Working Paper Research

October 2020 N° 389

The political economic of financing climate policy: evidence from the solar PV subsidy programs

by Olivier De Groote, Axel Gautier and Frank Verboven

National Bank of Belgium
Eurosystem

Editor

Pierre Wunsch, Governor of the National Bank of Belgium

Editoral

On October 22-23, 2020 the National Bank of Belgium hosted a Conference on *"Climate Change: Economic Impact and Challenges for Central Banks and the Financial System".*

Papers presented at this conference are made available to a broader audience in the NBB Working Paper Series (www.nbb.be). This version is preliminary and can be revised.

Statement of purpose:

The purpose of these working papers is to promote the circulation of research results (Research Series) and analytical studies (Documents Series) made within the National Bank of Belgium or presented by external economists in seminars, conferences and conventions organized by the Bank. The aim is therefore to provide a platform for discussion. The opinions expressed are strictly those of the authors and do not necessarily reflect the views of the National Bank of Belgium.

Orders

The Working Papers are available on the website of the Bank: http://www.nbb.be.

ISSN: 1375-680X (print)
ISSN: 1784-2476 (online)

The political economy of financing climate policy – evidence from the solar PV subsidy programs

Olivier De Groote, Axel Gautier and Frank Verboven*

October 2020

Abstract

To combat climate change, governments are taking an increasing number of technology-specific measures to support green technologies. In this paper, we look at the very generous subsidy policies to solar PVs in the three regions of Belgium to ask the question of how voters responded to these programs. We provide evidence that voters did not reward the incumbent government that was responsible for the program, as predicted by the 'buying-votes' hypothesis. Instead, we find that voters punish the incumbent government because of the increasing awareness of the high financing costs. These did not only affect the non-adopting electricity consumers who did not benefit from the programs, but also the adopting prosumers, who saw unannounced new costs such as the introduction of prosumer fees to get access to the grid.

* Olivier De Groote, Toulouse School of Economics, University of Toulouse Capitole, Toulouse, France (olivier.de-groote@tse-fr.eu).
Axel Gautier, HEC Liège, University of Liège (agautier@uliege.be).
Frank Verboven, Department of Economics, KU Leuven (frank.verboven@kuleuven.be).
The financial support of the National Bank of Belgium is gratefully acknowledged.

Contents

1 Introduction

There is now a broad consensus among scientists that the massive increase in CO2 emissions has been responsible for the climate change observed over the past decades. There is also a growing awareness that drastic policies are required to reduce the CO2 emissions and prevent a further acceleration of global warming in the future.

However, there is much less consensus on the type of policies that are required to reduce CO2 emissions. Economists often favour Pigouvian taxes on CO2 emissions to correct for the externalities.[1] But such taxes may not be politically feasible for a variety of reasons: distributional concerns, industry pressure, aversion to taxes, lack of coordination, or fiscal competition between countries (see e.g. Fowlie, 2019). As a result, politicians have often favored a variety of subsidy programs to promote specific renewable energy sources (RES), such as solar, wind or biofuel, and more generally to support the adoption of green technologies. Governments have used a wide range of instruments, including tax incentives, investment subsidies and production subsidies.

In this paper, we aim to better understand the political economy that lies behind technology-specific subsidies. We exploit the unique setting of the generous subsidy programs to solar photovoltaic (PV) systems in Belgium. Each of the country's three regions adopted similar policies, consisting of a combination of rebates of part of the investment costs and subsidies on green electricity production. Because policies led to massive adoption, two of the three regions also needed to cope with comparable financing problems, and it led to continuous political debate. The main policies were designed during the period 2004-2009 by the regional governments, which at that time were center or center-left coalitions in the three regions. Because the regions differed in their timing and magnitude of the programs, and because they had separate political responsibilities towards their voters, this provides an interesting setting to understand how voters responded to these programs. In particular, we first consider their decision to adopt or not the solar technology. Next, we see if and how, technology adopters and non-adopters modified their vote to eventually reward or punish the politicians who designed these programs.

Our analysis consists of different parts. First, we describe the various types of subsidy programs that have been introduced. An important feature of our setting is that the programs quickly shifted away from rebates to future production subsidies under the form of Green Certificates (GCs) and net-metering.[2] Under net metering, the energy produced by the solar panels is valued at the retail price, including all taxes and surcharges. With a mechanical meter (the most common metering technology in Belgium in the absence of smart meters), net metering is simply implemented by having the meter running backwards when the solar production exceeds the house's consumption. This shift to production subsidies, granted for long periods, implies that the financing of the programs is postponed to the future and current technology adopters are financed by future energy consumers. Moreover, it requires a larger budget, because households are more responsive to upfront subsidies i.e. they discount these future benefits too heavily (De Groote and Verboven, 2019). Second, we show how

---

[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.

[2] One reason for abandoning the investment subsidies may have been the fact that EU fiscal rules impose governments to fully cover the costs of environmental investment subsidies, even if they imply productive future benefits (see De Grauwe, 2018).

the programs led to massive adoption of solar PVs. This highlights again the central role of the generous GCs. Third, given the magnitude and success of the GC system to promote adoption, the financing of the program became critical, leading to intense political debate and discussions. These financing issues raised important redistributional concerns. A central question was who should pay for the generous subsidies: technology adopters or non adopters; and current or future consumers? The financing of these costs was one of the most important and contentious debates during the last years, both in Flanders and in Wallonia. This brings us to our main question. We ask how voters responded to the subsidy program in the regional election years 2009, 2014 and 2019 (i.e. after the main programs had been designed by the government elected in 2004).

We consider various possible hypotheses. A first hypothesis is that voters who benefited from the subsidies reward the government that initially designed the subsidy scheme by voting for the responsible parties. This is the 'buying votes' hypothesis, according to which governments will implement certain policies to buy votes from the current beneficiaries of the subsidies (Biais and Perotti, 2002 and Ovaere and Proost, 2015). A second hypothesis is that voters do not reward the parties that were responsible, but instead reward the green parties whose political program has always focused on climate policy. Comin and Rode (2013) document such a green effect in Germany. A third hypothesis is that voters who did not benefit from the subsidies (i.e. the non-adopters) punish the government if it becomes apparent that they end up paying a considerable part of the subsidy costs without receiving any benefits. Punishment may also come from the adopters themselves if they see that some of their benefits are taken away by the imposition of new fees that ultimately reduce their return on investment.

To evaluate these hypotheses, we exploit local market variation in the solar PV adoption levels across the country (as documented in our second part). We specify a model for the election outcomes of the incumbent parties (i.e. the center or center-left parties that designed the programs) at the local market level (municipality) during the regional election years 2009, 2014 and 2019, in comparison 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 local markets where solar PV adoption had been higher. The idea is that in such markets there is a higher awareness of the various effects of the policies (to both adopters and non-adopters). Since we control for both local market effects and election time effects (including previous regional elections), our model may be interpreted as a difference-in-difference framework.

Our main finding is that the incumbent parties received *fewer* votes in local markets where PV adoption had been more successful. This is inconsistent with the buying votes hypothesis, according to which voters reward the incumbent parties. Adopters did not reward the politicians who designed the generous subsidy programs. Instead, our finding is consistent with our alternative hypothesis that voters who did not directly benefit from the programs punish the incumbent parties, once it became apparent that the financing costs would be high and be paid to a large extent by non-beneficiaries. We also find that the punishment tends to be more severe in Flanders, where most of the costs had already been passed on to consumers through substantially higher electricity prices.

We extend the analysis to consider which political parties were most affected. Among the incumbent parties, we find that mainly the left (and not the center) parties were negatively affected. This is intuitive as they were also most associated with the policies in the public debate. Furthermore, the parties that benefited and received more votes were to a small extent the green parties (consistent with our second hypothesis), but especially the parties on the most extreme sides of the political spectrum (both on the left and the right).

Background literature

The deployment of renewable energy sources, mainly solar and wind was subsidized in many countries, sometimes very heavily. For solar PV systems, subsidies were usually provided by combining different instruments: investment subsidies, tax credits, net metering and production subsidies under the form of a feed-in-tariff (FiT), feed-in-premium (FiP) or tradable green certificates (TGC). 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. Partial information on subsidy programs in Belgium is available in De Groote et al. (2016) and De Groote and Verboven (2019) for Flanders from 2006 to 2012 and in Boccard and Gautier (2015, 2020) for Wallonia from 2008 to 2014. The present paper completes these earlier studies by providing a comprehensive description of the programs in the three regions and estimations of the corresponding NPV.

The literature has estimated the impact of different subsidy programs on PV adoption and compared the relative effectiveness of the policy instruments. Hughes and Podolefsky (2015) focus on the impact of investment subsides on adoption in California. Matisoff and Johnson (2017) and Gautier and Jacqmin (2020) focus on the role of net metering policies. Crago and Chernyakhovskiy (2016) 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. Using detailed data at the individual or at the district level, Vasseur and Kemp (2015) and De Groote et al. (2016) study the various factors driving PV adoption.

Subsidies for renewable energy sources do not only promote investments in green technologies but they also have redistributive aspects. For this reason, it is important to study how they are determined by the political process. The literature studied two different issues. First, the lobbying by interest groups for or against energy policies. For instance, Aidt (1998) studies the structure of environmental taxes under lobbying and Jenner *et al.* (2013) show that energy producers from conventional sources are actively and successfully lobbying against subsidies for energy from renewable sources. Second, the literature has focused on the way politicians can use subsidies to gain votes. 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. Following the idea of Biais and Perotti (2002), Ovaere and Proost (2015) propose a political economy model where candidates buy the citizens' votes by offering generous subsidies for solar PVs. Their model explains why politicians prefer inefficiently high subsidies for solar relative to wind because the solar subsidies are paid to households (voters) while wind subsidies are paid to firms. Our objective is to test this 'buying vote' hypothesis.

However, high subsidies have a drawback, they are costly and they have to be paid by non-adopters which, may eventually punish the politicians at the election.

The outline of the paper is as follows. In section 2, we discuss the electricity market, and the types and magnitude of the subsidy programs to promote the adoption of residential PV installations. Section 3 presents evidence on the impact of the programs on PV adoption. Section 4 discusses the financing issues and political debate following the massive success of the programs. Section 5 provides our main analysis of how the programs affected election outcomes. Finally, section 6 concludes.

2 Subsidy programs to promote residential PV installations

After a brief description of the Belgian electricity market, we first describe the various types of measures that were used to promote residential solar PV installations in the three regions of Belgium (section 2.1). Next, we describe the evolution of the magnitudes of the support mechanisms over time (section 2.2).

Belgium is a federal state composed of three regions: Flanders, Wallonia and Brussels. The electricity market is fully liberalized since 2007. Production and retailing are competitive activities, while transport and distribution remain organized as a regulated monopoly. Transport (high voltage grid) is regulated at the federal level by the CREG, the national regulator. The national transport system operator (TSO) is Elia. Distribution (low voltage grid) is regulated by the regional energy regulators: VREG in Flanders, CWaPE in Wallonia and Brugel in Brussels. There are 9 local distribution system operators (DSOs): 2 in Flanders, 7 in Wallonia and 1 in Brussels and each of them has its own regulated distribution tariff.

The promotion of green energy is a regional responsibility, and each region has designed its own policy to support solar energy. We will focus our analysis on the generous programs for residential PV installations.[3] All regions have combined the same instruments but they differ in both the magnitude and the timing of their support measures. We provide an overview of the most important measures below. Appendix 1 lists the sources we used to write this overview, as well as the data and assumptions to calculate each component of the costs and benefits of adoption that we will use in the rest of this paper.

2.1 Types of subsidy programs

The supporting schemes combine three types of measures: rebates on the investment costs, production subsidies through Green Certificates (GCs) and net metering. The support schemes have been gradually phased out, starting with rebates for part of the investment cost (which existed for only a short period), and followed by the GCs, suppressed in 2014 in Flanders and in 2018 in Wallonia but still in place in Brussels. Finally, the net metering system will no longer be used in Brussels (2020), Flanders (2021) and Wallonia (2023).

[3] Flanders and Wallonia also had programs for commercial PV installations, which usually have a larger scale. These programs showed some common elements but had a more limited impact on the public debate.

2.1.1 Rebates on the investment costs

In the early years, all regions offered rebates, specified as a percentage of the PV investment with a cap. Flanders offered a 10% subsidy in 2006-07, Wallonia granted a 20% subsidy in 2008-09, and Brussels offered a subsidy of up to 50% of the investment value until 2011.

In addition, for the years 2006-2011, the federal government supported investments in energy-saving technologies, including solar panels, by granting a tax credit. Since 2009, this tax credit could be spread over up to four years. Finally, some municipalities offered additional investment premiums for investment but the amount was rather modest (De Groote, Pepermans and Verboven, 2016; Gautier and Jacqmin, 2020).

2.1.2 Green certificates (GCs)

Already before providing specific support to solar PVs, the three regions had implemented a general system of green certificates to support renewable energy sources (RES), such as wind, solar and biomass. The green certificates are production subsidies. They are awarded for the production of energy from certified renewable sources. During a given granting period (t), producers of green energy receive n certificates for each MWh produced. Initially, the granting period (t) was set to ten years and the granting rate (n) was technology specific and related to CO2 savings. At the same time, the energy retailers have to meet quota obligations: a given percentage of their sales, fixed annually, should come from certified renewable sources. To meet their quota obligations, the retailers can buy certificates from producers. They can pass through the cost of these obligations to end-consumers. On the GC market, there is a price ceiling, which corresponds to the administrative fine for not meeting the quota obligations. The fine is equal to 100€ per missing certificate in the three regions. There is also a default buyer that has the obligation to buy the GCs at a minimum guaranteed price (p).

In Flanders, for the residential PV installations connected to the low voltage grid, the default buyers are the publicly-owned DSOs and the minimum price (p) depends on both the technology and the installation date. In Wallonia and Brussels, the default buyer is the TSO (Elia) and the guaranteed price for GCs is equal to 65€, irrespective of the technology.

Starting, in 2005, the regions wanted to encourage the installation of small-scale PV on the rooftop by the households, which were not profitable under the current GC mechanism in place. To that end, the GC mechanism was modified for residential PV installations of less than 10 kWp. These specific supports consisted of two elements: first, an extension of the granting period of GCs for residential PVs; and, second, an increase in the production support per MWh produced. In Wallonia and Brussels, this was done by increasing the granting rate (n) above one GC per MWh produced. In Flanders instead, the granting rate was left unchanged (n=1) but the region increased the guaranteed price (p) above the price ceiling.

In Flanders, the system started in 2006 with a guaranteed price for the GC of p=450€, far above the market price and an extended granting period of t=20 years. In Wallonia, the system started in 2008, with a granting rate of n=7 GCs per MWh and a granting period of t=15 years. In Brussels, it started in 2007 with n=7 and t=10. At the early stage, the regional governments of Flanders and Wallonia showed a strong political commitment to the parameters of the mechanism (n, p and t), regardless of the rapidly changing market conditions. In both regions, the generous initial support combined with rapidly declining module prices makes the investment in solar PV extremely profitable. Both regions eventually adapted their mechanism but the adjustments were slow.

As we show below, the return on investment (net present value) was high and adoption was massive, especially until 2012, making the subsidies extremely costly. The system was reformed in 2013 in Flanders and in 2014 in Wallonia to introduce more flexibility. The idea was that, instead of committing to some specific values of n, p and t for the whole life of the PV installation, the supporting schemes would guarantee a return on investment and the parameters defining the subsidy scheme would adapt to market conditions. Importantly, these changes only applied to new installations.

As a result, the system of GCs was adapted and gradually phased out. Flanders no longer offers GCs to residential PV installations since July 2014. In Wallonia, from 2014, the GCs were replaced by an annual premium paid by the DSOs during five years. The premium was based on the installation's capacity and it was capped (to a level corresponding to a capacity of 3 kWp). The amount was revised every six months to take into account the changes in the market conditions. The capacity premium system was eventually abolished in Wallonia in July 2018. The region of Brussels continues to offer GCs at a rate of n=3 GCs per MWh produced .

The GC mechanisms turn out to be costly for society because of generous subsidies, combined with high adoption. Therefore, governments had to increase the energy price, by imposing specific surcharges, to finance them. We will discuss these financing issues in greater details in Section 4.

2.1.3 Net metering

All regions applied a net metering system to small-scale solar PV installations. With net metering, the electricity produced by the PV installation is valued at the electricity retail price. As such, the energy imported from the grid (when solar production is insufficient to cover consumption) and the energy exported to the grid (when solar production exceeds consumption) are valued at the same price[4]. The grid thus acts as a giant storage facility, where households are 'prosumers' and can store their excess production for later consumption. There is, however, a limit to that. At the end of the billing period, usually one year, any excess production is 'lost', i.e. the household does not receive payment for this production. For a household with excess production, the volumetric part of the bill is thus equal to zero. In sum, net metering acts like an additional production subsidy, equal to the volumetric retail electricity price, multiplied by the annual electricity production (or consumption if the annual production exceeds the annual consumption).

This benefit is particularly important because the tariff structure in the three regions of Belgium is essentially volumetric, i.e. based on the recorded consumption in kWh. For the prosumers, it means that their bill is based on their annual net consumption (consumption minus solar production), and it is almost zero if production is sufficient to cover consumption over the year. Therefore, the contribution of prosumers to the grid costs has shrunk. To correct that, regulators have modified the tariff structure to introduce a prosumer fee, which is a contribution of the prosumers to the grid costs. This fee is proportional to the PV capacity (in kWp). It was introduced in 2015 in

[4] Most of the households were equipped with a mechanical meter that runs backward when the electricity is injected to the grid.

Flanders and in October 2020 in Wallonia.[5] Brussels instead has abandoned the net metering system in 2020 for all installations, including those installed before 2020.

2.2 Evolution of the magnitude of the programs

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_{cjt}. We distinguish between five capacity sizes of PV: $j = 1,2,3,4,5$ (with corresponding capacities 2, 4, 6, 8 and 10 kW), the region $c = F, W, B$ (Flanders, Wallonia and Brussels) and the month t (time frame: January 2006-December 2016).

We first describe the methodology for computing the different components of the net present value (section 2.2.1), and then show the evolution of the net present value and its various components in the three regions (section 2.2.2).

2.2.1 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 c, but the present discounted value of benefits (b_{cjt}) differs. The net present value therefore differs as $NPV_{cjt} = b_{cjt} - p_{jt}$. For the monthly investment cost, we use the same price variable as in De Groote & Verboven (2019), but extend the index to also capture the price evolution after 2012. We also scale the model in prices of 2013.

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:

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

Most of these benefits apply over future periods, and we calculate their present value using an annual interest rate of $r = 3\%$. This corresponds to a monthly discount factor of $\delta = (1+r)^{-1/12}$. We will now discuss these various components in turn.

The rebates b_{cjt}^{rebate} are a percentage of the investment cost p_{jt}. They are usually payed shortly after the investment so we abstract from discounting here. The tax cuts (granted at the federal level) 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 an 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 at a rate of 0.071 MWh/kWp/month, which corresponds to a capacity factor of 9.73%.[6] We also assume that the installation has a lifetime of 20 years, so in months the lifetime is $R^E = 240$. Furthermore, we assume the installation has a yearly deterioration rate of 1%, with a corresponding monthly deterioration rate denoted by λ.

The net metering benefits are then given by:

---

[5] Earlier attempts to introduce a prosumer fee in both regions were cancelled by the Courts.

[6] The capacity factor is computed as the yearly production (12×71 KWh = 852 KWh), divided by the potential production of a 1KW generator (365×24 = 8760 KWh).

$$b_{cjt}^{netmeter} = \delta \frac{1-(\delta^E)^{R^E}}{1-\delta^E} \bar{b}_{cjt}^{EL} - \delta \frac{1-(\delta)^{R_t^{pros\_fee}}}{1-\delta} \tilde{b}_{cjt}^{pros\_fee}.$$

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 ($R_t^{pros\_fee}$) that the grid fee applies. The variable b_{cjt}^{EL} is the monthly benefit from net metering based on the observed electricity price at time t. $b_{cjt}^{pros\_fee}$ 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. $b_{cjt}^{pros\_fee} = 0$.[7] 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 (set to the long-run increase, estimated in a first stage) to capture changes in future net metering benefits.

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

$$b_{cjt}^{GC} = \delta \frac{1-(\delta_{ct}^G)^{R_t^G}}{1-\delta_{ct}^G} \bar{b}_{cjt}^{GC},$$

where $\bar{b}_{cjt}^{GC}$ 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 $\bar{b}_{cjt}^{GC}$ 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_{ct}^G is also region-specific. In Flanders ($c = F$), we set $\delta_{jFt}^G = (1-\lambda)(1-\pi)\delta$ where π is the monthly inflation rate (set to a yearly rate of 2%), to capture the fact that the model is in real prices while GC benefits were guaranteed at nominal prices. We use the same specification for Brussels (δ_{jBt}^G) and Wallonia (δ_{jWt}^G) until the reform of March 2014. We change it for Wallonia after this reform: we set $\delta_{jWt}^G = (1-\pi)\delta$ since the benefits were then based on capacity and not on actual production.

2.2.2 Evolution of the benefits of the PV subsidy programs

Figure 1 shows the evolution of the various components of the benefits of the PV subsidy programs in the three regions, for a representative 4 kWp system. The benefits, b_{cjt}^{rebate}, b_{jt}^{taxcut}, $b_{cjt}^{netmeter}$ and b_{cjt}^{GC}, are measured in present value terms based on the methodology of section 2.2.1 (shaded areas). They are compared with the upfront investment price (black line). According to Figure 1, the upfront investment price has been continuously declining.[8]

For all three regions, the benefits from the rebate (red) and tax credits (green) were relatively small and were only present in the early years. The main part of the benefits came from the GCs (blue) and the net metering system (gray). Both started off very high in the early years.

[7] The grid fee did not apply in the early years. But when it was introduced, it immediately applied to all PV installations, even those installed before the introduction.

[8] Note that prices before 2009 should be interpreted with caution as they are predictions, based on a foreign price index. See De Groote and Verboven (2019) for details.

The benefits from the GCs decreased over the period, though at a different pace between the regions. In Flanders (top left), the GC benefits were almost eliminated during 2012. In Wallonia (top right), the GC benefits also dropped considerably, though remained in place until the end. Also in Brussels, the GCs remained in place until the end of our data.

An increasing electricity price made the net metering benefits increase steadily over time, except for the introduction of the grid fee in Flanders in 2015. Because of the decline in PV prices and other benefits, its relative importance in the investment decision increased substantially.

Figure 1. Evolution of the components of the subsidy programs (4KWp system)

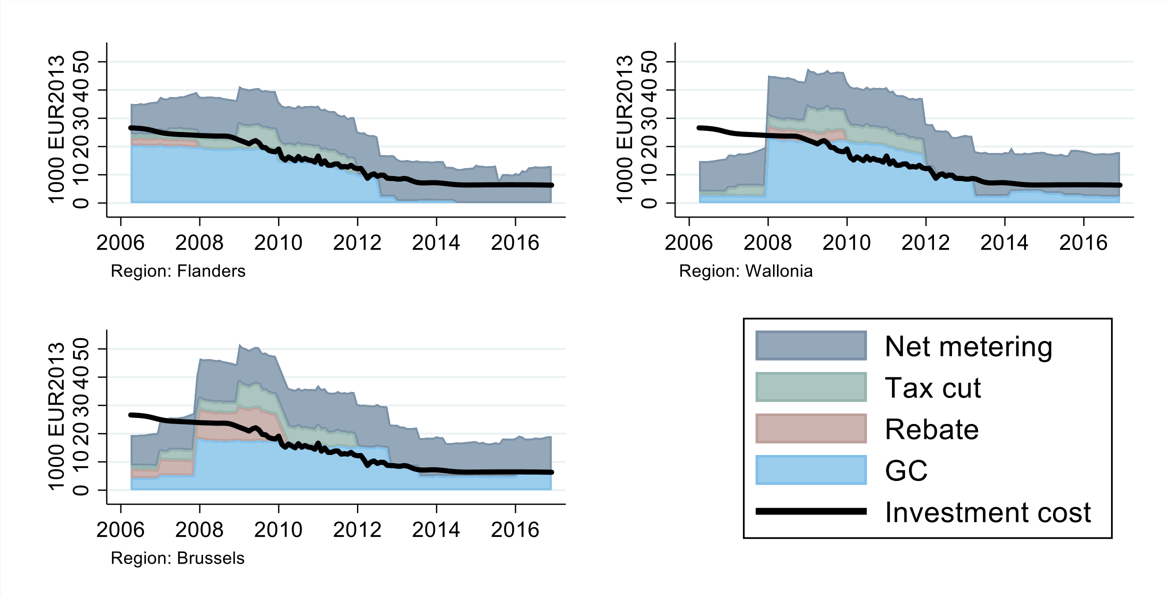
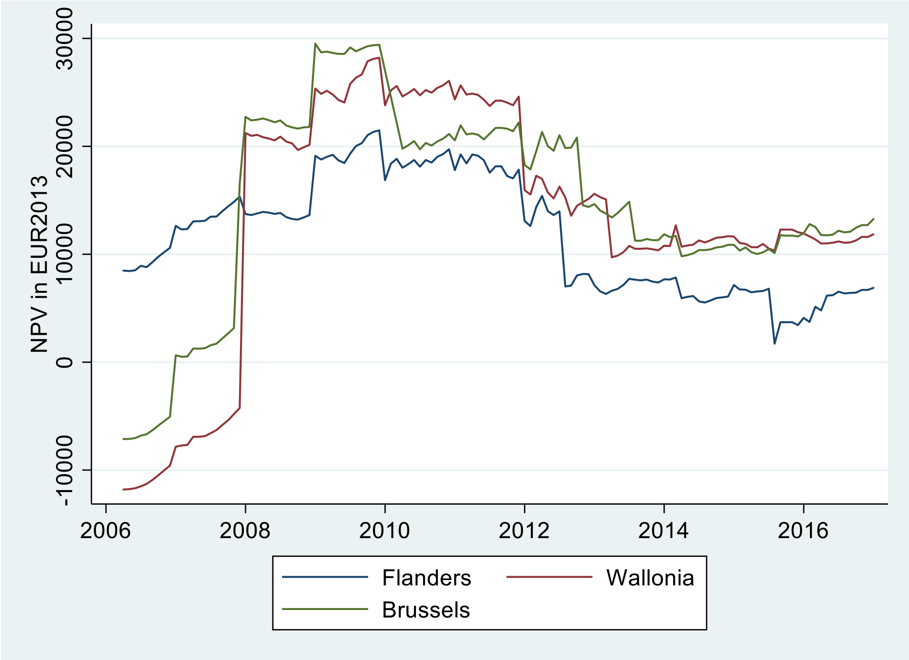


Figure 2 directly compares the regional evolution of the net present value, i.e. the difference between the present value of the future benefits and the investment price ($NPV_{cjt} = b_{cjt} - p_{jt}$). It again considers a 4 kWp system. In Flanders (blue line) the NPV was immediately positive with the introduction of the generous GC policy. It then further increased when investment costs went down (gradually) and the federal tax cut policy became more beneficial (2009-2011), but it dropped rather drastically in 2012 when changes in GC prices were implemented. Note however that it did remain positive over the entire period. In Wallonia and Brussels, the generous GC policy kicked off only in 2008, explaining the negative values in 2006 and 2007. Since then, the NPV in these regions has always been higher than in Flanders.

Figure 2. Evolution of the NPV of the subsidy programs (4 kWp system)



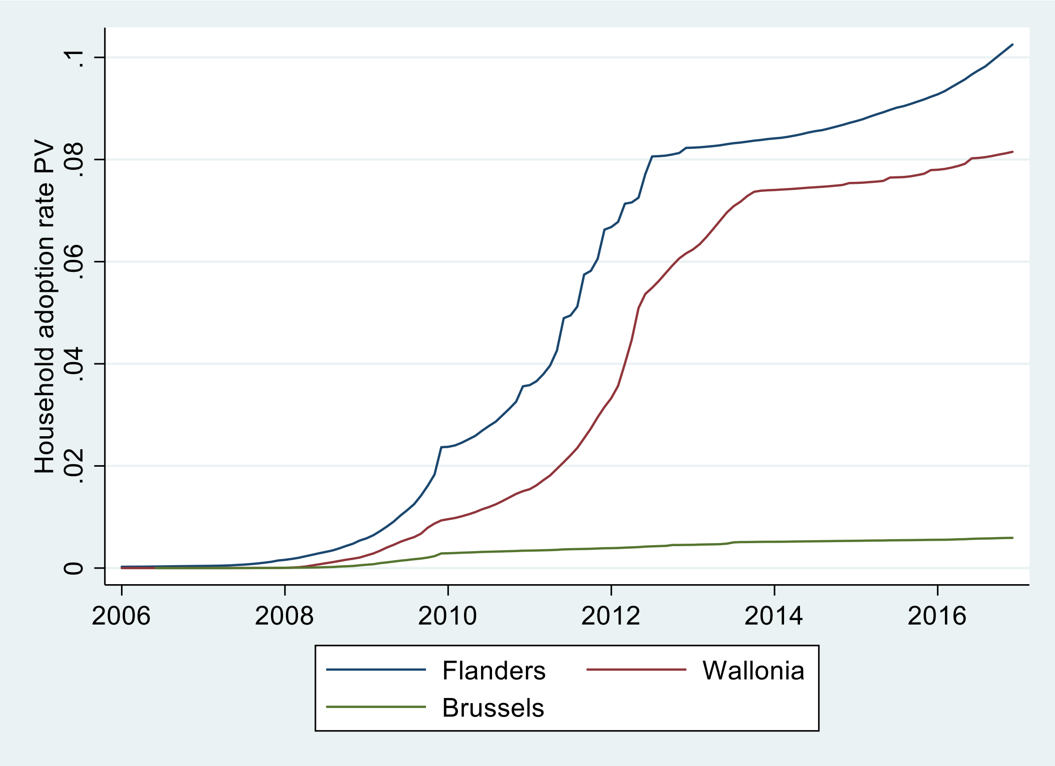
In sum, Figures 1 and 2 show that the structure of the subsidy programs was similar for the three regions, in the sense of showing a comparable emphasis on production subsidies in the form of GCs and net metering, with a faster fade-out of the GCs. But the timing and the magnitudes differed. Flanders started off earlier at very generous levels, but also eliminated the GCs more quickly and made the net metering less attractive through the introduction of a grid fee.

3 The impact of the subsidy programs on PV adoption

How did the generous subsidy programs affect the adoption of solar PVs? Before addressing this question in further detail, it is informative to have a first look at the aggregate numbers for the three regions. Figure 3 shows the evolution of the total adoption rate, i.e. the cumulative number of PV installations divided by the number of households.[9] The total adoption rate has grown sharply in both Flanders and Wallonia, while it remained limited in urban Brussels. Wallonia started slightly later than Flanders, as may be expected because it introduced the programs at a later point. New adoptions were especially high during 2009-2012 when the NPV of investment reached the highest levels. Adoption rates in both regions reached a first plateau in 2012-2013, when the generous GC system was phased out. After that, the adoption rate gradually started to grow again, especially in Flanders. This is consistent with the recent evolution in the NPV. While the introduction of the grid fee in Flanders lowered it initially, the increase in electricity prices quickly made up for this. In Wallonia, the lower observed growth might be explained by the uncertainty surrounding the possible adoption of a prosumer fee, that was constantly debated, but only implemented in October 2020.

[9] 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).

Figure 3. Evolution of PV adoption



In sum, the large subsidy programs appear to have resulted in massive adoption of new PVs. As of today, despite a relatively low solar irradiance, the penetration of solar panels is important with 10.25% of the households equipped with solar PVs in Flanders, 0.6% in Brussels and 8.15% in Wallonia at the end of 2016.

The graph also shows that the announced changes in GC subsidies were anticipated by the households. We indeed observe kinks in the curves, especially in Flanders, corresponding to announced drops in GC subsidies. Prospective adopters anticipated their investments to benefit from the most generous PV subsidies, leading to spikes and drops in adoption just before and after a policy change.

In the rest of this section, we explore in more detail how the programs have affected adoption. In subsection 3.1 we estimate a descriptive model that explains how differences in adoption across the regions can (partly) be attributed to differing local market demographics (e.g. urbanized areas such as most of the Brussels region are less suited for rooftop PV modules). We estimate the model at the yearly level, to also investigate the impact of the main changes in financial incentives. In subsection 3.2, we explore the role of financial incentives in more depth. We use a dynamic model of technology adoption, where households trade off upfront costs against future benefits, while taking into account future investment opportunities. In the next section 4, we then discuss how the massive adoption has imposed strong financing challenges given the generosity of the system.

3.1 The determinants of PV adoption: a descriptive approach

In this subsection, we propose a descriptive model to explain the determinants of adoption and have a first idea on the role of the GC policy.

3.1.1 Model and data

We are interested in explaining the number of new PV adopters, PV_{mt}, with a panel data set of local municipalities m and years t. We observe this information for 11 years (2006-2016) for each of the 589 municipalities of Belgium, of which 308 are located in Flanders (region $c = F$), 262 in Wallonia ($c = W$), and the remaining 19 in Brussels ($c = B$). The local determinants of adoption, x_m, are time-invariant socioeconomic variables (retrieved for 2011): the number of households, population density, income, education, percentage of male and foreigners, percentage of homeowners (versus renters), household size, house size (number of rooms) and year of construction of the house. In addition, we include the present value of the GC benefits b_{ct}^{GC} (as the maximum value of a 4kWp system within a year). This benefit variable has been quantitatively the most important and it also shows most variation over time.

We observe large time and cross-sectional variation. Figure 3 showed that adoption rates increased substantially over time, probably due to differences in subsidization policies and the drop in investment costs. Figure 4 presents a map of adoption rates at the end of our sample, and shows that there is also large cross-sectional variation. Table 1 presents the descriptive statistics we use for the analysis.

Figure 4: PV adoption (in % of households) by municipality in December 2016

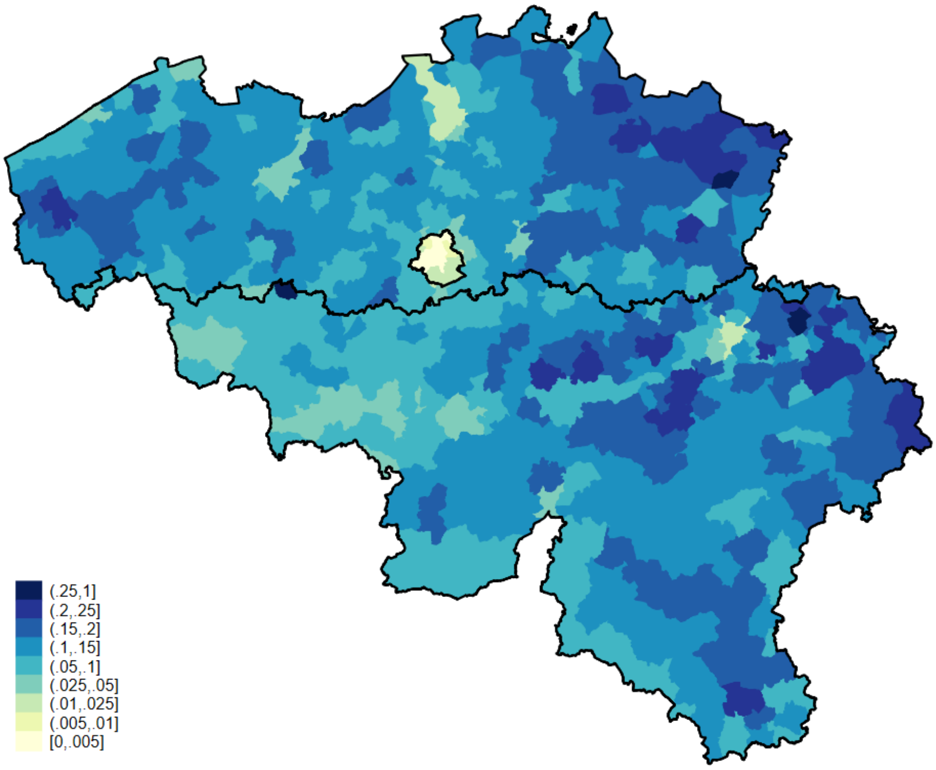


Table 1: Descriptive statistics

	Mean	Sd	Min	Max
PV adoptions (count by year)	61.646	100.366	0	1,484
log(households)	8.515	0.893	3.555	12.358
Log(population density)	5.733	1.158	3.215	10.100
Income group 2	0.200	0.400	0	1
Income group 3	0.200	0.400	0	1
Income group 4	0.200	0.400	0	1
Income group 5	0.200	0.400	0	1
% home owned	0.731	0.096	0.252	0.911
% higher education	0.308	0.076	0.127	0.592
% male	0.493	0.009	0.454	0.553
% foreign	0.068	0.074	0.009	0.497
Average household size	2.410	0.146	1.658	2.802
Average year of construction	1,962.502	11.121	1,931.096	1,982.188
Number of rooms	5.867	0.400	4.202	7.184
Wallonia	0.445	0.497	0.000	1.000
Brussels	0.032	0.177	0.000	1.000
GC (in 1000 EUR)	11.199	8.495	0.000	23.502

Total of 6,479 observations (589 municipalities x 11 years).

Similar to De Groote, Pepermans and Verboven (2016), we assume that the number of new PV adopters, PV_{mt}, has an exponential conditional mean function:

$$E[PV_{mt} \,|x_m, c, t, b_{ct}^{GC}] = exp(x_m\beta + \gamma_c b_{ct}^{GC} + FE_c + FE_t),$$

where FE_c represents region fixed effects, and FE_t captures a full set of year fixed effects, so the impact of the GC benefit variable b_{ct}^{GC} is identified from variation that is specific to each region. We estimate the model using a Poisson pseudo-maximum-likelihood estimator (Silva and Tenreyro, 2006).[10]

3.1.2 Empirical results

Table 2 presents the empirical results of five specifications.

[10] A linear regression with $ln(PV_{mt})$ as the dependent variable gave comparable results.

Table 2. Descriptive model results

	(1) **Base**	(2) **Demographics**	(3) **GC**	(4) **Remove early years**
log(households)	0.633***	0.987***	0.987***	0.987***
	(0.031)	(0.028)	(0.028)	(0.028)
Log(population density)		-0.155***	-0.155***	-0.156***
		(0.020)	(0.020)	(0.020)
Income group 2		0.219***	0.219***	0.219***
		(0.064)	(0.064)	(0.063)
Income group 3		0.299***	0.299***	0.301***
		(0.073)	(0.073)	(0.073)
Income group 4		0.297***	0.297***	0.300***
		(0.076)	(0.076)	(0.076)
Income group 5		0.280***	0.280***	0.283***
		(0.082)	(0.082)	(0.082)
% home owned		1.153***	1.153***	1.170***
		(0.287)	(0.287)	(0.285)
% higher education		-0.922***	-0.922***	-0.972***
		(0.262)	(0.262)	(0.259)
% male		8.866***	8.866***	8.797***
		(2.141)	(2.141)	(2.119)
% foreign		-1.178***	-1.178***	-1.157***
		(0.327)	(0.327)	(0.324)
Average household size		0.289**	0.289**	0.282**
		(0.138)	(0.138)	(0.138)
Average year of construction		0.020***	0.020***	0.019***
		(0.002)	(0.002)	(0.002)
Number of rooms		0.105**	0.105**	0.102**
		(0.049)	(0.049)	(0.049)
Wallonia	-0.346***	0.258***	0.563***	0.627***
	(0.034)	(0.047)	(0.050)	(0.052)
Brussels	-2.463***	-0.920***	-1.857***	-1.543***
	(0.129)	(0.155)	(0.212)	(0.214)
GC in Flanders (in 1000 EUR)			0.093***	0.075***
			(0.005)	(0.006)
GC in Wallonia (in 1000 EUR)			0.046***	0.030***
			(0.004)	(0.005)
GC in Brussels (in 1000 EUR)			0.137***	0.098***
			(0.013)	(0.014)
Year fixed effects (base=2016)	YES	YES	YES	YES
Sample period	2006-2016	2006-2016	2006-2016	2009-2016
Constant	-1.344***	-48.922***	-49.072***	-48.423***
	(0.275)	(3.545)	(3.546)	(3.502)
Observations	6,479	6,479	6,479	4,712

Descriptive model on total count of PVs in each year and municipality. Robust standard errors in parentheses, clustered within municipality. Estimates from Poisson Pseudolikelihood estimator. *** p<0.01, ** p<0.05, * p<0.1

Specification (1) includes only the log of the number of households. This variable has a positive effect, but the estimated coefficient of 0.633 is significantly less than 1, suggesting that new adoptions increases less than proportionally with the number of households. Specification (2) incorporates the demographic variables x_m. This results in a coefficient for the number of households that does not differ significantly from 1, implying an intuitive proportional relationship between new adopters and the number of households. The estimated coefficients of the socio-economic variables have the expected sign. For example, adoption is lower in more densely populated (urbanized) markets. It is higher in markets from the higher income groups (compared with the 20 percent lowest income group), in markets with a large fraction of homeowners, and with large houses and household sizes. The regional dummies (relative to the base Flanders) show some interesting effects. The coefficient for the Brussels region becomes much smaller, implying that the demographics (notably population density) explain a substantial part of the observed low adoptions in Brussels. The coefficient for Wallonia also becomes smaller in absolute value, but it changes sign. So after controlling for the demographics Wallonia had a higher propensity to adopt than Flanders.

Specifications (3) and (4) of Table 2 include the present value of the GC benefits, b_{ct}^{GC}, as an explanatory variable. The year fixed effects then capture common effects, such as the federal tax cut policies or the investment price of PVs. Hence, (3) and (4) identify the effect of the GC benefits from within-region time variation.

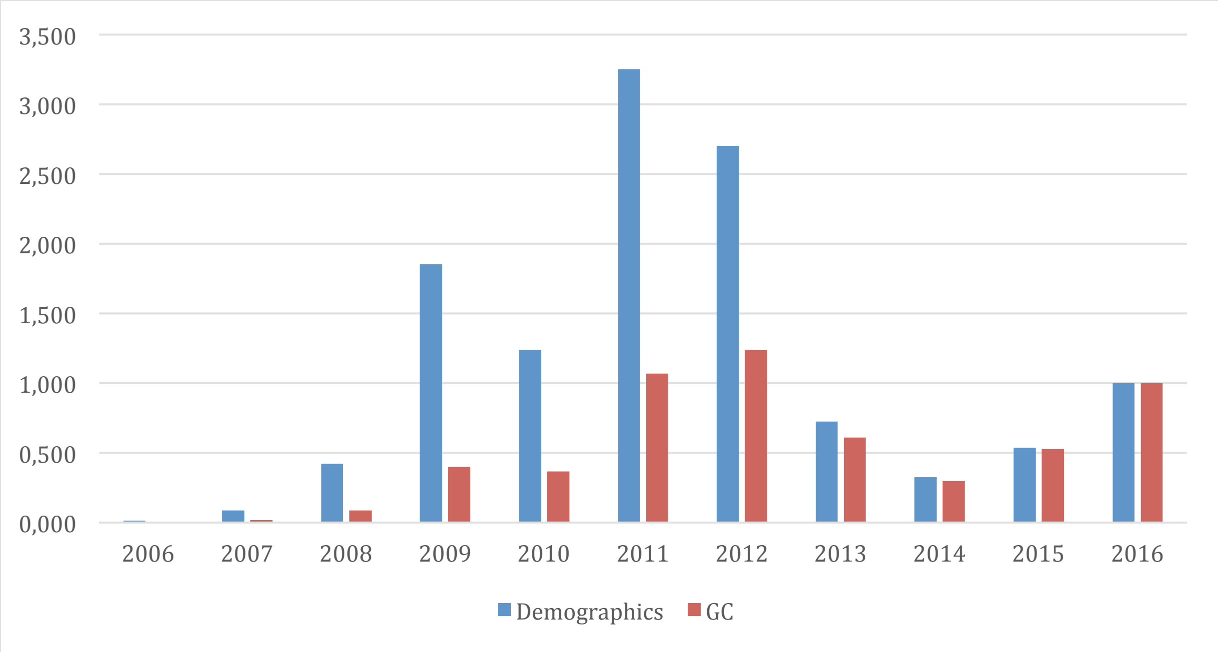
According to specification (3), an increase in the net present value of GCs by 1000 EUR raises the number of adoptions 9.3% in Flanders, 4.6% in Wallonia, and 13.7% in Brussels. Specification (4) restricts the sample to 2009-2016, to capture the possibility that in the early years (2006-2008) households may not have been aware of the policy, or postponed their adoption to the time when prices dropped sufficiently. The estimated effects remain similar but become slightly smaller (respectively, 7.5%, 3.0% and 9.8%). For both (3) and (4), the higher estimated effect in Flanders than in Wallonia may be because GCs have a fixed price in Flanders, while their price fluctuates in Wallonia and this implies more uncertainty to investors.[11] Alternatively, it may be the case that households in Flanders are overall more price sensitive (to both GCs and the investment costs). We will further investigate this in the dynamic model.

To illustrate further the importance of the GC policies, Figure 5 compares the estimated year fixed effects for specifications (2) and (3) in index form relative to 2016.[12] According to (2), which does not control for the GCs, there are very large fluctuations in the number of adopters (blue bars). At the start of the subsidization policy in Flanders (2006), the number of adoptions was still very low at only 1.3% of the level in 2016. In 2009-2012, when GC subsidies were high in every region, the number of adoptions was up to 3.2 times larger than in 2016. In contrast, according to specification (3), which

[11] Our NPV estimates are based on the GC price at the adoption date. In Wallonia, market prices were continuously declining due to an oversupply of certificates. The nominal GC price falls from 89.95€ in 2007 to 68.14€ in 2016. Hence, our estimated present value of the GCs is higher than the true value on investment.

controls for the impact of the GCs, the fluctuations become much smaller. The adoptions in 2011 and 2012, when the subsidy programs were the most generous, are now more comparable to 2016.[13] The gradual increase after 2013 may be due to the continuous improvement of PV technology, implying lower prices for a given capacity.

Figure 5. Evolution of PV adoption: without and with accounting for GC policy (based on time fixed effects of specifications (2) and (3), relative to 2016)



These findings are suggestive of the role of the GC policy in explaining the adoption levels, but they need to be interpreted with proper caution. First, the descriptive model is not motivated by economic theory: it does not explicitly model how households trade off upfront investment costs with future benefits. This makes it difficult to include all sources of costs and benefits and obtain reliable estimates of their effect, especially when some of them show little variation in the data. Second, the data were aggregated at the yearly level, while Figure 3 showed that there is also rich within-year variation in adoptions. A model with forward-looking agents is crucial to exploit this variation as households often postpone their adoption to the last month before a regime drop. Looking only at the current period investment opportunities is therefore not appropriate to explain their behavior at such a high frequency. Third, the analysis was done for a representative PV model of 4kWp, but there is relevant variation in the costs and benefits of different capacity levels, which may influence the timing of adoption decisions. To take these into account, the next subsection considers a dynamic adoption model.

3.2 The dynamics of PV adoption

Our dynamic model follows De Groote and Verboven (2019). It explicitly takes into account two trade-offs households face. First, it considers the investment trade-off by comparing the investment costs that households pay for their installation with the expected investment benefits (which largely result from government policy). Second, it takes into account a dynamic trade-off by modeling households as forward-looking agents who have expectations about future costs and benefits and wait for the ideal time to adopt.

The estimates from this model will enable us to derive the households' general sensitivity to monetary incentives, as well as how they value benefits (and therefore subsidies) relative to upfront investment costs, and this effect can be estimated for each region.

3.2.1 Dynamic model and data

We consider a model at the level of the region c (rather than the individual municipalities as in the static model).[14] In a given month t a household i located in region c may either choose not to adopt a PV, $j = 0$, or choose to adopt one of the available PV alternatives, $j = 1, \dots, J$, i.e. the different capacity sizes of the PVs in our setting. A key feature of the model is that the adoption decision ($j \neq 0$) is a terminating action. Not adopting ($j = 0$) gives the option to adopt at a later period, when the prices may have decreased, or when the financial benefits may have changed.

Households can differ in their valuation of a PV. In each month t a household i located in region c obtains a random taste shock for alternative j, ε_{icjt}, assumed to follow a type 1 extreme value distribution.

Conditional value of adoption

Let v_{cjt} be the expected discounted utility of adoption, net of the taste shock ε_{icjt}. We can write this as follows:

$$v_{cjt} = x_{cjt}\gamma_c - \alpha_c p_{jt} + \alpha_c \theta_c b_{cjt} + \xi_{cjt}, \qquad j = 1, \dots, J$$

where x_{cjt} is a vector of characteristics of alternative j at period t in region c, p_{jt} is the upfront investment cost and b_{cjt} is the total discounted benefits for adoption at time t. We described the various components of b_{cjt} earlier in section 2.2.1. The term ξ_{cjt} is an unobserved product characteristic, known to the household but not to the econometrician.

The parameter α_c, which is allowed to be specific to each region c, measures the households' sensitivity to the upfront investment price. The parameter θ_c captures the households' relative valuation of future financial benefits. If $\theta_c = 1$, households value future benefits in the same way as upfront investment costs. If $\theta_c = 0$, households fully ignore future benefits.

Conditional value of no adoption

Let v_{c0t} be the expected discounted utility of not adopting PV ($j = 0$). We can write this as follows:

$$v_{c0t} = u_{c0t} + \delta E_t \bar{V}_{ct+1},$$

where u_{c0t} is the utility derived from not adopting PV at time t, $\bar{V}_{ct+1}$ is the ex-ante value function, i.e. the continuation value from behaving optimally from period $t + 1$

14 De Groote and Verboven (2019) show that accounting for local market heterogeneity changes little to the estimates that explain (average) sensitivity to prices and subsidies.

onwards, before taste shocks are revealed. The parameter δ is the monthly discount factor corresponding to an annual interest rate of 3%.[15]

Linear regression equation

Following Scott (2013) and De Groote and Verboven (2019), we can derive the following linear regression equation (see Appendix 2):

$$\ln S_{cjt} - \ln S_{c0t} - \delta \ln S_{c1t+1} \ = \left(x_{cjt} - \delta x_{c1t+1}\right)\gamma_c$$
$$-\alpha_c(p_{jt} - \delta p_{1t+1}) + \alpha_c\theta_c(b_{cjt} - \delta b_{c1t+1}) + \xi_{cjt} - \delta(\xi_{c1t+1} - \eta_{ct}),$$

where $\eta_{ct} \equiv \bar{V}_{ct+1} - E_t\bar{V}_{ct+1}$ is an expectation error, and S_{cjt} is the observed market share of alternative j, i.e. the number of new adopters of j relative to the potential number of households who did not yet adopt a PV system.

This regression equation is essentially a dynamic Euler equation. Note that the error term of the regression consists of both the unobserved characteristics and the expectation error. If the price is endogenous (correlated with unobserved characteristics), we could estimate this using instrumental variables. We will instead treat prices as exogenous, conditional on a set of fixed effects for each capacity choice and each year. We also do a robustness check with a full set of capacity/year fixed effects. Intuitively, this assumption means that any monthly price variation within a year is not driven by local demand forces, but rather by global market conditions, which appears to be reasonable given the small size of Belgium.[16]

To estimate the model we make use of our data on new PV installations for each capacity level j, region c and month t and on the upfront investment price p_{jt}, and we measure the future benefits as

$$b_{cjt} = b_{cjt}^{upfront} + b_{jt}^{taxcut} + b_{cjt}^{netmeter} + b_{cjt}^{GC}.$$

In a sensitivity analysis, we also conduct a more flexible specification, where the non-GC benefit terms enter as separate terms.

3.2.2 Empirical results

Table 3 presents the empirical results of the dynamic model, for four different specifications. The total number of observations is 920, consisting of 5 capacity alternatives, observed in 2 regions[17] over 92 months (i.e. 7 years and 8 months from May 2009 to December 2016). The "common valuations" specifications (1) and (2) assume that the regions have a common valuation of price ($\alpha_c = \alpha$) and a common relative valuation of future benefits ($\theta_c = \theta$). The "regional valuations" specifications (3) and (4) allow these valuations to be specific to the regions. The odd-numbered specifications include only capacity fixed effects, while the even-numbered specifications also include year fixed effects and quarter fixed effects.

---

[15] Alternatively, as in De Groote and Verboven (2019), we also estimated a (non-linear) specification that imposes $\theta_c = 1$, and estimates δ as the households' implicit discount factor (possibly region-specific), both in the conditional value function of $j = 0$ and in the calculation of benefits b_{cjt}. We then derive similar conclusions about price sensitivity and the valuation of benefits.

16 We also replicate De Groote and Verboven (2019) who use Chinese module prices as an instrument with the data for Flanders until 2012. We find similar results when prices are assumed to be exogenous.

[17] We do not include Brussels in this dynamic model because adoption was too low to be considered.

Table 3. Empirical results from dynamic adoption model

	(1)	(2)	(3)	(4)
	Common valuations		**Regional valuations**	
	Base	+ time controls	Base	+ time controls
Price sensitivity (α)				
Common	0.259	0.243		
	(0.0333)	(0.0344)		
Wallonia			0.219	0.207
			(0.0255)	(0.0278)
Flanders			0.367	0.344
			(0.0881)	(0.0892)
Relative valuation benefits (θ)				
Common	0.380	0.372		
	(0.0226)	(0.0212)		
Wallonia			0.321	0.313
			(0.0280)	(0.0309)
Flanders			0.442	0.439
			(0.0228)	(0.0174)
Region and capacity specific constants	YES	YES	YES	YES
Controls non-GC benefits	NO	NO	NO	NO
Year FE and quarter of year FE	NO	YES	NO	YES
Common alpha and theta	YES	YES	NO	NO
Observations	920	920	920	920
R-squared	0.641	0.671	0.650	0.679

Results from linear regression on market share inversion for two regions (Flanders and Wallonia) over five capacity choices and 92 months (May 2009-December 2016). Robust standard errors in parentheses. Observations clustered within time period. Standard errors theta obtained using delta method.

The common valuation specifications (1) and (2) show that households have a significant general price sensitivity (α), and that the relative valuation of future benefits compared with upfront costs is low (θ close to 0.4). This suggests stronger time discounting than found by De Groote and Verboven (2019), which applied to a shorter period (up to 2012) and only the region of Flanders. They found that consumers are willing to pay only 0.5 Euro upfront for one extra euro of future subsidy benefits (at an interest rate of 3%). The results in specifications (1) and (2) show slightly higher discounting.

In our descriptive model (section 3.1), we found a smaller impact of GC subsidies in Wallonia, compared to other regions. The dynamic model allows us to investigate if this follows from a higher sensitivity to monetary incentives (α) or a lower relative valuation of benefits compare to investment costs (θ). Specifications (3) and (4) allow for these regional differences and show evidence of both: households in Flanders are more price-sensitive ($\alpha_F > \alpha_W$) and undervalue the benefits to a lesser extent ($\theta_F > \theta_W$). The latter seems to suggest that households in Wallonia may be less forward-looking. This higher discounting of the GC benefits in Wallonia compared to Flanders might be explained by the different design of the GC schemes guaranteeing a fixed price for the GC in Flanders while guaranteeing a fixed tradable GC allowance in Wallonia. The relative uncertainty on the evolution of the GC price may imply a higher discounting of future benefit in Wallonia.[18] However, it is also possible that this is due to the different policy context, which may have created confusion or political uncertainty.

In sum, these findings show that households show significant sensitivity to monetary incentives, especially so in Flanders. After controlling for this difference in sensitivity to monetary reasons to adopt, it appears that the design of the GC policy was relatively more effective in Flanders than in Wallonia. Households in Wallonia more strongly undervalue financial benefits, including the GC subsidies, but they were so generous that they still led to massive adoption in both regions.

4 Financing issues of the policies and the political debate

The generous subsidies (documented in section 2) and the massive PV adoption (documented in section 3) implied substantial and increasing financial costs to society. This has subsequently led to intense political debate and subsidies to solar PV became a political issue. In this section, we will discuss the financing issues and subsequent political debate. This debate mainly focused on the financing of the GC system and the net metering, and not on the rebates (which were relatively small and only in the first years).

4.1 Financing issues

4.1.1 Investment support

The investment rebates and the tax credits were financed by the general budget of the regions and the federal government, respectively. This involved only a limited debate because it concerned relatively small amounts that were phased out very quickly as we have seen. Furthermore, financing through the general budget is less visible as it is just a small part of the overall government budget.

4.1.2 GC system

The main cost overrun came from the cost of the GC mechanism, especially the generous schemes offered at the early stages. High adoption and generous production subsidies have generated an unanticipated green certificate debt in both Flanders and Wallonia.[19] This GC debt is an accumulated amount of subsidies that were paid to the beneficiary households (the prosumers) but which were not yet paid by society (through increased electricity prices or taxes). Around 2012, it became apparent that the GC mechanism was extremely costly and that this cost would be passed through to consumers. The financing of the GC debt became a political issue. Given that each region had specific measures to support PVs, it is important to clarify how this debt was generated and how it was financed.

---

[18] Nicolini and Tavoni (2017) document that feed-in-tariffs guaranteeing a fixed payment per kWh produced (like the GC system in place in Flanders for solar) are more effective than the tradeable green certicate mechanism to stimulate investment in renewables.

[19] The government in charge clearly underestimated the high take-up rate and its consequences. For example, the bill in Flanders 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 <10kW, 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).

In Flanders, the public DSOs had the obligation to buy the GCs from the prosumers at a guaranteed price in their role of default buyers. The DSOs could then resell the GCs on the market to the retailers, who had quota obligations to sell an (increasing) share of green electricity. When the guaranteed price exceeds the market price, the DSOs are making losses when they resell GCs. These losses are important and continue to be accumulated because the GC rights are granted for a long period.

To finance this debt, Flanders imposed, in 2015, a flat tax on each consumption point. 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 substantial. Consumers with a consumption level <5MWh/year had to pay an additional €100. The tax was abolished from January 2018 on and replaced by a low fee of about €9 per year.[20] The abolishment of this contentious tax[21] came after a decision by the constitutional court on June 2017.

In Wallonia, prosumers received more GCs compared to producers of alternative sources of green energy. This high granting rate generated an excessive supply of GCs on the market i.e. the number of issued GCs exceeded, by large, the yearly quota.[22] This had two consequences. First, the GC price dropped and is now close to the price floor. Second, the default buyer, the TSO, had to buy many GCs at the minimum guaranteed price.

Some of the excessive GCs bought by the TSO were cancelled and, therefore, no longer available on the market. In exchange, the TSO introduced a specific surcharge to the electricity consumers in Wallonia.[23] This surcharge was insufficient to cover the full cost borne by the TSO, but the regional government did not want to increase further the energy price, i.e. it did not want a full pass-through of the cost. Instead, it bought back the additional GCs from the TSO. To that end, the government created a special purpose vehicle (SPV) which accumulated the GC debt to be passed on to future consumers.

4.1.3 Net metering

The cost of net metering is essentially a lost income to the DSOs. The prosumers' bill is based on their net consumption (consumption minus solar production). Consequently, their contribution to the network cost decreases and could be zero if their yearly production exceeds their yearly consumption.[24]

To recover their costs (mostly fixed), the DSOs have to adapt their tariffs. Flanders and Wallonia decided to impose a prosumer fee. This prosumer fee is based on the PV capacity (in kWp) and it is designed as a contribution of the prosumers to the grid cost. Brussels instead decided to stop net metering in 2020, also for PVs that were installed before.

---

[20] Source: https://www.tijd.be/politiek-economie/belgie/vlaanderen/hoe-tommelein-de-turteltaks-van-100-naar-9-euro-doet-zakken/9935978.html (consulted on 21/09/2020).

[21] This tax is known as the "Turteltaks", after the name of the Flemish minister in charge of energy, Annemie Turtelboom who imposed it. The opposition against the tax eventually caused her to step down as minister.

[22] See Gautier and Boccard (2015, 2019) for a detailed analysis of this market.

[23] Currently the surcharge is equal to 13.82€/MWh.

[24] This would not be the case with a net purchasing system that records and price separately the imports from the grid and the exports to the grid. For a comparison between net metering and net purchaisng see Gautier *et al.* (2018).

The imposition of grid 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 *ex-post* the return on their investment. For these reasons, the earlier attempts to impose such a fee were (successfully) challenged in courts by some prosumers.

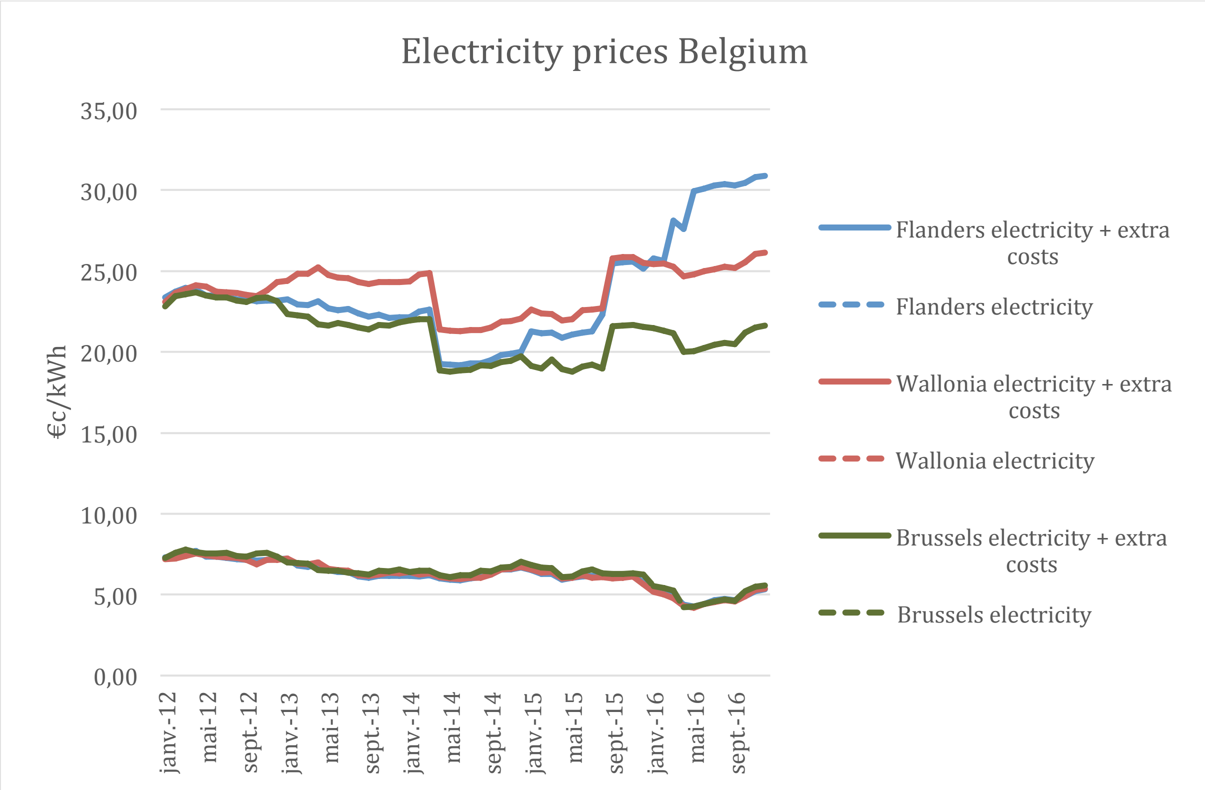
In Flanders, the prosumer fee was introduced in January 2013 and canceled by the Court in November 2013. It was then reintroduced successfully in July 2015.

In Wallonia, the prosumer fee was introduced in 2014 but canceled by the Court in June 2015 and, in practice, the fee was never applied (contrary to Flanders where the DSOs had to pay back the fee after the Court found it illegal). The regulator introduced a fee, in principle in January 2020, but the regional government opposed it. After long discussions, the fee will be applied in October 2020.

4.2 Evolution of electricity prices

The cost of the subsidies and the way they were financed translated into changes in electricity prices. The following figure show the evolution of the retail price of electricity for a representative consumer in Flanders, Wallonia and Brussels. Prices started to diverge from 2012, reflecting the different policy choices made by the regions, mainly to finance the support to green energy sources. As can be observed on the figure, the commodity price is almost the same in the three regions and the price differences mainly come from grid fees and surcharges to support green energy. The lower price in Brussels can be explained by the absence of a GC debt because of lower adoption. 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.

Figure 6: Electricity prices in the three regions (2012-2016), nominal prices



4.3 Political debate

The above financing issues involved a political debate around two main controversies. First, there was a debate on the generosity of the GC subsidies, which were considered too generous, and needed to be revised downwards several times. The prosumers who had adopted in the most generous years (up to 2012) had received very important windfall profits, and there was an increasing awareness that these would eventually have to be paid by the electricity consumers. The evolution of electricity prices shows that it is indeed the case.

Second, there was a debate as to whether the introduction a prosumer fee was appropriate. Some viewed this as a way to make prosumers contribute more to the grid costs. But others argued that this created legal uncertainty to investors and that it would also make adoption to future adopters much less attractive.

These controversies were largely echoed in the press. They were part of the political debate. The issue is important because it is related to the energy transition and the policies that should be implemented to address climate change. The discussions on the subsidies given to solar PVs illustrate that the energy transition is costly process and that costs and benefits were unequally shared among citizens i.e. there are important redistributional concerns associated with climate change.

Finally, although the debates and the controversies were similar in Flanders and Wallonia, people in one region are not necessarily aware of the controversies taking place in the other region. As people speak a different language in the two regions and as newspapers have only a regional coverage, the controversies that were highly debated in the Dutch speaking press in Flanders found little echoes in the French-speaking press in Wallonia, and vice-versa. Hence, political responsibility and accountability are really specific to one region.

4.4 Political responsibility

The support to green energy is a regional competency and each region has a minister in charge of energy. The regional governments are appointed for a period of five years, following the regional elections that took place in 2004, 2009, 2014 and 2019. The electoral system is a proportional system and the political spectrum is highly fragmented. Regional governements are governed by a coalition of parties, 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 2004-09.[25] The government acting during the 2009-2014 legislature had to adapt and later suppress the GC mechanism. During this term, it became apparent that, on the one hand, the investors benefited from a high return and, on the other hand, that the mechanism was costly and that these costs will be passed through to consumers. Furthermore, earlier unsuccesful attempts to impose a prosumer fee were discussed during this term. The government appointed for the 2014-19 term had to impose correcting measures to finance the GC debt and the net metering. As we explained above, the government in Flanders had the intention to pass all the cost to consumers and, to that end, it imposed a flat tax on electricity consumption and a prosumer fee in 2015. The government in Wallonia was more prudent and passed only part of the GC debt to consumers. The prosumer fee that the regulator wanted to impose was challenged by the government and it became a political issue during the campaign for the 2019's election.

It should 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 was not part of the regional government since 2004. In Wallonia, the green party was part of the majority only for the period 2009-2014 and, during this term, it was in charge of the energy policy. The following table details the composition of regional each government.

Table 4: Regional majorities

	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

5 Voters' responses to the subsidy programs

The previous sections discussed how the generous subsidies (section 2) led to massive adoption of PVs (section 3), which in turn implied substantial financial costs and an intense political debate (section 4). In this section, we provide evidence on the impact of

[25] In Flanders, the program was approved by parliament just before the election of 2004 by an alternative majority. The parties who approved it formed the government after the 2004 election, which was responsable to carry out the decision.

the policies on voters' responses. We will first discuss the hypotheses, and the empirical model to evaluate them. Next, we discuss our findings.

5.1 Hypotheses

We consider various possible hypotheses on the impact of the subsidy programs on voters' responses. Our first hypothesis is that voters who benefited from the subsidies reward the government that designed the subsidy scheme by voting for the responsible parties. This is the 'buying votes' hypothesis, according to which governments will implement certain policies to buy votes from the current beneficiaries of the subsidies (Biais and Perotti, 2002 and Ovaere and Proost, 2015). A second hypothesis is that voters do not reward the responsible parties, but instead they are becoming more concerned by environmental issues. Consequently, they reward the green parties whose political program has always focused on climate policy. Comin and Rode (2013) found support for this hypothesis in Germany. A third alternative hypothesis is that voters who did not benefit from the subsidies punish the government, if it becomes apparent that they end up paying a considerable part of the subsidy costs without receiving any benefits.

Finally, instead of rewarding the government that established the program (as in the buying votes hypothesis), investors may punish the government that changed the program by imposing corrective measures. An example of such a corrective measure was the prosumer fee or the flat energy tax imposed in Flanders, which *ex post* reduced the return of their solar investment.

5.2 Model and data

To evaluate these hypotheses, we exploit cross-sectional variation in the cumulative PV adoption levels across the country. We specify a model for the election outcomes at the municipality level for all the regional election years (1995, 1999, 2004, 2009, 2014 and 2019). We calculate the vote share of the 2004-2009 government parties in each municipality m and election year t and consider the following regression model:

$$Y_{mt} = X_m\beta_t + \gamma_t CUM\_PV_m + FE_m + FE_t + e_{mt},$$

where CUM_PV_m is the cumulative adoption rate in municipality i at the end of the first (most generous) phase of the GC policy, X_m are local market demographics, and FE_m and FE_t are municipality and election time fixed effects.[26] Note that we only observe data at the municipality-level since 2014. Appendix 3 explains how we combine this with data at the (more aggregate) "canton"-level during other years.[27]

Our identification strategy is similar to that of a differences-in-differences estimator. The parameters γ_t are our main interest. They capture how votes changed differently in areas with more PVs, while controlling for time-invariant differences between municipalities, aggregate trends over time, and local changes in votes related to

[26] 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).

27 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.

demographic characteristics. A non-significant value for γ means that votes are not affected by PV adoption; on the contrary, a significant γ means that a higher adoption of PVs is expected to have a stronger impact on votes. We expect a significant value for γ after 2009, to give support to our hypotheses,. First, if votes by PV owners change, we should see larger effects in these areas. Second, if votes of non-PV owners change, we can still expect a larger effect in these areas as people living close to PVs are expected to be more aware of this policy issue.

We use the election year $t = 2004$ as the base: this is the time when the relevant government parties were elected and designed the main PV subsidy schemes. Our main interest is in the coefficients in the subsequent years, i.e. γ_{2009}, γ_{2014} and γ_{2019}. These coefficients will tell us how voters rewarded or punished the government. We also estimate the γ_t for the two election years preceding 2004. These serve as placebo tests as we expect these coefficients to be insignificantly different from zero if the parallel trend assumption holds.

In an extension to our analysis, we change the outcome variable Y_{mt} to consider election outcomes of different parties. Furthermore, we look at the impact on votes for municipalities that observe high adoption rates in neighboring municipalities to check if our results can be explained by the behavior of non-adopters.

5.3 Empirical results

Before going to the results, we first illustrate our approach in Figure 7.

Figure 7 : vote changes for the 2004-2009 government parties

Change in votes with the 2004 election for 2004-2009 government parties: difference between cantons with highest adoption rates and lowest adoption rates (among 3 equally-sized groups).

The figure uses canton-level data on adoption rates for the two largest regions. We first distinguish between 3 groups of cantons, categorizing them in low, middle or high adoption areas. We then calculate the change in votes for the 2004-2009 government parties since 2004 and plot the difference between the high adoption and the low adoption group. In both regions, we observe a negative effect in the first election after the policy change, suggesting that voters punished, rather than rewarded the government. It further suggests that the effect remained persistent in 2014 and then diminished in Wallonia, but got amplified in Flanders.

Table 5 investigates this more formally through our regression model. The outcome variable Y_{mt} refers to the election results of the incumbent parties. Specification (1) is our base specification, which includes a full set of municipality and region-specific time fixed effects. According to the specification, municipalities with a high cumulative adoption rate voted significantly less for the incumbent parties in the election year 2009 (compared with 2004). A 10 percentage point increase in the adoption rate reduces votes by 2.44 percentage points. This effect persisted in the subsequent election year, and it even strengthened in the last election. The coefficients of our pre-program placebo election years 1995 and 1999 are both insignificantly different from zero.

Table 5. Empirical results from voting model: incumbent government

	(1)	(2)	(3)		
	Base	**+ controls**	**Region-specific effects**		
			Base	x Flanders	x Brussels
Year x %PV					
1995	0.122	0.167	0.098	0.170	-5.707
	(0.128)	(0.241)	(0.304)	(0.250)	(8.694)
1999	0.109	0.184	0.113	0.169	-8.429
	(0.089)	(0.160)	(0.195)	(0.167)	(6.643)
2004			Benchmark		
2009	-0.244**	-0.556**	-0.439	-0.311	0.840
	(0.117)	(0.233)	(0.272)	(0.259)	(6.539)
2014	-0.247**	-0.752***	-0.528**	-0.630***	-4.837
	(0.123)	(0.218)	(0.224)	(0.235)	(8.188)
2019	-0.456***	-0.872***	-0.642***	-0.622***	-0.826
	(0.119)	(0.240)	(0.240)	(0.239)	(9.324)
Municipality FE	YES	YES	YES		
Year FE x controls	NO	YES	YES		
Year x region FE	YES	YES	YES		
Observations	1,991	1,991	1,991		
R-squared	0.967	0.972	0.973		

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. *** p<0.01, ** p<0.05, * p<0.1

To explore this further, we ask to what extent voters behaved differently in the three regions. Specification (3) therefore extends specification (2) by including interaction effects for the regions (γ_{ct} instead of γ_t). The base refers to Wallonia, and shows that the negative impact has strengthened for the last two election years. There is a significant additional negative impact in Flanders, consistent with both the special energy tax that was introduced (affecting all voters) and the earlier introduction of the grid fee (affecting only the adopters). For Brussels, we do not find significant differences but results are imprecise due to the small number of cantons and municipalities.

Although the increase in the electricity price affects all consumers, the punishment effect is more important in those municipalities where there are more prosumers. We see two reasons for this. First, voters have many reasons to choose one party over another. The visibility of PVs in the neighborhood can make the PV policy relatively more salient in these areas and therefore have a big 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 visibles than in the places where there are a lot of PVs. Furthermore, as our descriptive model shows, there is more adoption in richer places, where houses are bigger, etc., this policy may generate a Matttew effect which might 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.

We provide further evidence that the negative effect is driven by non-adopters by extending our regression model with the cumulative adoption rate of neighboring municipalities and estimate election-specific effects. If non-adopters drive the results, we should expect to see similar effects for this new variable. Table 7 in Appendix 4 shows that this is indeed the case.

If voters punished the incumbent parties, which parties of the coalition have been most affected, and which opposition parties have benefited? Table 6 addresses this question by estimating our specification (2) from Table 4 for alternative outcome variables Y_{mt} of the political parties: (4) the far left party, (5) the green, (6) the left parties, (7) the center parties, (8) the liberal party, and (9) the far right parties.

Table 6. Empirical results from voting model: individual parties

	(4)	(5)	(6)	(7)	(8)	(9)
	PTB	**ECOLO**	**PS**	**CDH**	**MR**	**FN, PP**
	PVDA	**GROEN**	**SPA**	**CD&V, NVA, VU**	**VLD**	**VLB, LDD**
Year x %PV						
1995	0.001	-0.059	0.039	0.059	-0.069	-0.058
	(0.013)	(0.079)	(0.232)	(0.277)	(0.268)	(0.091)
1999	-0.003	-0.033	0.068	-0.022	-0.104	-0.007
	(0.011)	(0.076)	(0.182)	(0.168)	(0.189)	(0.065)
2004				Benchmark		
2009	0.035**	0.216*	-0.259*	-0.242	-0.134	0.361***
	(0.014)	(0.118)	(0.138)	(0.204)	(0.134)	(0.123)
2014	0.228***	-0.052	-0.422**	-0.271	0.007	0.329***
	(0.075)	(0.065)	(0.180)	(0.251)	(0.204)	(0.123)
2019	0.127	-0.028	-0.510***	-0.360	0.091	0.486***
	(0.094)	(0.082)	(0.175)	(0.250)	(0.197)	(0.148)
Municipality FE	YES	YES	YES	YES	YES	YES
Year FE x controls	YES	YES	YES	YES	YES	YES
Year x region FE	YES	YES	YES	YES	YES	YES
Observations	1,991	1,991	1,991	1,991	1,991	1,991
R-squared	0.954	0.934	0.953	0.969	0.921	0.956

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. *** p<0.01, ** p<0.05, * p<0.1

Our first finding is that the negative impact for government parties is mainly driven by the votes for the left parties (PS and SP.A). Both parties were consistently part of the regional governments between 2004 and 2014 and had an important role in the policy design. Note that effects on parties in the center are also negative and large, but not estimated precisely.[28]

[28] Flemish minister of energy from 2004-2007, Kris Peeters (CD&V), executed the Flemish policy, but Steve Stevaert (SP.A) provided the preliminary work in a preceeding government and is often considered the founder of the GC subsidies. Freya Van den Bossche (SP.A) (Flemish minister of Energy 2009-2014) has later been critized for not responding fast enough to the decline in PV prices to reduce subsidies for new investments. See for example: https://www.demorgen.be/nieuws/sp-a-weigert-schuld-op-zich-te-nemen-black-out-in-geheugen-turtelboom~bb5f96ef/, consulted 16/09/2020. In Wallonia, the generous support to PV was largely inspired by the success of the Flemish experience. It was implemented by the Minister of energy A. Antoine (CDH) in a government headed by the socialist party (PS). In the press and in the public opinion, the main political responsibilities for the high cost of the mechanism are attributed to A. Antoine (CDH) who designed the program and J.-M. Nollet (Ecolo) who was in charge of the energy department during the period 2009-2014 and who did not take corrective measures sufficiently quickly.

A second finding is that the votes primarily went to parties that were never part of a government. They are situated on the most left (PTB-PVDA) or most right (FN, PP, LDD, VLB) side of the political spectrum. It provides further evidence of the animosity of voters against policies that had broad support among more centrist parties.

Finally, we find only limited evidence for a "becoming green" effect, as was established in Germany by Comin and Rode (2013). We see a positive impact on votes for the green party in the first election after the introduction of the program, significant at the 10% level only, but no effect afterwards.[29]

6 Conclusion

Governments are taking an increasing number of technology-specific measures to combat climate change. This paper has looked the very generous subsidy policies to solar PVs in the three regions of Belgium to ask the question how voters responded to these programs. We have provided evidence that voters did not reward the incumbent government that was responsible for the program, as predicted by the 'buying-votes' hypothesis. Instead, we found that voters punish the incumbent government because of the increasing awareness of the high financing costs. These did not only affect the non-adopting electricity consumers who did not benefit from the programs, but also the adopting prosumers, who saw unannounced new costs such as the introduction of prosumer fees to get access to the grid.

This case study illustrates some of the weaknesses of technology-specific policies for the energy transition. First, the design by the government of the supporting schemes is done in a context where uncertainty is important. There is a lot of uncertainty surrounding the evolution of the technology and its costs, the willingness to adopt by citizens, etc. Furthermore, there is an uncertainty on the appropriate instruments to use. In the context we studied, policy makers underestimated the massive adoption responses by households (due to the rapid evolution of the technology). They therefore substantially underestimated the budgetary costs of the subsidy policies,. As a result, subsidies were too high for a period that was too long.[30] Furthermore, governments (who are constrained by tight budgetary rules) preferred production subsidies to upfront rebates, although these turned out to be less effective.

Second, governments did not commit to a mechanism to adapt the support to the changing market conditions. Pani and Perroni (2018) show that politicians do not want to commit to a progressive fading-out of the subsidy schemes for political and electoral reasons. Lack of commitment clearly increased the cost of the mechanism. Furthermore, the government failed to commit to a clear funding of the mechanism or, alternatively to a clear budget to support the policy. This lack of commitment imposed adjustments *ex-post* that were considered by both adopters and non-adopters as unfair. Finally, the lack of commitment to a clear financing policy creates uncertainty, and depresses adoption, as our results show.

[29] Note that the green parties were not part of the 2004-2009 governments, except for Ecolo, which was part of the government of Brussels. We find similar results when we omit the municipalities of Brussels.

[30] Sanden and Azar (2005) recommend to use of economy-wide instruments for technologies that can be picked 'from the shelves' and to leave technology specific support to bring new technologies 'to the shelves'.

Third, politicians appeared to have a short term vision. By providing high subsidies to households, they wanted to make them active in the energy transition and, eventually, gain political support. But they did not integrate this with the long-term consequences of their policy. This induced voters to punish the parties responsible for the policies, as they viewed them wrongly designed because of the high associated costs.

Designing technology specific policies is a very difficult task for governments who often lack the necessary information. One way to overcome part of these difficulties is to design a mechanism that is fexible enough to adapt to the economic and technological changes. Alternatively, economic-wide measures like CO2 taxation could be used. These measures are often not implemented because they lack the political support that technology-specific policies do tend to have. An independent institution could therefore help in improving policies, and prevent the costly mechanism through which voters punish the government.

-

Appendix

1 Appendix: sources of policy and net present value

This appendix describes the sources we used to describe the policy environment, the data sources and the assumptions for computing the NPV .

1.1 Investment costs

Our starting point in the price index for 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 prediction from a German price index (they do not use it in estimation and we do not either).

We use the most common VAT rate (6%) and extrapolate the data by using four data points that were used by government agency VEA to calculate subsidies in June 2013, December 2013, June 2014 and January 2015 for a 5kW system.[31] We additionally use a data point in February 2018 for a larger system because subsidies were no longer calculated for smaller ones (source: https://www.energiesparen.be/overzicht-bandingfactor-zonnepanelen, consulted on 28/02/2020). Finally, we requested the price of a 5kW system on the website of energy supplier, Luminus, to assign a price for the end of 2019 (source: https://www.luminus.be/nl/apps/flows/prijs-zonnepanelen/, consulted on 17/01/2020). We use this data to calculate the growth rate in the relevant size category since the last observation in De Groote & Verboven (2019) and apply this rate on all capacity options. Finally, we apply cubic spline interpolation to fill in the missing months.

1.2 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) contain detailed information on the functioning of the GC market in Wallonia.

[31] A house had to be at least 5 or 10 years old (depending on the year of adoption) to make use of the 6% VAT rate instead of the 21% VAT rate.

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

1.3 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 Hindricks and Serse (2020) on the basis of the data obtained from the CREG.[32]

1.4 Assumptions net present value

We follow the assumptions in De Groote and Verboven (2019). We also correct for inflation and express net present value in prices of 2013 using the HICP.

The assumptions we use are:

- 1 kWp produces 0.85 MWh/year (as explained in the text, this is equivalent to a capacity factor of 9.73%.)
- Yearly deterioration: 1%
- Lifetime PV: 20 years
- Inverter replacement not anticipated
- Inflation: 2%
- Grid fee never anticipated
- Yearly expected increase electricity prices: 3.4% (corresponding to the historical trend)
- Current price of GCs guaranteed at nominal values through investment period

Additionally, instead of estimating a discount factor, we assume people discount at market interest rates and assume a real rate of 3%.

[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%.

2 Appendix: further details of the dynamic model

Rewriting the conditional value function of no adoption

With a type 1 extreme value distribution for the random taste shocks ε_{ijt}, the ex ante value function has the well-known closed-form logsum expression:

$$\bar{V}_{ct+1} = 0.577 + \ln \sum_{j=0}^{J} \exp(v_{cjt+1}),$$

where 0.577 is Euler's constant (the mean of the extreme value distribution). Hotz and Miller (1993) show that when there is an alternative $j = 1$ that terminates the decision process, we can rewrite the logsum such that:

$$\bar{V}_{ct+1} = 0.577 + v_{c1t+1} - \ln s_{c1t+1}(v_{ct+1}),$$

where $s_{c1t+1}(v_{ct+1})$ is the probability to choose option $j = 1$ when agents have information $v_{ct+1} = (v_{c0t+1}, v_{c1t+1}, \dots, v_{cJt+1})$. This follows from rearranging $s_{c1t+1}(v_{ct+1}) = \exp(v_{c1t+1}) / \sum_{j=0}^{J} \exp(v_{cjt+1})$, taking logs and substituting in the first expression.

Now define the expectation error $\eta_{ct} \equiv \bar{V}_{ct+1} - E_t \bar{V}_{ct+1}$, and substitute this together with the above expression for $\bar{V}_{ct+1}$ to write the conditional value function of no adoption from the main text as:

$$\begin{aligned} v_{c0t} &= u_{c0t} + \delta 0.577 + \delta v_{c1t} - \delta \ln s_{c1t+1}(v_{ct+1}) - \delta \eta_{ct} \\ &= u_{c0t} + \delta 0.577 + \delta(x_{c1t+1}\gamma_c - \alpha_c p_{1t+1} + \alpha_c \theta_c b_{c1t+1} + \xi_{c1t+1}) \\ &\quad - \delta \ln s_{c1t+1}(v_{ct+1}) - \delta \eta_{ct}. \end{aligned}$$

Deriving the regression equation

With random utility maximization, we obtain the following choice probabilities or predicted market shares for each alternative $j = 0, \dots, J$ at period t in region c:

$$S_{cjt} = s_{cjt}(v_{ct}) = \frac{\exp(v_{cjt})}{\sum_{j'=0}^{J} \exp(v_{cj't+1})}$$

with S_{cjt} the observed market shares. Taking logs and rearranging, we write the following linear regression equation:

$$\begin{aligned} \ln S_{cjt} - \ln S_{c0t} & \\ &= x_{cjt}\gamma_c - \alpha_c p_{cjt} + \alpha_c \theta_c b_{cjt} + \xi_{cjt} \\ &\quad - (u_{c0t} + \delta 0.577 + \delta(x_{c1t+1}\gamma - \alpha_c p_{c1t+1} + \alpha_c \theta_c b_{c1t+1} + \xi_{c1t+1}) \\ &\quad - \delta \ln s_{c1t+1}(v_{ct+1}) - \delta \eta_{ct}) \end{aligned}$$

We assume the flow utility of the outside option remains constant over time and normalize it such that $u_{c0t} = -\delta 0.577$. We also make use of random utility maximization to set $s_{c1t+1}(v_{ct+1}) = S_{c1t+1}$. Rearranging terms we obtain:

$$\ln S_{cjt} - \ln S_{c0t} - \delta \ln S_{c1t+1}$$
$$= (x_{cjt} - \delta x_{c1t+1})\gamma_c - \alpha_c(p_{cjt} - \delta p_{c1t+1}) + \alpha_c \theta_c (b_{cjt} - \delta b_{c1t+1}) + \xi_{cjt} - \delta(\xi_{c1t+1} - \eta_{ct}).$$

If δ is known (we use a yearly market interest rate of 3%), this is a linear regression with outcome variable $Y_{cjt} = ln\ S_{cjt} - ln\ S_{c0t} - \delta\ ln\ S_{c1t+1}$ and regressors $X_{cjt} = \left(x_{cjt} - \delta x_{c1t+1}, p_{cjt} - \delta p_{c1t+1}, b_{cjt} - \delta b_{c1t+1}\right)$.

3 Appendix: 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:

$$Y_{mt} = X_m\beta_t + \gamma_t CUM\_PV_m + FE_m + FE_t + e_{mt}.$$

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:

$$Y_{at} = \beta_t \sum_{m\in A} w_m X_m + \gamma_t \sum_{m\in A} w_m\, CUM\_PV_m + \sum_{m\in A} w_m\, FE_m + FE_t + \sum_{m\in A} w_m\, e_{mt}.$$

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.

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

4 Appendix: additional results on votes

Table 7: results of the vote model with cumulative PV adoption in adjacent municipalities

	Base		+ controls	
	%PV in municipality	**%PV in adjacent municipalities**	**%PV in municipality**	**%PV in adjacent municipalities**
Year x %PV				
1995	0.088	0.090	-0.228	0.579*
	(0.135)	(0.133)	(0.311)	(0.335)
1999	0.133	-0.066	-0.015	0.417*
	(0.090)	(0.104)	(0.213)	(0.224)
2004				
2009	-0.218*	-0.069	-0.418	-0.374
	(0.126)	(0.107)	(0.358)	(0.366)
2014	-0.123	-0.276**	-0.260	-0.862***
	(0.126)	(0.111)	(0.263)	(0.301)
2019	-0.304***	-0.358***	-0.439	-0.551
	(0.116)	(0.117)	(0.301)	(0.335)
Municipality FE	YES	YES	YES	YES
Year FE x controls	NO	NO	YES	YES
Year x region FE	YES	YES	YES	YES
Observations	1,991		1,991	
R-squared	0.967		0.975	

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. *** p<0.01, ** p<0.05, * p<0.1

References

Aidt, T. 1998. Political internalization of economic externalities and environmental policy, *Journal of Public Economics*. 69, p. 1-16.

Biais, B., Perotti, E. 2002. Machiavellian privatization, *American Economic Review*. 92, p. 240-258.

Boccard, N., Gautier, A., 2015. Le coût de l'énergie verte en Wallonie, 2003-2012. *Reflets et Perspectives de la Vie Economique*. 54, p. 71-85.

Boccard, N., Gautier, A. 2019. Certificats verts ou prime de rachat ? Évolution du marché des certificats verts en Wallonie. *Reflets et Perspectives de la Vie Economique. 57*, p. 163-171.

Campoccia A., Dusonchet L., Telaretti E., Zizzo G. 2009. Comparative analysis of different supporting measures for the production of electrical energy by solar PV and wind systems: Four representative European cases. *Solar Energy*. 83, p.287–97.

Comin, D., Rode, J., 2013. From green users to green voters. NBER working paper.

Crago, C. L., Chernyakhovskiy, I. 2017. Are policy incentives for solar power effective? Evidence from residential installations in the Northeast. *Journal of Environmental Economics and Management*. 81, p. 132-151.

De Grauwe, Paul, 2018. "Who should pay for the cost of climate policies?" *Vox Europe*.

De Groote, O., Pepermans, G., Verboven, F., 2016. Heterogeneity in the adoption of photovoltaic systems in Flanders. *Energy Economics*. 59, p. 45-57.

De Groote, O., Verboven, F., 2019. Subsidies and the time discounting in new technology adoption: Evidence from solar photovoltaic systems. *American Economic Review*. 109, p. 2137-72.

Dusonchet L., Telaretti E. 2010. Economic analysis of different supporting policies for the production of electrical energy by solar photovoltaics in western European union countries. *Energy Policy*. 38, p. 3297–3308.

Dusonchet L., Telaretti E. 2015. Comparative economic analysis of support policies for solar PV in the most representative EU countries. *Renewable and Sustainable Energy Reviews*.42. p. 986–998.

Fowlie, M. 2019. The Trouble with Carbon Pricing. *Energy Institute Blog*.

Gautier, A., Jacqmin, J., Poudou, J. C. 2018. The prosumers and the grid. *Journal of Regulatory Economics*. 53, p. 100-126.

Gautier, A., Jacqmin, J. 2020. PV adoption: the role of distribution tariffs under net metering. *Journal of Regulatory Economics.* 57, p. 53–73.

Hindricks, J., Serse, V. 2020. The incidence of VAT reforms in electricity markets: Evidence from Belgium, CORE DP 2020/12.

Hughes, J. E., and Podolefsky, M. 2015. Getting green with solar subsidies: evidence from the California solar initiative. *Journal of the Association of Environmental and Resource Economists*. 2, p. 235-275.

Jenner, S., Ovaere, L., Schindele, S. 2013. The impact of private interest contributions on RPS adoption. *Economics & Politics*. 25, p. 411-423.

Nicolini, M., Tavoni, M. 2017. Are renewable energy subsidies effective? Evidence from Europe, *Renewable and Sustainable Energy Reviews*. 74, p. 412-423.

Ovaere, L., Proost S., 2015. Buying votes with discriminatory support for renewable energy technologues. *Reflets et Perspectives de la Vie Economique*. 54, p. 87-102.

Pani, M., Perroni C. 2018. Energy subsidies and policy commitment in political equilibrium. *Energy Economics.* 71, p. 149-160.

Rodrigues, S., Torabikalaki, R., Faria, F., Cafôfo, N., Chen, X., Ramezani Ivaki, A., Mata-Lima, H., Morgado-Dias, F. 2016. Economic feasibility analysis of small scale PV systems in different countries, *Solar Energy*. 131, p 81-95.

Sanden, B., Azar, C. 2015. Near-term technology policies for long-term climate targets — economy wide versus technology specific approaches. *Energy Policy*. 33, 1557-1576.

Silva, J., Tenreyro, S. 2006. The Log of gravity. *Review of Economics and Statistics.* 88, p. 641–658.

Vasseur, V., Kemp, R. 2015. The adoption of PV in the Netherlands: A statistical analysis of adoption factors. *Renewable and Sustainable Energy Reviews*. 41, 483-494.

NATIONAL BANK OF BELGIUM - WORKING PAPERS SERIES

The Working Papers are available on the website of the Bank: http://www.nbb.be.

348. "Can inflation expectations in business or consumer surveys improve inflation forecasts?", by R. Basselier, D. de Antonio Liedo, J. Jonckheere and G. Langenus, *Research series*, October 2018.
349. "Quantile-based inflation risk models", by E. Ghysels, L. Iania and J. Striaukas, *Research series*, October 2018.
350. "International food commodity prices and missing (dis)inflation in the euro area", by G. Peersman, *Research series*, October 2018.
351. "Pipeline pressures and sectoral inflation dynamics", by F. Smets, J. Tielens and J. Van Hove, *Research series*, October 2018.
352. "Price updating in production networks", by C. Duprez and G. Magerman, *Research series*, October 2018.
353. "Dominant currencies. How firms choose currency invoicing and why it matters", by M. Amiti, O. Itskhoki and J. Konings, *Research series*, October 2018.
354. "Endogenous forward guidance", by B. Chafwehé, R. Oikonomou, R. Priftis and L. Vogel, *Research series*, October 2018.
355. "Is euro area lowflation here to stay? Insights from a time-varying parameter model with survey data", by A. Stevens and J. Wauters, *Research series*, October 2018.
356. "A price index with variable mark-ups and changing variety", by T. Demuynck and M. Parenti, *Research series*, October 2018.
357. "Markup and price dynamics: Linking micro to macro", by J. De Loecker, C. Fuss and J. Van Biesebroeck, *Research series*, October 2018.
358. "Productivity, wages and profits: Does firms' position in the value chain matter?", by B. Mahy, F. Rycx, G. Vermeylen and M. Volral, *Research series*, October 2018.
359. "Upstreamness, social upgrading and gender: Equal benefits for all?", by N. Gagliardi, B. Mahy and F. Rycx, *Research series*, December 2018.
360. "A macro-financial analysis of the corporate bond market", by H. Dewachter, L. Iania, W. Lemke and M. Lyrio, *Research series*, December 2018.
361. "Some borrowers are more equal than others: Bank funding shocks and credit reallocation", by O. De Jonghe, H. Dewachter, K. Mulier, S. Ongena and G. Schepens, *Research series*, December 2018.
362. "The origins of firm heterogeneity: A production network approach", by A. B. Bernard, E. Dhyne, G. Magerman, K. Manova and A. Moxnes, *Research series*, January 2019.
363. "Imperfect competition in firm-to-firm trade", by A. Ken Kikkawa, G. Magerman and E. Dhyne, *Research series*, January 2019.
364. "Forward guidance with preferences over safe assets", by A. Rannenberg, *Research series*, January 2019.
365. "The distinct effects of information technologies and communication technologies on the age-skill composition of labour demand", by S. Blanas, *Research series*, January 2019.
366. "A survey of the long-term impact of Brexit on the UK and the EU27 economies", by P. Bisciari, *Document series*, January 2019.
367. "A macroeconnomic model with heterogeneous and financially-constrained intermediaries", by Th. Lejeune and R. Wouters, *Research series*, February 2019.
368. "The economic importance of the Belgian ports: Flemish maritime ports, Liège port complex and the port of Brussels – Report 2017", by E. Gueli, P. Ringoot and M. Van Kerckhoven, *Document series*, March 2019.
369. "Does banks' systemic importance affect their capital structure and balance sheet adjustment processes?", by Y. Bakkar, O. De Jonghe and A. Tarazi, *Research series*, March 2019.
370 "A model for international spillovers to emerging markets", by R. Houssa, J. Mohimont and C. Otrok, *Research series*, April 2019.
371. "Estimation methods for computing a branch's total value added from incomplete annual accounting data", S. Vansteelandt, F. Coppens, D. Reynders, M. Vackier and L. Van Belle, *Research series*, April 2019.
372. "Do SVARs with sign restrictions not identify unconventional monetary policy shocks?", by J. Boeckx, M. Dossche, A. Galesi, B. Hofmann and G. Peersman, *Research series*, June 2019.
373. "Research and development activities in Belgium: A snapshot of past investment for the country's future", by S. Vennix, *Research series*, July 2019.
374. "State dependent fiscal multipliers with preferences over safe assets" by A. Rannenberg, *Research series*, July 2019.
375. "Inequality, the risk of secular stagnation and the increase in household debt", by A. Rannenberg, *Research series*, August 2019.
376. "Welfare effects of business cycles and monetary policies in a small open emerging economy", by J. Mohimont, *Research series*, October 2019.

377. "Learning about demand abroad from wholesalers: a B2B analysis", by W. Connell, E. Dhyne and H. Vandenbussche, *Research series*, November 2019.
378. "Measuring trade in value added with Firm-level Data, by R. Bems and A. K. Kikkawa, *Research series*, November 2019.
379. "Scrapping the entitlement to unemployment benefits for young labor market entrants: An effective way to get them to work?", by B. Cockx, K. Declercq, M. Dejemeppe, L. Inga and B. Van der Linden, *Research series,* December 2019.
380. "The impact of Brexit uncertainties on international trade: Evidence from Belgium", by E. E. Schmitz, *Research series*, December 2019.
381. "The heterogeneous employment outcomes of first- and second-generation immigrants in Belgium", by C. Piton and F. Rycx, *Research series*, January 2020.
382. "A Dane in the making of European Monetary Union – A conversation with Niels Thygesen", by I. Maes and S. Péters, *Research series*, May 2020.
383. "Multi-product exporters: Costs, prices and markups on foreign vs domestic markets", by Catherine Fuss, *Research series*, June 2020.
384. "Economic importance of the Belgian maritime and inland ports – Report 2018", by I. Rubbrecht and K. Burggraeve, *Document series*, July 2020.
385. "Service characteristics and the choice between exports and FDI: Evidence from Belgian firms", by L. Sleuwaegen and P.M. Smith, *Research series*, July 2020.
386. "Low pass-through and high spillovers in NOEM: What does help and what does not", by G. de Walque, T. Lejeune, A. Rannenberg and R. Wouters, *Research series*, July 2020.
387. "Minimum wages and wage compression in Belgian industries", by S. Vandekerckhove, S. Desiere and K. Lenaerts, *Research series*, July 2020.
388. "Network effects and research collaborations", by D. Essers, F. Grigoli and E. Pugacheva, *Research series*, July 2020.
389. "The political economy of financing climate policy – evidence from the solar PV subsidy programs", by O. De Groote, A. Gautier and F. Verboven, *Research series*, October 2020.

National Bank of Belgium
Limited liability company
RLP Brussels – Company's number: 0203.201.340
Registered office: boulevard de Berlaimont 14 – BE-1000 Brussels
www.nbb.be

Statement of purpose

The purpose of these working papers is to promote the circulation of research results (Research Series) and analytical studies (Documents Series) made within the National Bank of Belgium or presented by external economists in seminars, conferences and conventions organized by the Bank. The aim is therefore to provide a platform for discussion. The opinions expressed are strictly those of the authors and do not necessarily reflect the views of the National Bank of Belgium.

Editoral

On October 22-23, 2020 the National Bank of Belgium hosted a Conference on "Climate Change: Economic Impact and Challenges for Central Banks and the Financial System".

Papers presented at this conference are made available to a broader audience in the NBB Working Paper Series (www.nbb.be). This version is preliminary and can be revised.

Editor

Pierre Wunsch
Governor of the National Bank of Belgium

Orders

The Working Papers are available on the website of the Bank: http://www.nbb.be.

ISSN: 1375-680X (print)
ISSN: 1784-2476 (online)

Layout: Analysis and Research Group
Cover: NBB CM – Prepress & Image

Published in October 2020