0.382)
Neighbor PV adoption rate		
$\times I(year \geq 2009)$	−0.427	−1.066
	(0.230)	(0.373)
Municipality FE	YES	YES
Year × region FE	YES	YES
Demographics × $I(year \geq 2009)$	YES	YES
Neighbor demographics × $I(year \geq 2009)$	NO	YES
Observations	1,995	1,995
R-squared	0.971	0.972
P-value local effect = neighbor effect = 0	0.000	0.000
P-value local effect = neighbor effect	0.874	0.179

Notes: Linear regression on vote share of 2004–2009 government parties. Neighbor PV adoption rate and controls calculated using row-standardized contiguity matrix. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

Table 5
Regression results model (1), per political party.

	(7) Rad left	(8) Green	(9) Social	(10) Center	(11) Liberal	(12) Rad right
Local PV adoption rate						
$\times I(year \geq 2009) \times Flanders$	0.208	−0.141	−0.430	−0.482	−0.174	0.730
	(0.061)	(0.091)	(0.164)	(0.304)	(0.237)	(0.167)
$\times I(year \geq 2009) \times Wallonia$	0.100	0.141	−0.427	−0.129	0.214	0.230
	(0.084)	(0.093)	(0.181)	(0.233)	(0.211)	(0.100)
Municipality FE	YES	YES	YES	YES	YES	YES
Demographics × $I(year \geq 2009)$	YES	YES	YES	YES	YES	YES
Year × region FE	YES	YES	YES	YES	YES	YES
Observations	1,995	1,995	1,995	1,995	1,995	1,995
R-squared	0.927	0.918	0.951	0.965	0.935	0.943
P-value no regional differences	0.164	0.009	0.985	0.191	0.066	0.004

Notes: Linear regression on vote share of families of parties. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

of the spectrum. This suggests that voters were not able to well identify who was responsible for the policy. This is very plausible considering the policy changes that happened later by ministers of different parties. It is also consistent with the growth of anti-establishment votes as the result of failed policies. Similarly, Sartre et al. (2022) show that the populist vote for both the extreme right and the extreme left is on the rise in the French municipalities that contracted toxic loans before the financial crisis.

5. Conclusion

In this paper, we investigated the electoral impact of technology-specific subsidies for parties that introduced them. We considered the generous subsidy programs for solar PVs in Belgium, which led to unexpectedly massive success. The resulting financing problems were the subject of intense political debate in the subsequent years. We exploited variation in the PV adoption rates across municipalities to evaluate the impact of the subsidy policies on election outcomes. Our results are consistent with retrospective voting, where voters punished the incumbent political parties for a costly policy that highly benefited a relatively small group, without creating sufficient (environmental) gains for others.

This has important implications for green energy policy. Political rather than economic reasons have been used to justify the choice of technology-specific policies to combat climate change over other measures such as a market for carbon emission rights or a carbon tax. This political choice was risky, as the total financial impact of supporting a specific and new technology is hard to predict and can therefore create high unanticipated costs. Our results show that these costs are not ignored by voters, such that the incumbent parties actually lost votes. These results give an optimistic message about the role of democracy in improving policy-making, at least in the face of new challenges such as taking necessary measures to combat climate change.

Future research could provide more evidence behind the mechanisms for our results. The anonymity of voting data required us to aggregate all variables of interest at the level of the municipality. As we explain through a micro-founded model, we use adoption rates in adjacent municipalities to infer that the effect must have been driven mainly by non-adopters. A more in-depth analysis of treatment effect heterogeneity would require the collection of other types of data. For instance, one may obtain further insights from survey data about voting behavior of adopters and non-adopters before and after the introduction of the policy. Survey data can, unlike election data, be combined with individual data and provide additional information on the individuals' underlying motivations.

Moreover, we need to be cautious about the external validity and research on policies in other contexts is needed. The cost of the policy was made very salient through surcharges on the electricity bill, intense political debate and high rates of adoption. It is not clear if the punishment would appear in response to policies of a smaller scale. Nevertheless, a punishment effect was already found before the large increase in costs, suggesting that voters can understand the impact of a subsidy on future taxation. Further research could investigate the role of dedicated taxes to finance subsidy programs on political accountability.

Declaration of competing interest

The authors declare that they have no conflict of interests.

Data availability

The data that has been used is confidential.

Appendix A. Computing the NPV: Model and data sources

This appendix discusses the data sources and assumptions needed to obtain an estimate of the net present value of adopting a PV, as well as the commitments and payments by the government.

A.1. Model

We collected detailed information on the timing and the magnitude of the different support schemes in the three regions. Based on that, we compute the various components of the net present value: NPV_{rjt}, with j denoting the capacity of PV (up to 10 kW), the region $r = F, W, B$ (Flanders, Wallonia and Brussels) and the month t (time frame: January 2006-December 2016). We correct for inflation and express net present value in prices of 2013 using the HICP.

A.1.1. Computing the net present value components

We assume the upfront investment cost of a solar PV with capacity size j at month t (p_{jt}) is the same across the three regions r, but the present discounted value of benefits (b_{rjt}) differs. The net present value therefore differs as $NPV_{rjt} = b_{rjt} - p_{jt}$.

The financial returns of adopting a solar PV differ between regions and come in the form of rebates, tax cuts, net metering benefits and green certificates:

$$b_{rjt} = b_{rjt}^{rebate} + b_{jt}^{taxcut} + b_{rjt}^{netmeter} + b_{rjt}^{GC}.$$

Most of these benefits apply over future periods, and we calculate their present value using a monthly discount factor of $\delta = (1+r)^{-1/12}$, where r is the annual real interest rate. We will now discuss these various components in turn.

The rebates b_{rjt}^{rebate} are a percentage of the investment cost p_{jt}. They are usually paid shortly after the investment so we abstract from discounting here. The tax cuts were applicable for a period of up to four years, and are given by:

$$b_{jt}^{taxcut} = \sum_{\tau=1}^{4} \delta^{12\tau} \tilde{b}_{jt}^{taxcut,\tau},$$

where $\tilde{b}_{jt}^{taxcut,\tau}$ is the tax cut applicable τ years after adoption at time t.

The remaining benefit components all relate to future electricity production. We assume that the PVs start generating electricity the month after the investment and they have a lifetime of 20 years ($R^E = 240$). The monthly production (in kWh) per unit of capacity (in kW) is given by a constant capacity factor β and there is a monthly deterioration rate denoted by λ. The net metering benefits are then given by:

$$b_{rjt}^{netmeter} = \delta \frac{1-(\delta^E)^{R^E}}{1-\delta^E} \tilde{b}_{rjt}^{Electricity} - \delta \frac{1-(\delta)^{R_t^{ProsFee}}}{1-\delta} \tilde{b}_{rjt}^{ProsFee}.$$

The first term captures the net metering benefits over the PV's lifetime (R^E), and the second term captures the costs of the prosumer fee over the period ($R_t^{ProsFee}$) that it applies. The variable $\tilde{b}_{rjt}^{Electricity}$ is the monthly benefit from net metering based on the observed electricity price at time t. $\tilde{b}_{rjt}^{ProsFee}$ is the monthly cost of the prosumer fee. If at the installation date, such a fee was not yet in place, we assume people did not anticipate it, i.e. $\tilde{b}_{rjt}^{ProsFee} = 0$. Finally, the adjusted monthly discount factor δ^E is given by $\delta^E = (1-\lambda)(1+\kappa)\delta$, where κ denotes the expected percentage increase in electricity prices to capture changes in future net metering benefits.

Finally, the GC benefits, which are also related to electricity production, are given by:

$$b_{rjt}^{GC} = \delta \frac{1-(\delta_{rt}^{G})^{R_t^G}}{1-\delta_{rt}^{G}} \tilde{b}_{rjt}^{GC}$$

where $\tilde{b}_{rjt}^{GC}$ denotes the monthly benefits from GCs for adoption at time t, and R_t^G number of periods that the GCs are guaranteed. The monthly benefits $\tilde{b}_{rjt}^{GC}$ stem from the GC price. In Flanders, we simply use the fixed price of the GCs applicable at the time of adoption t. In Wallonia and Brussels, the GC price is market-based, so we have to make an estimate of the price: we take it to be equal to the expected price at the moment of adoption for the entire period R_t^G. The adjusted monthly discount factor δ_{rt}^{G} is given by $\delta_{rt}^{G} = (1-\lambda)(1-\pi)\delta$ where π is the monthly inflation rate, to capture the fact that the model is in real prices while GC benefits were guaranteed at nominal prices. We use a different formulation for Wallonia after the March 2014 reform $\delta_{Wt} = (1-\pi)\delta$ as benefits were then based on PV capacity and not on actual production.

A.1.2. Assumptions

To calculate the various components of b_{rjt}, we make the following assumptions:

- 1 kW produces 850 kWh/year: capacity factor $\beta = 0.0973$
- Yearly deterioration is 1%: $\lambda = 1.01^{1/12} - 1$
- Lifetime PV is 20 years: $R^E = 240$
- Inverter replacement is not anticipated
- Yearly inflation is 2%: $\pi = 1.02^{1/12} - 1$
- Annual interest rate: $r = 3\%$
- Grid fee is never anticipated
- Yearly expected increase electricity price increase is 3.4%: corresponding to estimated monthly trend of $\kappa = 0.0028148$
- Current price of GCs is guaranteed at nominal values through the investment period

A.1.3. NPV computations per region

See Fig. 4.

A.2. Computing the cost of the subsidies

A.2.1. The green certificate debt

The governments commit to grant GCs for a given period (up to 20 years) and GCs have a given value (in euro). Using the estimation of solar production, we can compute the GC subsidy paid each year during the granting period.

We summarize the evolution of this green certificate debt in two figures. Fig. 5(a) shows the present value of the commitments made to new adopters between 2006 and 2016. Fig. 5(b) shows the yearly flow of payments to adopters between 2006 and 2036, based on these commitments and assuming no new commitments.

Fig. 5(a) shows the evolution of the net present value of new commitments since the start of the program in 2006. In the peak year 2011 the present value of new GC commitments to those who installed a PV system during that year represented more than 400€ per household in both Flanders and Wallonia. This cost will be spread over the subsequent granting period. This is evident from Fig. 5(b), which shows that the annual payments reached the peak amount of 100€ per household in Flanders in 2011, and 140€ in Wallonia one year later. Payments remain high in subsequent years, even though new commitments had stopped: they extend to up to 2027 in Wallonia and 2034 in Flanders.

A.2.2. The cost of net metering

With net metering, imports from the grid and exports to the grid are both valued at the electricity retail price. The retail price is the sum of three components: the commodity price paid to retailers, the grid tariff and the different taxes and surcharges. To estimate the subsidy from net metering, we consider a net billing counterfactual (Gautier et al., 2018) where the electricity imports are valued at the retail price but the exports are valued at the commodity price. We consider that a prosumer self-consumes 35% of his/her solar production.[29] The subsidy from net metering can then be computed as:

$$\text{Subsidy} = (\text{solar production in MWh}) \times (1 - 0.35) \times (\text{retail price - electricity price})$$

which is the lost income of the DSOs.

Figs. 5(a) and 5(b) report the present value and the yearly payments corresponding to the subsidy from net metering. The figures show that this component is non-negligible but smaller than the GC benefits. Nevertheless, its importance is rising in recent years.

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[29] A similar rate is used by the Belgian regulators to compute the profitability of a representative PV installation. Self-consumption depends on the consumption profile, the installation size and the incentives. Empirical estimations show a lot of variation in self-consumption rate across consumers and countries (McKenna et al., 2019). Lang et al. (2016) estimate an average self-consumption of 40% for small residential buildings and McKenna et al. (2018) an average of 45% for UK households with PV.

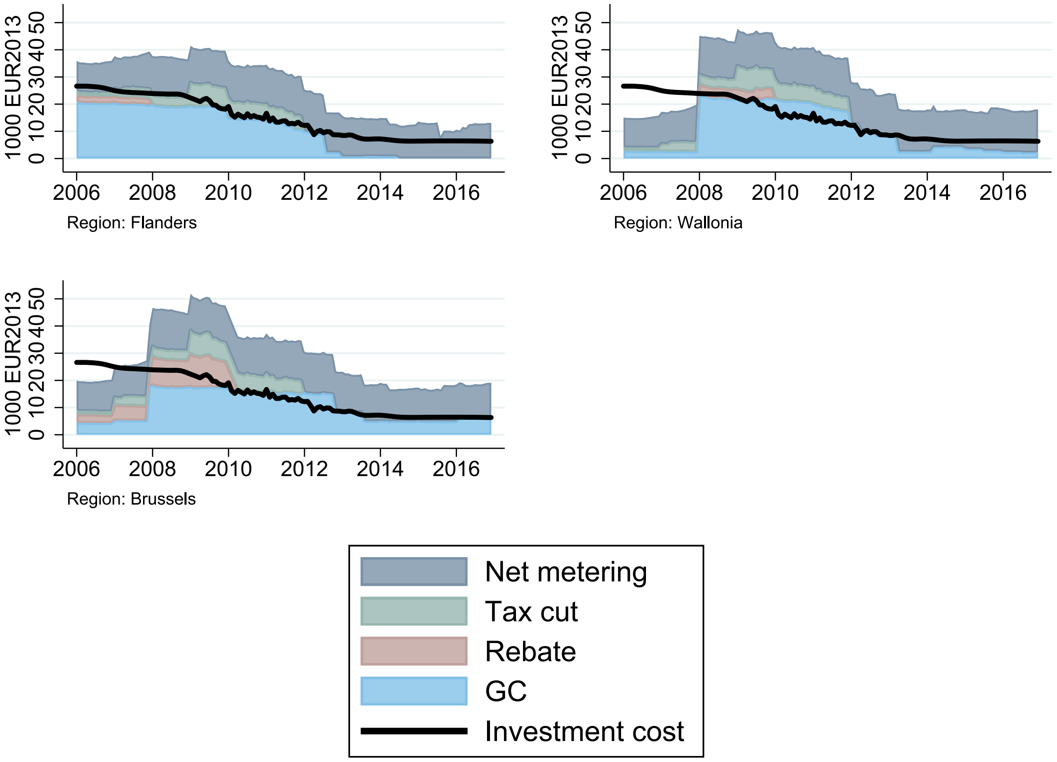
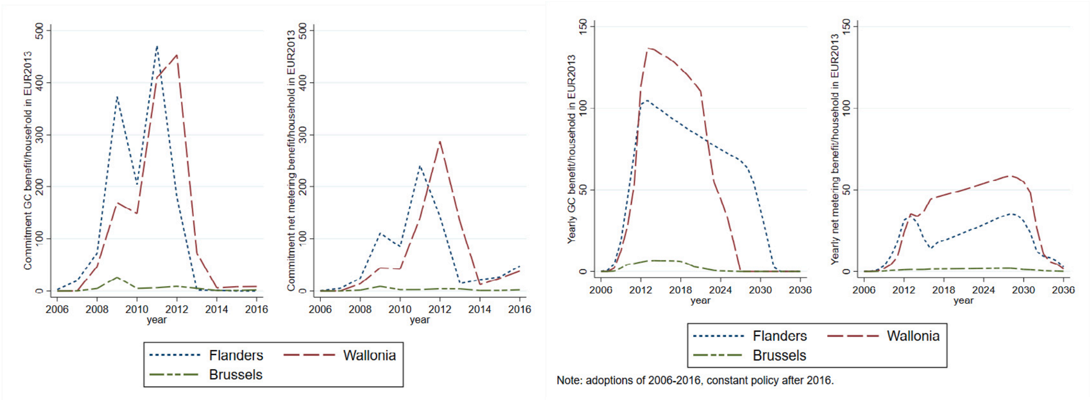


Fig. 4. Total subsidies of a 4 kWp installation in each region, 2006–2016.

Notes: Each graph refers to one region (Flanders, Wallonia, Brussels) during 2006–2016. It shows the annual evolution of the investment cost, i.e. module price, of a 4 kWp installation (black line) and the present value of the associated financial benefits from the green certificates (blue area), net metering (gray area), tax cuts (green area) and rebates (pink area). The amounts are expressed in 1000 Euro, adjusted for inflation (in 2013 prices). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)


(a) Present value of commitments to new adopters, 2006-2016

(b) Flow of payments to all adopters, 2006-2036

Note: adoptions of 2006-2016, constant policy after 2016.

Fig. 5. Commitments and payments in each region.

Notes: Panel (a) shows the annual evolution of the present value of commitments to new adopters, stemming from green certificates (left panel) and net metering (right panel). Panel (b) shows the annual evolution of the payment flow to eligible past adopters, stemming from green certificates (left panel) and net metering (right panel). In both panels, the amounts are expressed in Euro per household, adjusted for inflation (in 2013 prices).

Table 6
Composition of regional governments .

Legislature	Flanders	Wallonia	Brussels
2004–2009	**CD&V**, SP.a, VLD, NVA	PS, **CDH**	PS, **Ecolo**, CDH, Open VLD, CD&V, SP.a
2009–2014	CD&V, **SP.a**, NVA	PS, CDH, **Ecolo**	PS, **Ecolo**, CDH, Open VLD, CD&V, Groen
2014–2019	NVA, CD&V, **Open VLD**	**PS**, CDH (2014–2017), **MR**, CDH (2017–2019)	PS, Défi, **CDH**, Open VLD, CD&V, SP.a

Notes: The party who had energy minister in bold.

Table 7
Positionnement of political parties .

	Rad left	Green	Socialist	Center	Liberal	Rad right
Flanders	PVDA	Groen	SP.a, SLP	CD&V, NVA	Open VLD	Vlaams Belang, LDD
Wallonia	PTB	Ecolo	PS	CDH	MR, Défi	PP, FN

Notes: All parties were present in Brussels. When a political party changed its name, we use the most recent.

A.3. Data sources

A.3.1. Investment cost

Our starting point is the price index for five capacity sizes (2, 4, 6, 8 and 10 kW) in Flanders from 2006–2013 in De Groote and Verboven (2019). Note however that the authors are cautious about price information before 2009 as it is based on predictions from a German price index (they do not use it in estimations).

We use the most common VAT rate (6%) and extrapolate the data by using four data points that were used by the government agency VEA to calculate subsidies in June 2013, December 2013, June 2014 and January 2015 for a 5 kW system. We additionally use a data point in February 2018 for a larger system because subsidies were no longer calculated for smaller ones.[30] Finally, we requested the price of a 5 kW system on the website of energy supplier, Luminus, to assign a price for the end of 2019.[31] We use this data to calculate the growth rate in the relevant size category since the last observation in De Groote and Verboven (2019) and apply this rate on all capacity options. Finally, we apply cubic spline interpolation to fill in the missing months.

A.3.2. Government policies

Our starting point is again De Groote and Verboven (2019) who describe all federal and Flemish policies until the beginning of 2013. No new policies have been implemented since at the federal level.

For Flanders, additional information was collected on the government website

www.energiesparen.be. It contains the reports of the VEA about the newly applicable granting rates of GCs (we used the same reports to obtain information on investment costs), as well as information on the grid fees.

For the policies that are specific to Wallonia, we use the specific report on green certificates published yearly by the regional regulator and the specific information published on its website. Boccard and Gautier (2015, 2019, 2021) contain detailed information on the functioning of the GC market in Wallonia.

Finally, our main source for the policies in Brussels is the regional regulator. Data and information were collected on its website and it provides additional information and data on request.

A.3.3. Electricity prices

As in De Groote and Verboven (2019) we use the electricity price in Belgium, reported every six months by Eurostat and we apply cubic spline interpolation to obtain monthly data. However, from 2012 on we use a region-specific measure with monthly variation, computed by Hindriks and Serse (2021) based on data obtained from the CREG.[32]

Appendix B. Additional information on regional governments and political parties

See Tables 6 and 7.

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[30] Source: https://www.energiesparen.be/overzicht-bandingfactor-zonnepanelen, consulted on 28/02/2020.

[31] Source: https://www.luminus.be/nl/apps/flows/prijs-zonnepanelen/, consulted on 17/01/2020.

[32] At the time of switching between prices indexes (January 2012), the difference between the national and Flemish price was only 0.4%, the difference between the national and the one in Wallonia was 0.7% and the difference with the one in Brussels was 2%.

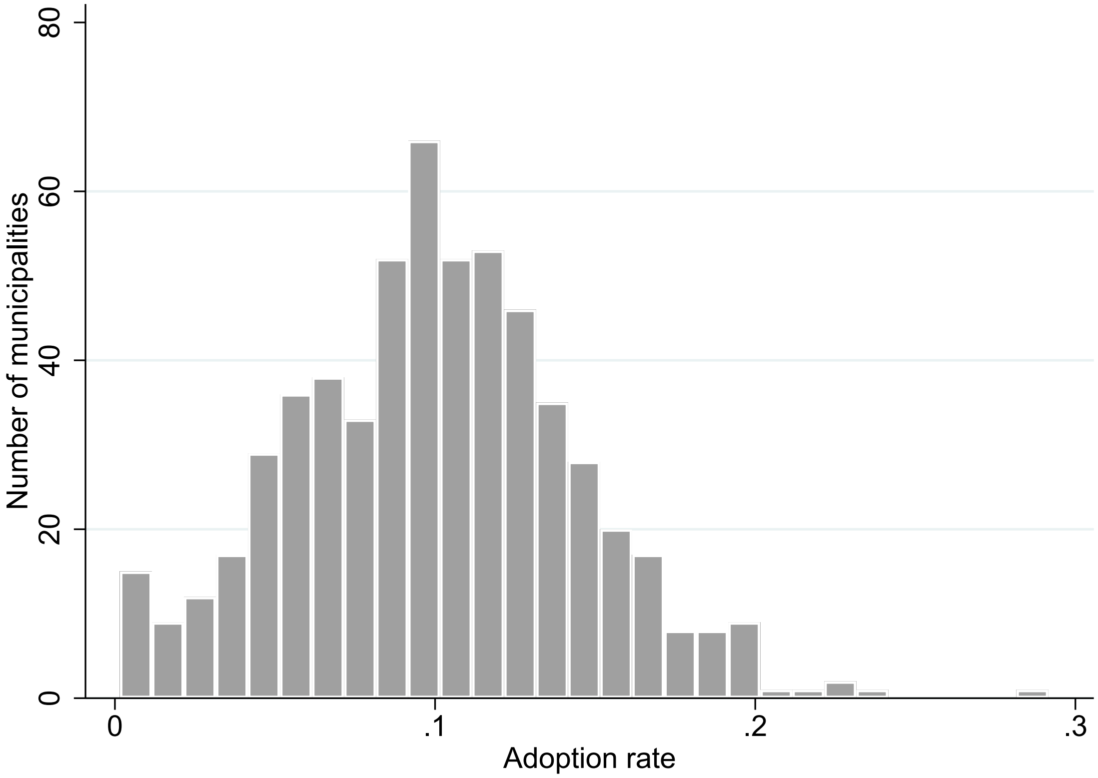

Fig. 6. Histogram of adoption rates.

Appendix C. Further details on the voting model

We use the specification detailed in the main text of the paper for the election years 2014 and 2019, but we lack data at the municipality level for the elections of 1995, 1999, 2004 and 2009. For these years, data are only available at the canton level. A canton is either a municipality or a group of adjacent municipalities. There are 209 cantons in Belgium and 589 municipalities. To include this in a single regression, we proceed as follows.

Let the regression at the municipality level be given by:

$$Y_{mt} = \gamma PV_m \times I(t \geq 2009) + \beta X_m \times I(t \geq 2009) + FE_m + FE_{rt} + e_{mt} \quad (1)$$

In some years we do not observe Y_{mt} but we do observe the canton-level vote shares, defined as $Y_{at} = \sum_{m\in A} w_m Y_{mt}$ with a an indicator for the aggregated unit (i.e. the canton), A the set of municipalities in a and w_m the share of voters that come from each municipality. We assume this share is stable over time and proxied by the share of households living in each municipality, a variable we observe in our data.[33] We can then rewrite the municipality-level regression at the canton level:

$$\begin{aligned} Y_{at} &= \gamma \sum_{m\in A} w_m PV_m \times I(t \geq 2009) + \beta \sum_{m\in A} w_m X_m \times I(t \geq 2009) \\ &\quad + \sum_{m\in A} w_m FE_m + FE_{rt} + \sum_{m\in A} w_m e_{mt} \end{aligned} \quad (3)$$

The linearity of the regression equation makes it straightforward to apply this. Before estimation, we need to calculate weighted averages of control variables, adoption rates, and the dummy indicators that estimate the municipality fixed effects. We can then regress the canton-level vote share on these weighted averages when municipality-level data are not available.

Appendix D. Additional tables and figures

See Fig. 6, Tables 8–15.

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[33] It is compulsory to vote in Belgium so we expect this to be a good proxy.

Table 8
Summary statistics: local demographics.

	Mean	SD	Min	Max
Ln(population density)	5.752	1.168	3.215	10.100
Income group 2	0.212	0.377	0.000	1.000
Income group 3	0.203	0.364	0.000	1.000
Income group 4	0.178	0.346	0.000	1.000
Income group 5	0.181	0.361	0.000	1.000
% home owned	0.721	0.097	0.252	0.911
% higher education	0.303	0.071	0.127	0.592
% male	0.493	0.009	0.454	0.553
% foreign	0.071	0.075	0.009	0.497
Average household size	2.394	0.145	1.658	2.802
Number of rooms	5.842	0.396	4.202	7.184
Average year of construction house (/1000)	1.962	0.011	1.931	1.982
Neighbors: Ln(population density)	5.686	1.045	0.000	9.233
Neighbors: Income group 2	0.209	0.206	0.000	1.000
Neighbors: Income group 3	0.201	0.185	0.000	1.000
Neighbors: Income group 4	0.193	0.199	0.000	1.000
Neighbors: Income group 5	0.182	0.224	0.000	1.000
Neighbors: % home owned	0.722	0.081	0.000	0.856
Neighbors: % higher education	0.305	0.055	0.000	0.515
Neighbors: % male	0.492	0.024	0.000	0.509
Neighbors: % foreign	0.067	0.059	0.000	0.497
Neighbors: Average household size	2.391	0.149	0.000	2.698
Neighbors: Number of rooms	5.838	0.402	0.000	6.456
Neighbors: Average year of construction house (/1000)	1.956	0.095	0.000	1.981

Notes: This table provides summary statistics of local demographics. The unit of observation is the municipality.

Table 9
Regression results of Model (1), allowing for piece-wise linear effects.

	Base	Piece-wise linear
Local PV adoption rate $\times I(year \geq 2009)$		
All	−0.793	
	(0.226)	
Adoption rate ≤ 0.05		−0.809
		(0.591)
Adoption rate $> 0.05\, \&\, \leq 0.10$		−1.209
		(0.359)
Adoption rate $> 0.10\, \&\, \leq 0.15$		−1.007
		(0.285)
Adoption rate ≥ 0.15		−0.896
		(0.268)
Municipality FE	YES	YES
Year × region FE	YES	YES
Demographics $\times I(year \geq 2009)$	YES	YES
Observations	1,995	1,995
R-squared	0.971	0.971
P-value same effects		0.094

Notes: Linear regression on vote share of 2004–2009 government parties. The second column shows a specification that allows for different effects over four bins of the observed adoption rate. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

Table 10
Regression results, event study with region effects.

	Base	x Flanders
Local PV adoption rate		
$\times I(year = 1995)$	0.156	−0.019
	(0.197)	(0.231)
$\times I(year = 1999)$	0.114	0.046
	(0.146)	(0.172)
$\times I(year = 2009)$	−0.541	−0.342
	(0.254)	(0.272)
$\times I(year = 2014)$	−0.541	−0.342
	(0.228)	(0.242)
$\times I(year = 2019)$	−0.545	−0.700
	(0.235)	(0.229)
Municipality FE	YES	
Year × region FE	YES	
Demographics × $I(year \geq 2009)$	YES	
Observations	1,995	
R-squared	0.972	

Notes: Linear regression on vote share of 2004–2009 government parties. The table shows the estimates of a single regression with effects that are allowed to differ by region. The second column shows the interaction effects for Flanders. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

Table 11
Regression results of Model (1) after adding time-varying income.

	Base	+ demo	Yearly effects	Regional effects
Local PV adoption rate				
$\times I(year \geq 2009)$	−0.276	−0.640		−0.473
	(0.099)	(0.202)		(0.215)
$\times I(year = 2009)$			−0.570	
			(0.220)	
$\times I(year = 2014)$			−0.547	
			(0.198)	
$\times I(year = 2019)$			−0.767	
			(0.214)	
$\times I(year \geq 2009) \times Flanders$				−0.452
				(0.202)
$\times I(year \geq 2009) \times Brussels$				−1.254
				(7.927)
Ln(yearly median income)		0.020	0.046	0.077
		(0.140)	(0.138)	(0.140)
$\times I(year \geq 2009)$		0.091	0.107	0.024
		(0.107)	(0.108)	(0.108)
Municipality FE	YES	YES	YES	YES
Year × region FE	YES	YES	YES	YES
Demographics × $I(year \geq 2009)$	NO	YES	YES	YES
Observations	1,568	1,568	1,568	1,568
R-squared	0.979	0.980	0.980	0.980

Notes: Linear regression on vote share of 2004–2009 government parties. Robust standard errors in parentheses, clustered within canton. Canton level data used in 2004–2009. Municipality-level data used in 2014–2019. For election year 2004, income of 2005 was used because of data availability.

Table 12
Regression results of Model (1) at canton level.

	Base	+ demo	Yearly effects	Regional effects
Local PV adoption rate				
$\times I(year \geq 2009)$	−0.349	−0.773		−0.582
	(0.119)	(0.210)		(0.256)
$\times I(year = 1995)$			0.148	
			(0.118)	
$\times I(year = 1999)$			0.132	
			(0.088)	
$\times I(year = 2009)$			−0.661	
			(0.207)	
$\times I(year = 2014)$			−0.667	
			(0.195)	
$\times I(year = 2019)$			−0.712	
			(0.201)	
$\times I(year \geq 2009) \times Flanders$				−0.582
				(0.256)
$\times I(year \geq 2009) \times Brussels$				4.371
				(6.159)
Municipality FE	YES	YES	YES	YES
Year × region FE	YES	YES	YES	YES
Demographics × $I(year \geq 2009)$	NO	YES	YES	YES
Observations	1,244	1,244	1,244	1,244
R-squared	0.955	0.960	0.960	0.960

Notes: Linear regression on vote share of 2004–2009 government parties. Robust standard errors in parentheses, clustered within canton. Canton level data used in all periods 1995–2019.

Table 13
Regression results of Model (1) with local support (Flanders only)

	Base	+ local support
Local PV adoption rate		
$\times I(year \geq 2009)$	−0.769	−0.902
	(0.274)	(0.367)
$\times I(year \geq 2009) \times Local\ \ support$		0.276
		(0.357)
Municipality FE	YES	YES
Year × region FE	YES	YES
Demographics × $I(year \geq 2009)$	YES	YES
Municipalities with local support		123
Observations	1,013	1,013
R-squared	0.952	0.952

Notes: Linear regression on vote share of 2004–2009 government parties in Flanders. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

Appendix E. Decomposition of the impact of adoption on the voting behavior

To better understand how to interpret the estimates we show how Eq. (2) can be derived from individual household behavior.

Let Y_{it} be a dummy = 1 if household i votes for the incumbent in year t.[34] Let m be the municipality in which i lives. Assume i's incumbency vote decision Y_{it} can be characterized by the following linear probability model:

$$Y_{it} = \rho_1 PV_i \times I(t \geq 2009) + \beta_1 X_i \times I(t \geq 2009)$$
$$+\rho_2 \frac{1}{hh_m - 1} \sum_{j \in m \setminus i} PV_j \times I(t \geq 2009) + \rho_3 \widetilde{PV_m} \times I(t \geq 2009) + \beta_2 \widetilde{X_m} \times I(t \geq 2009)$$
$$+FE_i + FE_{rt} + e_{it}$$

where hh_m is the number of households in m, PV_i is a dummy = 1 if i is an adopter and X_i are observed individual characteristics. FE_i is an individual fixed effect and e_{it} reflects remaining unobserved heterogeneity affecting i's vote decision. ρ_1 captures the impact of an adoption on i's vote for the incumbent after the policy change. ρ_2 and ρ_3 capture the impact from neighbors' adoption

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[34] For simplicity, we are considering that the observed vote shares results from one vote per household since we are also using household adoption rates.

Table 14
Regression results of Model (1) with flexible time effects.

	No controls	Controls pre and post	Controls by year
Local PV adoption rate			
$\times I(year = 1995)$	0.148	0.216	0.201
	(0.128)	(0.200)	(0.233)
$\times I(year = 1999)$	0.132	0.199	0.213
	(0.095)	(0.173)	(0.163)
$\times I(year = 2009)$	−0.237	−0.622	−0.537
	(0.115)	(0.212)	(0.230)
$\times I(year = 2014)$	−0.187	−0.560	−0.638
	(0.109)	(0.189)	(0.198)
$\times I(year = 2019)$	−0.396	−0.768	−0.756
	(0.107)	(0.203)	(0.216)
Municipality FE	YES	YES	YES
Year × region FE	YES	YES	YES
Demographics × $I(year \geq 2009)$	NO	YES	NO
Demographics × $I(year < 2004)$	NO	YES	NO
Demographics × Year dummies	NO	NO	YES
Observations	1,995	1,995	1,995
R-squared	0.968	0.972	0.973
P-value no pre-trend	0.369	0.515	0.424
P-value same effect after 2004	0.0110	0.0130	0.285

Notes: Linear regression on vote share of 2004–2009 government parties. Robust standard errors in parentheses, clustered within canton. Canton level data used in 2004–2009. Municipality-level data used in 2014–2019.

Table 15
Regression results of Model (2), distinguishing between urban and rural.

	Base	+ Controls
Local PV adoption rate		
$\times I(year \geq 2009)$	−0.482	−0.050
	(0.305)	(0.374)
$\times I(year \geq 2009) \times urban$	0.177	0.430
	(0.545)	(0.521)
Neighbor PV adoption rate		
$\times I(year \geq 2009)$	−0.443	−1.086
	(0.256)	(0.376)
$\times I(year \geq 2009) \times urban$	0.068	−0.086
	(0.436)	(0.391)
Municipality FE	YES	YES
Year × region FE	YES	YES
Demographics × $I(year \geq 2009)$	YES	YES
Neighbor demographics × $I(year \geq 2009)$	NO	YES
Urban municipalities	96	96
Observations	1,995	1,995
R-squared	0.971	0.972
Rural: P-value local effect = neighbor effect = 0	0.000	0.000
Rural: P-value local effect = neighbor effect	0.940	0.151
Urban: P-value local effect = neighbor effect = 0	0.024	0.000
Urban: P-value local effect = neighbor effect	0.938	0.147

Notes: Linear regression on vote share of 2004–2009 government parties. Neighbor PV adoption rate and controls calculated using row-standardized contiguity matrix. Robust standard errors in parentheses, clustered within canton. Canton level data used in 1995–2009. Municipality-level data used in 2014–2019.

on i's incumbency vote. $\frac{\rho_2}{100}$ is the impact of a one percentage point increase in the adoption rate among neighbors in the own municipality, $\frac{\rho_3}{100}$ is the impact of a one percentage point increase in the average adoption rate among neighboring municipalities. Note that FE_{rt} absorbs the impact of adopters in municipalities further away.

PV adopters reward the incumbent parties if $\rho_1 > 0$ and punish them if $\rho_1 < 0$. Punishment due to retrospective voting if salience increases with the local adoption rate implies $\rho_2 < 0$ and $\rho_3 < 0$. It also implies stronger punishment for nearby solar adoption: $\rho_2 < \rho_3$.

Summing the equation over all households in the municipality and dividing by the total number of households, we obtain the following expression for the aggregate vote share of the incumbent party in municipality m:

$$\begin{aligned}\frac{1}{hh_m}\sum_{i\in m} Y_{it} = \rho_1 \frac{1}{hh_m}\sum_{i\in m} PV_i \times I(t \geq 2009) + \beta_1 \frac{1}{hh_m}\sum_{i\in m} X_i \times I(t \geq 2009)\\ +\rho_2 \frac{1}{hh_m}\sum_{i\in m} PV_i \times I(t \geq 2009)\\ +\rho_3 \widetilde{PV_m} \times I(t \geq 2009) + \beta_2 \widetilde{X_m} \times I(t \geq 2009)\\ +\frac{1}{hh_m}\sum_{i\in m} FE_i + FE_{rt} + e_{mt}\end{aligned}$$

where we make use of the fact that $\sum_{i\in m}\sum_{j\in m\backslash i} PV_j = (hh_m - 1)\sum_{j\in m} PV_j$.

This is essentially our regression Eq. (2) on municipality averages. Similarly, Eq. (1) can be derived by setting $\rho_3 = 0$, and assuming neighbors in adjacent municipalities have the same effect as neighbors in municipalities further away. This clarifies what we can identify with aggregate data. First, average individual fixed effects are replaced by municipality fixed effects. Second, both ρ_1 and ρ_2 enter in front of the local adoption rate so we can only identify $\gamma_1 \equiv \rho_1 + \rho_2$. For ρ_3 the issue does not arise: $\gamma_2 \equiv \rho_3$.

We can use this set-up to interpret the empirical results from our regression Eq. (2). First, we find $\gamma_1 \equiv \rho_1 + \rho_2 < 0$, implying that either both adopters and neighbors of adopters in the same municipality punish, or the punishment by neighbors dominates. We also find $\gamma_2 \equiv \rho_3 < 0$, implying that there is punishment by neighbors of adopters who live in other municipalities. Assuming salience based on proximity, punishment by neighbors in the same municipality should be stronger: $\rho_3 - \rho_2 > 0$, and therefore $\rho_2 < 0$.

Second, we can use the results to investigate if adopters reward or punish the incumbent. If the estimates show $\gamma_2 < \gamma_1$, it implies $\rho_3 - \rho_2 < \rho_1$. Combining this with the proximity argument ($\rho_3 - \rho_2 > 0$) yields the reward effect: $\rho_1 > 0$. Although we find $\gamma_2 < \gamma_1$, we do not have enough variation to confidently reject the hypothesis $\gamma_1 = \gamma_2$. Our results are therefore inconclusive about a possible reward by adopters in ballots.

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