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Buying votes with discriminative support for renewable energy technologies

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Buying Votes with Discriminative Support for Renewable Energy Technologies[*]

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Abstract

This paper uses a political economy model to explain the discriminative support for some renewable technologies like photovoltaic. A two party model is used to show how subsidies for technologies that are installed by household voters can incentivise swing voters to vote for a party. It is in the interest of both the incumbent and the opposition party to propose discriminative support, even if it is highly inefficient.

Keywords: Renewable energy, photovoltaics, wind, political economy

JEL-codes: P48, Q42, Q48, Q54

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1 Introduction

In many European member states, the production of electricity from renewable energy resources has been intensely subsidized in the past decade. The most common support systems in EU member states for renewables are feed-in tariffs or a green certificate systems with minimum guaranteed prices (European Commission, 2011). These tariffs and guaranteed prices should compensate for the higher production costs of renewable technologies, relative to conventional sources of electricity production. In table 1 the production costs (a levelized cost covering the investment cost [1]) of both conventional and renewable technologies are presented for 2007. We can see that the production cost for onshore wind energy was competitive with the cost of conventional technologies in 2007, whereas solar PV was far from achieving grid parity.

In some member states we have observed a strong discrimination in support, favoring renewable

[1] For more detailed info on these costs, see European Commission, 2008. We are aware that the levelized cost of renewables is not the right basis of comparison as the real value of renewable energy production depends on the marginal cost of power that it substitutes (Joskow, 2011). In this paper, however, all we need are orders of magnitude.

Table 1: Production Cost of Electricity (2007)

	Levelized cost
Natural gas	50-75 €/MWh
Coal	40-55 €/MWh
Oil	95-125 €/MWh
Nuclear	50-85 €/MWh
Biomass	55-215 €/MWh
Hydro	35-185 €/MWh
Onshore wind	75-110 €/MWh
Solar PV	520-880 €/MWh

technologies that are installed in individual houses (solar PV). For instance in Germany, solar PV was guaranteed the largest financial support among all renewable energy technologies. In 2009, the feed-in tariff for solar PV in Germany equalled more than four times the feed-in tariff paid for electricity produced by on-shore wind turbines, and more than eight times the electricity price at the power exchange (Frondel et al. 2010). But also in other European countries, discrimination between technologies in terms of support levels persists. Table 2 shows the level of support for onshore wind and solar PV technology in Germany and Flanders, both in the first year of the support and in 2012.[2] The numbers clearly demonstrate the discrimination, which still remains despite the fact that support for solar PV technology has decreased over the years.[3,4]

Table 2: Support for wind and solar over time

	Onshore Wind		Solar PV	
	Start year	2012	Start year	2012
Germany	91 €/MWh	89 €/MWh	506 €/MWh	183 €/MWh
Flanders	80 €/MWh	90 €/MWh	450 €/MWh	250 €/MWh

In this paper we show that discrimination in support of different renewable technologies is inefficient. We also study the rationale for politicians in following this strategy in promoting renewable energy technologies. The objective is to explain the generous support for solar PV in the years right

[2] The support levels should only be compared within one country or region, as the green certificate system provides support on top of the electricity price. This is not the case with a feed-in tariff, which represents the full level of support.

[3] Start year wind onshore and solar PV support in Germany was 2000, wind onshore support in Flanders 2004 and solar PV support in Flanders 2006.

[4] For Germany these support levels are feed-in tariffs, for Flanders minimum guaranteed certificate prices. A comparison of the support levels between countries is thus not straightforward, but the discrimination within the country or region between technologies is obvious.

after the introduction of renewable technologies. In terms of technologies, our focus is on onshore wind and solar PV, where onshore wind represents a centralized, non individualized technology, and solar PV a decentralized and individualized technology.

We claim that in several EU member states, governments have introduced inefficiently high subsidies for solar PV panels installed with households, for electoral purposes. The idea behind this is that incumbent governments can use these subsidies to incentivize indecisive or swing voters to vote for them in upcoming elections. Our model also shows that it is not only a green party with extremely high preferences for renewable energy sources that would introduce large support for renewable technologies.

In Germany, for instance, Helmut Kohl's conservative government in the early 1990's initiated the feed-in tariff system. With the introduction of the Renewable Energy Sources Act (EEG), the support regime was amended in 2000 to guarantee stable feed-in tariffs for up to 20 years, thereby providing favorable conditions for investments in green electricity production over the long term. The tariffs established by the EEG for solar PV were more than four times the feed-in tariff for onshore wind turbines. (Frondel et al., 2010) In Flanders, the government that introduced the green certificates (with minimum guaranteed prices) for solar PV was the regional Flanders' Government-Leterme I. The majority in this government was formed by 4 parties (the right wing democratic VLD, the socialist SP, the Flemish Nationalists NVA and the Christian Democrats CD&V), while at that time the green party served in opposition.

The incumbent coalitions introducing high support for solar PV were re-elected both in Flanders and in Germany. We also verified whether this has been the case for France, the UK, the Netherlands and Wallonia. The results are in table 3.

As it is very difficult to separate the effect of introducing support for solar PV from other effects that play in elections, we only conclude from these stylized facts that there is some indication that high subsidies for solar PV may be inspired by elections.

The aim of this paper is to explain the discrimination in support for renewables from a political

Table 3: Re-election of parties introducing discriminatory support

Country/Region	Start support	Election date	Party/coalition (re-)elected?
Germany	2000	2002	yes
France	2003	2004	no
Flanders (Belgium)	2002	2004	yes
Wallonia (Belgium)	2003	2004	yes
United Kingdom	2010	2010	yes
Netherlands	2007	2010	yes

point of view. While there are certainly other reasons for discrimination between different renewable technologies, such as lobbying by interest groups for instance, our focus is solely on electoral motives. The paper is structured as follows. In section 2 we review the relevant literature. In section 3 we describe the optimal policy that will serve as a comparison for the political equilibrium described in section 4. In section 5 we conclude.

2 Literature Review

To explain discrimination in the support of RES for different groups of producers, we can build on two types of political economy theory. The first is the traditional lobby group model à la Dixit, Grossman, Helpman (1997). They develop a common agency model to show how organized special interests can lobby the government for consumer and producer taxes or subsidies and targeted lump-sum taxes or transfers. Aidt (1998) builds upon this model to discuss the political internalization of environmental externalities. Aidt argues that, in the presence of interest groups, the optimal environmental taxes deviate from the Pigouvian argument. There is empirical evidence for this kind of theory in the study of support policies for renewable technologies. Jenner et al. (2013) empirically verify the impact of private energy interest contributions on the adoption of support for renewable energy technologies in the US electricity sector. The authors find that both the adoption rate and the strength of Renewable Portfolio Standards in US states are positively influenced by renewable energy lobby campaign contributions, and negatively by conventional energy lobby campaign contributions.

Marques et al. (2010) study the motivations driving renewable energy support in Europe. Using a panel data approach, the authors find that interest groups favoring traditional energy sources hold back the use of renewable energy.

The second type of model studies the efficiency of policy choices in a dynamic and democratic political environment. Besley and Coate (1998) study the efficiency of policy choices in a representative democracy. They explain why potentially Pareto-improving public investments may not be introduced when policymakers are not able to commit to future policy outcomes. In the same context, Glazer (1989) shows how political decisions may be biased towards policies with long term effects as politicians are only in power for one or two terms. Biais and Perotti (2002) explain how the conservative government in the UK uses the privatization of public utilities as a strategy to remain in power. By allocating significant share ownership to a targeted section of the population, strategic privatization can build political support for right-wing parties.

It is the second type of modeling that we apply in this paper. We use the Biais and Perotti (2002) analysis as a basis for our theoretical model. We explain how an incumbent politician or political party gives a subsidy to long term investments in solar PV panels with a guaranteed return. In this way she can commit to a long term green policy and makes sure she creates a long term group of stakeholders and voters for a green policy. As previously modelled by for instance Alesina (1987) and Alesina and Tabellini (1990) for a bipartisan setting where parties always align preferences with their constituencies', we consider a model with two political alternatives: the incumbent coalition and the opposition. We show that it is in the interest of both the incumbent and the opposition to promise a subsidy for solar PV. With voters who have no outspoken preference for the opposition nor the incumbent because they are ideologically neutral, both the incumbent and the opposition adjust their subsidy policy for solar PV as desired by this group of voters.

Some evidence on the electoral motives of support for solar energy already exists. In their paper, Comin and Rode (2013) find strong evidence that individuals that use green technologies are more likely to become green party voters. They studied election patterns in Germany in the period of

1998-2009, and found that the diffusion of domestic PV systems caused 25% of the increment of green votes. So next to some other drivers of green voting such as occupation, political affiliation, education, income and location, the authors prove that the promotion of solar PV systems has influenced the popularity of the Green Party in Germany. This evidence solely focuses on Germany, but might serve as an indication for the practical evidence of our theoretical model. Of course, more exhaustive empirical research is necessary to draw larger conclusions on the general validity of our results.

3 The social planner's solution as benchmark

We derive the socially desirable support system for green technologies that will serve as a benchmark for the political equilibrium.

We consider a simplified production side for the electricity market and assume an inelastic demand. Electricity is produced by three types of energy sources: conventional energy (e.g. coal, gas), wind and solar. The conventional energy is polluting, while wind and solar are clean energy production sources. The conventional resources and wind serve as inputs in utilities to produce electricity, while solar energy production installations (solar panels) can be installed by the households to produce their own electricity.[5]

Production costs for wind and solar electricity production are higher than for the conventional source, and wind is a more competitive technology than solar.[6] If there are no constraints, it is cost efficient to meet the demand for electricity with the conventional technology alone. If the government wants a certain part of the electricity production to be generated from renewable sources, it must incentivize this type of production. The required production subsidy level[7] should compensate for the difference in production costs between the renewable technology and the conventional technology. Producers are encouraged to exploit all available generating sites until the marginal cost of producing electricity from wind and solar is equal to the proposed subsidy. The proposed subsidy is then set at a level that guarantees meeting the production level from those renewable sources that the government desires.

We assume cooperation among different economies is not possible (i.e. national sovereignty plays a dominant role in the design of the support systems, see also Jenner et al. (2013)), so we are in

[5] The profits of solar electricity production are in the hands of those consumers installing solar panels. In the next part of the paper, we further elaborate on this.

[6] This is an assumption based on the cost of both technologies as it was in the first half of the previous decade. Since then, the cost of solar PV technology has dropped tremendously, whereas wind technology has not experienced the same large cost decrease.

[7] We introduce a production subsidy but any other form of support would fit (tendering, renewable quota obligations, certificate systems with minimum guaranteed prices), as long as it stimulates the production of electricity from renewable resources.

a second best situation.[8] We do not consider learning effects as these are too small in the case of a country in isolation. This static setting is close to a Nash non-cooperative setting where each country takes the knowledge accumulated in the rest of the world as given.

In figure 1, we compare the costs of meeting the target with two types of subsidy schedules. The welfare loss of using a differentiated subsidy instead of a uniform subsidy to meet the target is indicated by the colored triangle. For a fixed level of electricity production from renewable energy sources, the loss in welfare from discrimination equals the increase in total production costs of the renewable target.

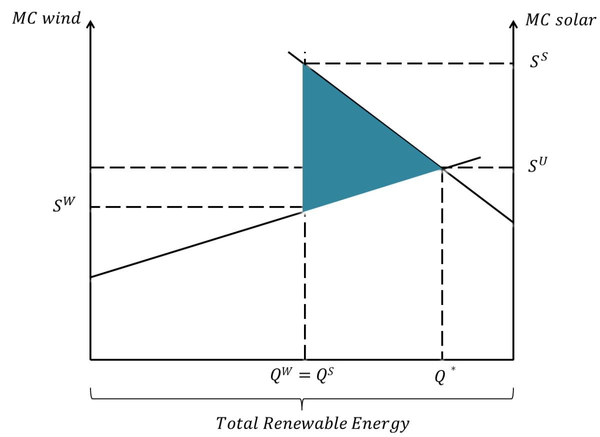

Figure 1: Welfare loss from discrimination in support

We can conclude that, from an efficiency point of view, the optimal subsidy scheme to support different technologies is uniform, despite the difference in production costs. Given that we do not observe this uniform pattern of support in practice (cf. supra), there must be reasons to deviate from the optimal support system that go beyond the economic efficiency objective.

In the following section, we study the justification for discrimination in favor of decentralized renewable technologies from a political economy point of view. We show that an incumbent coalition

[8] When we consider a common electricity market between several economies, the first best solution is full cooperation between all economies in generating the combined required level of renewable electricity. A common support system would enable trade of renewable energy and learning effects to play a significant role, such that subsidies would be set at the most efficient level. In practice, we do not observe a lot of cooperation in support systems, and there is almost no trade. Every economy decides on the optimal support levels, given the support system of the other economies. In this non-cooperative perspective, the optimal support levels will be lower than with (full) cooperation between economies, as learning benefits cannot be considered.

has an incentive to design a support scheme favoring a technology that can be installed at voters' houses in order to increase election chances. This explains inefficiently high subsidies for this type of technology.

4 Political model

We analyze politically motivated subsidies for decentralized RES in the electricity market in a bipartisan environment, where the residing government and the opposition are considered. We use a political setting close to the Biais and Perotti model (2002). The incumbent and the opposition differ in ideology, a permanent feature that cannot be modified as part of the electoral platform. Next to their ideological characteristics, both incumbent and opposition are electorally accountable for their subsidy policy for renewable energy. Both want to achieve the same level of renewable electricity production, but the choice of what technologies to subsidize and at what rate, is at their discretion. We simplify the analysis by only considering wind and solar PV as renewable sources. Solar PV is a decentralized technology which can be installed at household level. Wind farms, on the other hand, are assumed to be organized on a more industrial, centralized level, and are not available at household level: wind mills are are at too large of a scale to install by individual voters for self-sufficient energy production.[9] By introducing a uniform subsidy for solar PV and wind, the target is met at the lowest cost. The subsidy for solar PV can however be an instrument to influence election outcomes. A subsidy for solar PV directly affects voter welfare and can therefore influence voting behavior, while a subsidy for wind mills does not have this direct impact. We show that when an election is due, both the incumbent and the opposition have an interest in setting the subsidy for solar PV at a level that maximizes their (re-)election chance, instead of considering an

[9] The capacity of an average solar panel is about 4 kWp, that of an average wind farm 1500 kW. Wind farms that are owned by groups of households can be considered as a more decentralized technology as well. In Germany and Denmark, this form of co-operative ownership (or crowd funding) is popular, and has increased the acceptance of wind energy (Reiche, 2004). In order to obtain the same results as with solar PV at the household sites, the political parties need to be able to favor the wind farms owned by cooperatives over those owned by industry or by regular electricity producers.

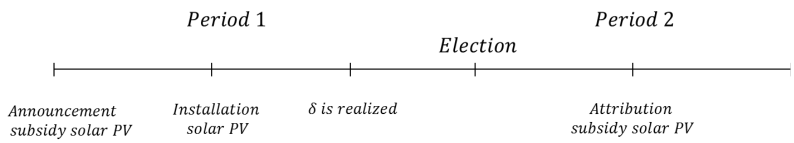

Figure 2: Timeline political game

efficient subsidy level.

4.1 Political parties and voters

Both the incumbent government and the opposition maximize the expected value of some exogenous ego rents, R, which reflect the value attached to winning the elections and holding office. By setting a subsidy level for solar PV, both the incumbent and the opposition aim to maximize $\pi_l R$, where π_l $(l = INC, OPP)$ is the probability of winning the election, given the other candidate's policy.

There are two periods to consider (cf. figure 2). In period 1, the politicians announce their subsidy policy for renewable technologies. After the announcement, voters can decide whether they want to invest in solar PV. Then elections are organized. In period 2, the elected incumbent allocates the subsidies announced in period 1.

All voters consume electricity, which can be either bought on the market, or produced domestically with solar panel technology. The installation of solar panels requires a large upfront investment. Once the panels are installed, the voter consumes electricity for free (maintenance and operational costs are negligible). The voter becomes a self-suffient electricity producer, and the variable cost of solar electricity provision is zero. The voters can be subdivided into different groups, based on 2 dimensions: their political ideology and their installation cost for solar PV.

Concerning the ideological dimension, we introduce a voter-specific parameter that measures a voter's individual ideological bias towards the opposition: σ^i. If $\sigma^i > 0$, the voter is ideologically biased to vote for the opposition, whereas a negative value for σ^i indicates voting behavior that has a bias towards the incumbent. When $\sigma^i = 0$, the voter is ideologically neutral, which means he only votes based on the announced subsidy for solar PV. We assume that this parameter σ^i has a uniform distribution over the interval $\left[-\frac{1}{2\phi}, \frac{1}{2\phi}\right]$, with density ϕ. We also introduce the parameter δ that represents a general shock in the political landscape, which occurs after the policy announcements of both political parties.[10] This parameter can be both positive and negative, and is uniformly distributed over the interval $\left[-\frac{1}{2\psi}, \frac{1}{2\psi}\right]$. If $\delta > 0$, the shock reforms the political landscape in a way that is beneficial for the opposition; if $\delta < 0$, the incumbent party benefits from the reform of the political landscape. The voter specific ideology σ^i is common knowledge, while the general policy shock is a stochastic element that makes the outcome of the election a random event.

The installation cost of solar PV differs among voters and depends on factors like the location of their house.[11] Therefore the minimal subsidy level to encourage voters to invest in solar panels differs among the voters. Maintenance and operation costs of solar PV are assumed to be zero. Each voter has a house in a different location, and we can rank the houses in order of their relative productivity regarding a solar panel. If the location is very attractive for solar panel installation, the subsidy necessary to convince that voter is lower. The installation cost is represented by a linear function: $C_i = a + bi$, where i stands for the i^{th} voter ranked from the most productive to the least productive roof orientation ($i \in [1, N]$ and $a, b > 0$). So there are N types of voters, based on their installation cost, and for each of these types of voters, the voters may be ranked based on their ideological bias towards both parties. This can be seen in figure 3.

[10] Examples of this type of shock are political scandals or economic crises.

[11] A house with an inclined roof or a southern facing orientation has a more productive solar panel than one with a flat roof or a northern facing orientation.

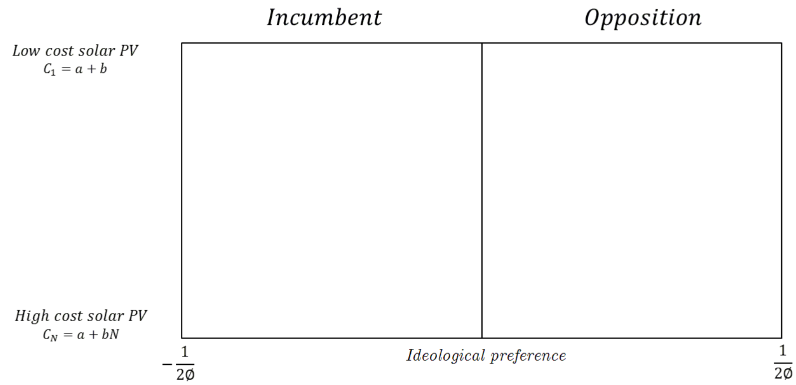

Figure 3: Double categorization of voters

Voters base their voting decision on the announcement of the subsidy for solar PV, and on the ideologies of the incumbent and the opposition parties. The investment in solar PV is beneficial whenever the discounted cost savings of electricity consumption exceed the investment cost of the panels. A subsidy for solar PV can convince voters to install the panel, as the subsidy covers the investment cost. Therefore the voter's decision to install a solar panel directly depends on the subsidy level.

We define demand for electricity for a representative consumer without solar installation as $Q(P)$, with $Q'(P) < 0$.[12] We assume that when a solar subsidy is granted to the households, this is financed with a mark-up on the electricity price.[13] The electricity price thus increases with the level of subsidy and the number of voters who receive the subsidy. Each voter (household) that installs solar PV is assumed to file for a subsidy. We define the price of electricity sold via the grid as $P(S, \widetilde{n})$, which depends on the subsidy level S and the number of installations $\widetilde{n}$. We have $P_S(S, \widetilde{n}) > 0$ and $P_{\widetilde{n}}(S, \widetilde{n}) > 0$.[14] When no subsidy for solar panels is being given, the price for electricity is $P(0, 0)$. This level is assumed to include support for renewable energy in the most efficient way. The surplus from consuming electricity is defined as the difference between

[12] Empirical studies on the demand for electricity point to an elasticity in the range of –0.1 to - 0.2 for households in the short term (Lijesen, 2007).

[13] In practice this mostly comes in the form of a higher distribution tariff, but we do not model distribution, and a mark-up in the electricity price creates the same outcomes for the model.

[14] Where $P_i(S, \widetilde{n})$ is the partial derivative to argument i, $i = S, \widetilde{n}$. The dependence of price on the subsidy level and the number of voters that receives the subsidy is not linear. This is because the subsidy induces a replacement of wind by solar PV, such that the base price ($P(0, 0)$ - cf. infra) is then actually lower.

the willingness to pay for electricity (the demand curve, $Q(P)$), and the price actually paid for the electricity. Consumer surplus decreases with the price of electricity. We define $CS(P)$, with $CS'(P) < 0$. When a voter decides to install solar PV on his house, he becomes self-sufficient and no longer has to buy electricity on the market.[15] We assume that this voter, from then onwards, has an inelastic demand for electricity: $\overline{Q}$.[16] This consumed quantity is fixed at the level consumed at the price of electricity without a mark-up to finance the solar subsidy: $\overline{Q} = Q(P(0,0))$. We define the surplus that a voter derives from consuming his own produced electricity as $CS(P=0)$, as he no longer pays for electricity (remember maintenance and operation costs are assumed to be zero).

Voter i has the following utility function:

$$\overline{U_i} \in \left[U_i^S, U_i^M\right] \tag{1}$$

$\overline{U_i}$ depends on the level of the subsidy. U_i^S stands for the utility when the voter chooses to install solar panels and U_i^M for the utility when the voter installs no solar PV and buys electricity on the market. The former is defined as the sum of subsidy S, consumer surplus from providing own electricity ($CS(P=0)$) and the installation cost of solar (- $(a+bi)$):

$$U_i^S = -(a+bi) + S + CS(P=0) \tag{2}$$

and the latter as:

$$U_i^M = U^M = CS(P(S,\widetilde{n})) \tag{3}$$

We now have that $\overline{U_i} = U_i^S$ if $S + [CS(P=0) - CS(P(S,\widetilde{n}))] \geq a + bi$, and $\overline{U_i} = U_i^M$ if $S + [CS(P=0) - CS(P(S,\widetilde{n}))] < a + bi$.

[15] This is a strong simplification as in reality, even on a yearly average basis, the consumer is not really self-sufficient, because during the winter he will need extra electricity from the grid, and during the summer he puts his additional electricity on the grid. Using the grid incurs a cost, which is not included in our analysis.

[16] This is a simplification of reality, as in practice free electricity results in larger consumption. However, support for solar panels for households is limited to a certain installation capacity per household, so this assumption is realistic.

4.2 Timing political game

The timing of events is as follows (cf. supra, figure 2). The two political parties, the incumbent and the opposition, simultaneously and non-cooperatively announce their subsidy for solar PV. We denote the subsidy announced by the incumbent as S_{INC} and the one by the opposition as S_{OPP}. At this stage, they know the voters' policy preferences. They also know the distributions for σ^i and δ, but not yet their realized values. The voters, on their part, decide whether or not to invest in solar panels on their roof. Next the actual value of δ is realized and all uncertainty is resolved. Next the elections are held, and the elected party puts the announced solar PV subsidy into action. We assume a discount factor of 1 between both periods. The order of events is chosen to resemble reality.[17]

4.3 Strategies and political equilibrium

Voter i votes for the incumbent if:

$$\overline{U_i}\left(S^{INC}\right) > \overline{U_i}\left(S^{OPP}\right) + \delta + \sigma^i \tag{4}$$

We introduce the swing voter, a voter whose ideological bias ($\overline{\sigma}$), given the subsidies announced by the parties, makes him indifferent between both parties:

$$\overline{\sigma} = \overline{U}\left(S^{INC}\right) - \overline{U}\left(S^{OPP}\right) - \delta \tag{5}$$

[17] In many European countries we have observed the allocation of very generous subsidies for solar PV for households over a period of about 15 to 20 years (which is also the payback period for the solar PV technology investment). This means that once a voter has installed solar PV, based on the promise of long term support, he needs to get this support over a certain length of time. Over that period, he has an interest to vote for those politicians that promise to continue paying the subsidies. This idea is captured with the installation decision of solar panels before elections, and the actual distribution of the subsidy after the election.

All voters with $\sigma^i \leqslant \overline{\sigma}$ prefer to vote for the incumbent. The vote share of the incumbent party is then

$$\Pi_{INC} = \phi\left(\overline{\sigma} + \frac{1}{2\phi}\right) = \frac{1}{2} + \phi\overline{\sigma} \tag{6}$$

The vote share for both the incumbent and the opposition is a random variable, since $\overline{\sigma}$ depends on the realized value of δ. The density ϕ represents how responsive the voters are to the level of the subsidy, or in other words, how voters reward the chosen subsidy policy with votes in the upcoming election.

The probability of winning, given (5), for the incumbent is

$$\pi_{INC} = \Pr_{\delta}\left[\Pi_{INC} \geqslant \frac{1}{2}\right] = \Pr\left[\left[\overline{U}\left(S^{INC}\right) - \overline{U}\left(S^{OPP}\right)\right] \geqslant \delta\right] \tag{7}$$

The probability that the opposition wins, is then $(1 - \pi_{INC})$.

The unique equilibrium involves both the incumbent and the opposition converging to the same subsidy level for solar PV. Indeed, both parties face exactly the same optimization problem. Intuitively, both incumbent and opposition share the same preferences (maximizing $\pi_l R$) and therefore find the same subsidy announcement optimal.[18] This is formally stated in the following proposition.

Proposition 1 *With probabilistic voting, the equilibrium is characterized by the incumbent and the opposition announcing the same subsidy level for solar PV.*

If a voter does not vote for the incumbent because he has low ideological preferences and does not benefit from the subsidy because he has high installation costs for solar PV, who shall he vote for? He will not vote for the opposition, as the opposition proposes the same subsidy as the incumbent. But the opposition must also propose the subsidy, because otherwise the party will face a net loss of voters (equal to $[A(S) - B(S)]$ - cf. infra). Therefore the solar subsidy is a prisoner's dilemma that can only be avoided by a binding agreement between the two parties.

[18] Also note that S^{INC} and S^{OPP} enter the maximization problem of both the incumbent and the opposition, and that the exogenous rents are such that $\pi_{INC} R = (1 - \pi_{INC}) R$.

We show here that the promise of a certain level of subsidy for solar PV is part of an electoral strategy, as it directly influences voters' utility function. The subsidy leaves room for convincing voters that are less ideologically inclined to vote for them, using a subsidy for solar PV as leverage.

In what follows, we show how the subsidy level announced by both parties is determined.

4.4 The equilibrium subsidy level

Suppose that the incumbent proposes subsidy S^1. We can then calculate the number of voters that will be gained and lost as a result of that subsidy proposal. The total number of voters that invest in a solar installation and vote for the incumbent equals area $A + C$ on figure 4. Area C represents those voters that ideologically favor the incumbent and have installation costs lower than the subsidy level. Area A represents those voters that would ideologically vote for the opposition, but are convinced with a subsidy to vote for the incumbent. For a fixed subsidy level, the stronger the ideological conviction of the voter, the lower the solar installation cost for the voter should be to convince him to vote for the incumbent. This linear relation This linear relationship causes area A to be a triangle.

The incumbent will lose area B by proposing subsidy level S^1. This area represents the voters that would ideologically vote for the incumbent, but have an investment cost that exceeds the subsidy level, making it more attractive for them to vote for the opposition. Voting for the incumbent would mean they finance the subsidies through a higher electricity bill, so they are better off without a subsidy and vote for the opposition.

The number of voters that will be gained with a subsidy S^1 is denoted $A\left(S^1\right)$ and the number of voters that will be lost is denoted as $B\left(S^1\right)$. This is graphically illustrated in figure 4. We introduce the monetary equivalent of the ideology parameter $\sigma\epsilon\left[-\frac{1}{2\phi}, \frac{1}{2\phi}\right]$: M. M is defined such that if the incumbent (opposition) would give an amount of M to the opposition (incumbent) voters, they would all vote for the incumbent (opposition). Building on this, α, as shown in figure

4, represents the amount that the incumbent would have to give to the opposition voter with the lowest installation cost, in order for that voter to elect the incumbent. α is defined as:

$$\alpha = \frac{1}{2}\frac{S - a + V}{M} \tag{8}$$

Where S is the subsidy, a the fixed installation cost, and V is a constant representing the consumer surplus advantage of consuming solar based electricity produced at home over buying electricity on the market:

$$V = CS(P = 0) - CS(P(0,0)) \tag{9}$$

The number of solar panels installed, $\widetilde{n}$, is such that

$$S - a - b\widetilde{n} + V = 0$$

which gives us

$$\widetilde{n} = \frac{S - a + V}{b} \tag{10}$$

Similarly, we define β as the amount the incumbent charges the incumbent voter[19] such that the incumbent (opposition) voters refrain from voting for their ideological candidate - the incumbent (opposition). β is defined as:

$$\beta = \frac{1}{2}\frac{M - \left[\frac{\widetilde{n}S}{N - \widetilde{n}}\right]}{M} \tag{11}$$

[19] Consider this amount to be the increase in the electricity bill of those consumers not installing solar panels.

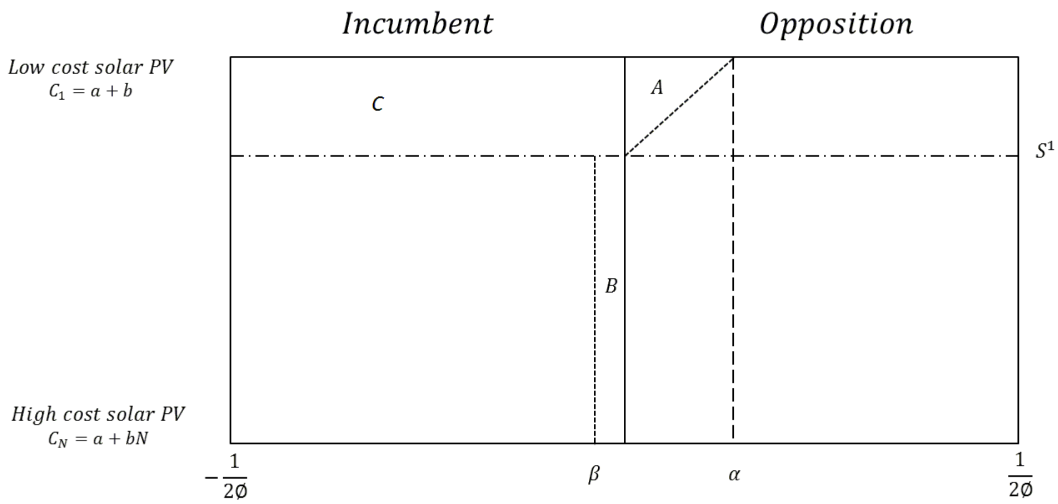

Figure 4: Incumbent proposes subsidy S^1

More generally, the incumbent chooses S in order to maximize the net gain in voters when introducing a subsidy, $A(S) - B(S)$. We have that the gain in voters equals

$$A(S) = \frac{\alpha \widetilde{n}}{2} \tag{12}$$

and the loss in voters equals

$$B(S) = \beta (N - \widetilde{n}) \tag{13}$$

Maximizing this difference gives us the optimal subsidy level:

$$S^* = \frac{M + a - V}{4} \tag{14}$$

The subsidy positively depends on the fixed cost of installation, a, and on the monetary value of ideology, M. The subsidy is negatively correlated with the consumer surplus advantage of consuming electricity produced with solar panels, V.

4.5 Properties of the equilibrium solar subsidy

We introduce the following propositions.

Proposition 2 *The more polarized is society, the higher the optimal subsidy needs to be.*

Indeed in the expression of the optimal subsidy level S^*, we can see that if M increases, S^* increases as well (by a factor of 0.25).

If the costs of solar technology are lower, which manifests as a horizontal shift downwards of the cost function $C_S = a + bi$, the total subsidy cost to convince a similar number of voters decreases. In fact we then get a new cost function: $C'_S = a' + bi$, with $a' < a$. Since the optimal subsidy level proposed by both the opposition and incumbent in equilibrium positively depends on the installation cost of solar PV, a lower installation cost results in a lower subsidy. This is formally stated in the following proposition.

Proposition 3 *The optimal subsidy level, for both the incumbent and opposition, decreases with the cost of technology, C_S.*

This last proposition is an argument in favor of gradually decreasing subsidy levels over time as solar technology improves. In order to study these dynamics in more detail, learning effects should be part of the analysis, but this goes beyond the scope of this paper.

5 Conclusion

Since the early years of support for solar PV, the technology has been allocated very high subsidies compared to other renewable technologies. This paper develops a political economy theory to explain the discrimination between different renewable technologies. We have shown that the design of a subsidy scheme favoring decentralized technologies (solar PV) relative to centralized technologies (wind, biomass) can increase election chances. It is in the interest of both the incumbent and the opposition to promise a subsidy for solar PV. The subisdy is used to convince those of the opposition's electorate whom are not strongly ideologically motivated. As the cost of solar PV technology decreases over time, due to learning effects, for instance, the level of subsidy that needs to be allocated per household is smaller.

Our theory is in line with stylized facts on subsidy schemes for renewable energy that can be observed in several European Union member states. Data on the support levels of different technologies clearly show the discrimination. The data certainly also indicate the possibility that discrimination between different renewable technologies has contributed to electoral victories in different European member states and regions.

In future research, it would be of great value to confront our model with data more directly, performing a comprehensive empirical study.

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