Mechanisms for Rebound Effects of Solar Electricity Prosuming in Germany: A Matching Approach

Tugba Atasoy, Hendrik Schmitz, Reinhard Madlener

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E.ON Energy Research Center
RWTH AACHEN UNIVERSITY

Central motivation

- How is energy consumption affected by switching to renewable energies?
- Possible unintended effects of subsidy schemes for solar PV on energy behavior
- Is there a rebound effect caused by prosuming?

Our research questions:

1. Are there differences in electricity consumption between prosumer and consumer households?

2. What are the mechanisms that explain these differences?
   - Different prices and incentive structures?
   - Different attitudes and opinions on environmental topics?
   - Different technical equipment (e.g. smart meters)?

Recent Literature

A few recent studies have addressed **Q1:**

- Qiu et al. (2019, JEEM)
  - They find that prosumers consume more on average; the effect persists after matching (rebound effect is ~ 18%)
- Frondel et al. (2020, USAEE Working Paper)
  - They find no strong evidence of rebound effects using data for Germany between 2000 and 2012
- Oberst et al. (2019, Ecological Economics)
  - They find that prosumers consume less before matching, but find no significant differences after matching

We provide additional evidence on **Q1**

To the best of our knowledge, no systematic research on **Q2** so far

Methodology

- The adoption decision for PV is clearly not random, which leads to selection bias

- The ideal setup would be to run a randomized controlled trial (RCT) with solar PV adoption at the household level
  1. Install PV systems on randomly selected households (prosumers)
  2. Randomly selected consumers for the control group
  3. Observe them over a long period of time
  4. Compare energy behavior of prosumers before and after adoption

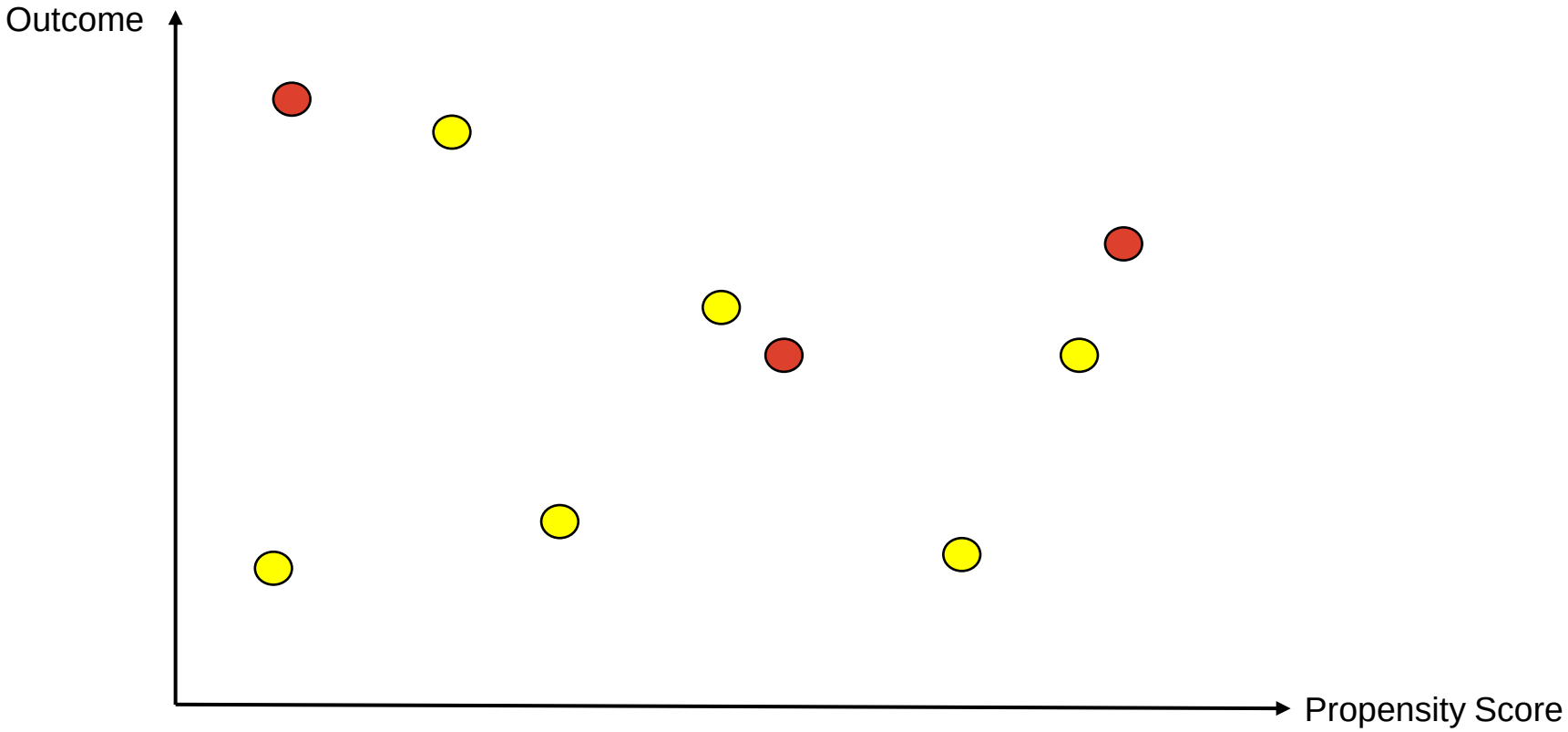
- This does not seem feasible due to ethical and legal limitations

→ We use a propensity score matching (PSM) approach to recreate a RCT

Main steps

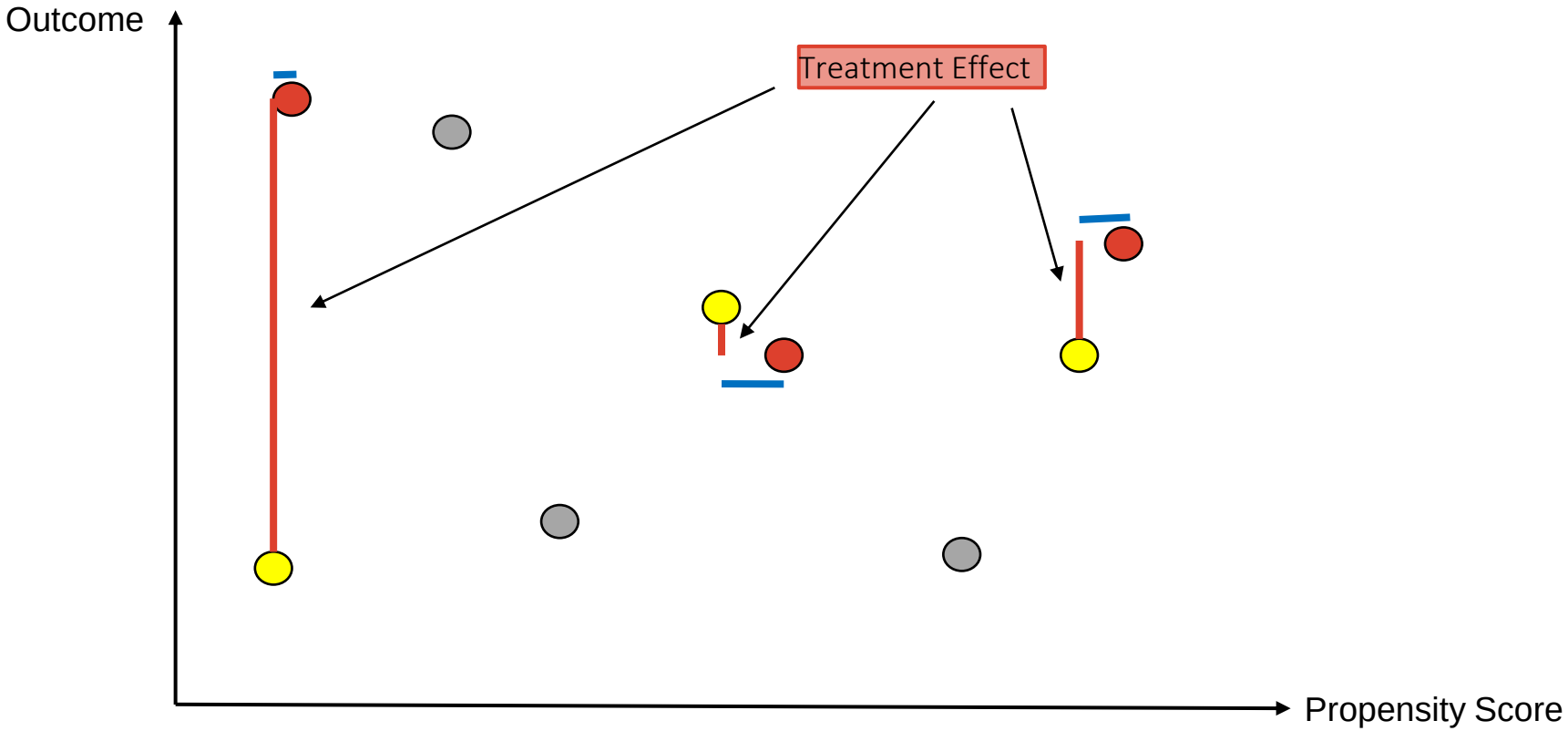
- Collect observational data on prosumers and consumers (treatment and control groups)
- Reduce dimensionality of covariates to a single value
  - This value is called the propensity score, defined as the probability of being treated
  - Can be estimated via a Logit or Probit regression
- Match each treatment observation to one control observation based on the propensity score
- Drop all unmatched control observations
- In the ideal case, the two groups are now much more comparable in terms of their covariate distribution
  - This significantly reduces selection bias

Propensity Score Matching
Visual example



- Red: treatment group
- Yellow: control group

Propensity Score Matching
Visual example



- Red: treatment group
- Yellow: control group
- Gray: unmatched (dropped) control observations
- Blue horizontal lines: difference in propensity score (to be minimized)

Data

- We designed an online survey that was conducted in 2020 in Germany
- Respondents are both prosumers (N = 297) and consumers (N = 1,291), homeowners only
- The questionnaire focused on three major channels

1. Informedness, consumption feedbacking

- Smart meters, how often they control their bills, etc.

2. Incentives and financial structures

- Installation year and size of PV system, electricity prices, electricity consumption in the previous year, other taxes and subsidies etc.

3. Environmental attitudes, preferences, and perceptions

- Political preferences, environmental preferences measures, perceived consumption etc.

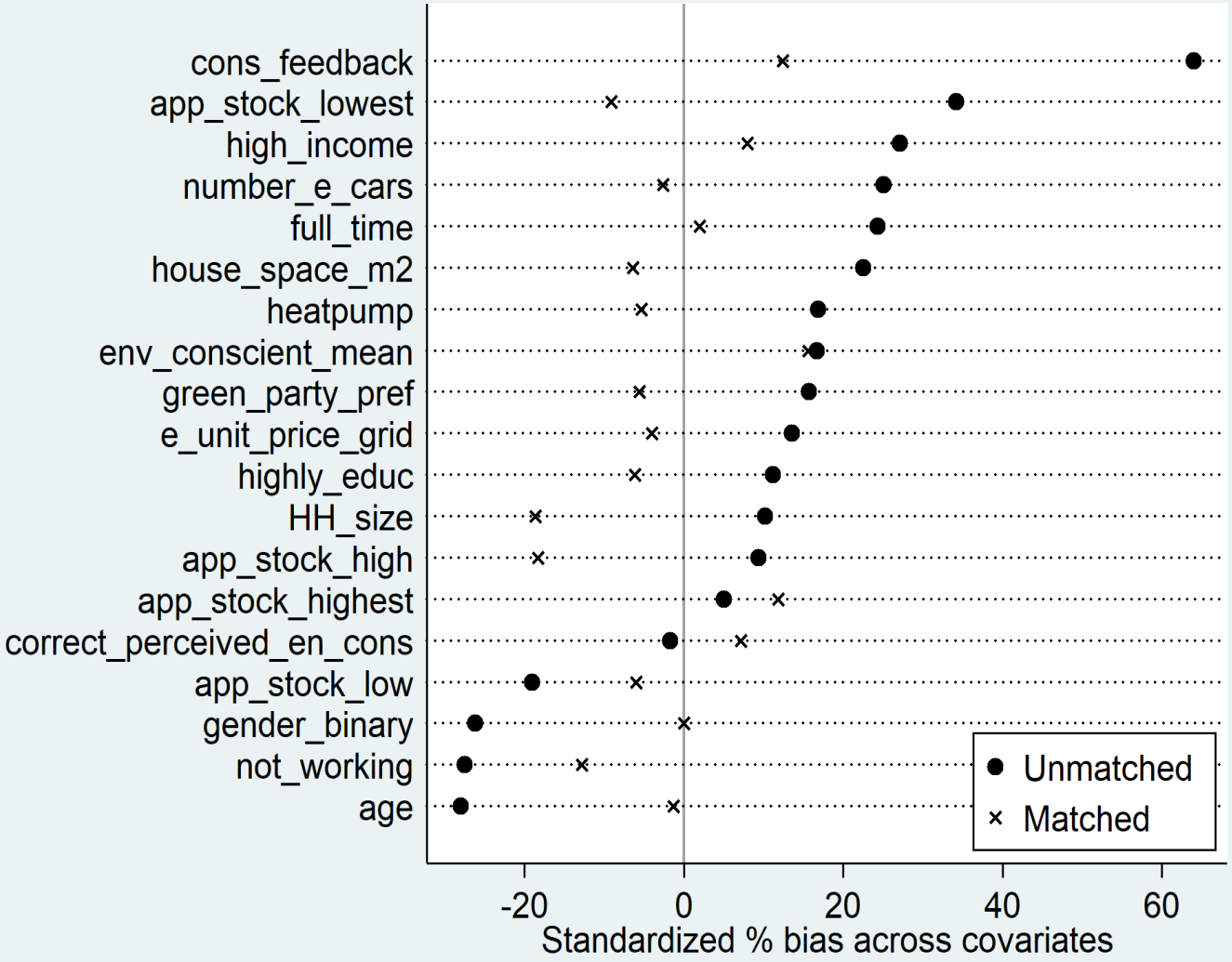
Descriptive Statistics

- Selection of variables before and after matching

Variable	Treatment	Control before matching	Control after matching
Age	52.60	56.05	54.32
# of people in HH	3.16	2.95	3.37
# of Electric vehicles	0.06	0.01	0.01
Heatpump, 1 = yes	0.29	0.21	0.24
Living space in m^2	156.04	143.76	155.52
Green party support, 1 = yes	0.18	0.12	0.15

- Differences between control and treatment groups are smaller after matching on average

Matching: Differences Between Prosumers and Consumers



Yearly electricity consumption on kWh

Effect	Prosumers	Consumers	Difference
Without matching	4,104	3,624	480***
ATT	4,104	3,772	332
ATU	3,624	3,641	17

*** = statistically significant

- ATT (Average treatment effect on the treated): If prosumers in the sample were consumers, they would consume 332 kWh more per year on average
- ATU (Average treatment effect on the untreated) : If the consumers in the sample were prosumers, they would consume 17 kWh less per year on average

→ After matching, the difference in consumption levels between consumers and prosumers is no longer statistically significant

Incentives for self consumption

$$C = p \cdot g + t \cdot s$$

C = Cost of electricity consumption
p = electricity price per kWh
g = amount of electricity consumed from the grid
t = Feed in tariff received per kWh
s = Self consumption amount in kWh

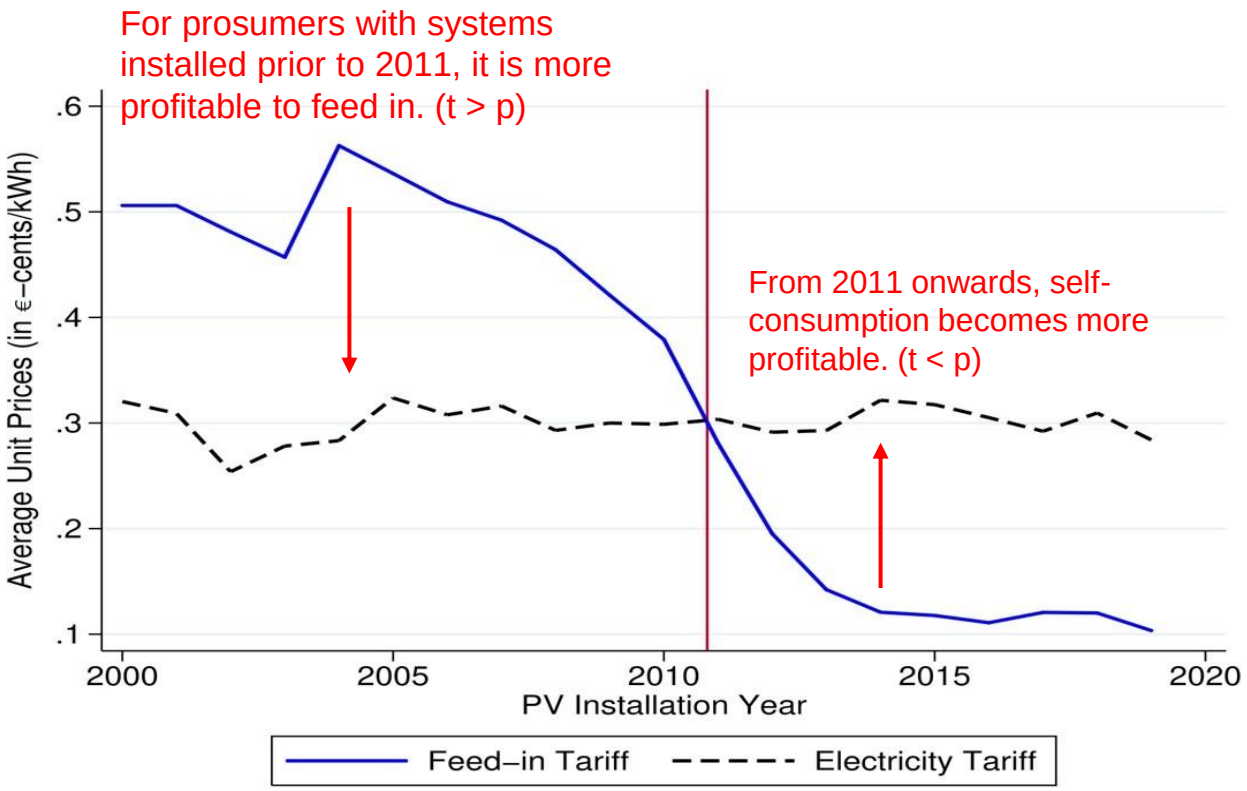
- Consuming one kWh from the grid has the cost p
- One additional kWh of self consumption has opportunity cost t

- If t > p, the incentive to consume is identical compared to consumers
  - In this case, prosumers should feed in 100% of their generation and consume only from the grid

- If t < p, the incentive to consume is higher compared to consumers
  - Incentive to maximize self consumption and also to increase total consumption

Prices and feed in tariffs

- Comparison of electricity price and feed in tariff in 2020, depending on the installation year



Prosumers pay an overall lower unit electricity price when self-consumption is accounted for

→ Solar PV adopters do not have the incentives to consume less if they installed after 2010/2011

Matching Results: Differences Between Prosumers and Consumers

Effect	Prosumers	Consumers	Difference
Full Sample			
Without matching	4,104	3,624	480***
ATT	4,104	3,772	332
PV System installed in 2011 or earlier			
Without matching	3,718	3,624	96
ATT	3,718	3,493	227
PV System installed after 2011			
Without matching	4,345	3,624	722***
ATT	4,345	3,670	676***

*** = statistically significant

- Prosumers who have installed their system after 2011 consume significantly more than consumers
- Unlike in the full sample and the pre-2012 sample, this effect persists after matching

Conclusions

- In the main model, the higher consumption of prosumers diminishes after matching
  - This suggest that prosumers do not consume more electricity because they are prosumers, but for other reasons
- Lower feed in tariff increases the incentive to self consume
  - This may also increase the incentive to consume more electricity in total
- Rebound effects seem to be induced by the regulation and the existing incentive structures
  - The data shows no significant differences in consumption before 2012

Next steps

- Which other factors can explain differences in electricity consumption?
- What are the policy implications with regard to emissions?

Thank you for your attention!

Atasoy A.T., Schmitz H., Madlener R. (2021). Mechanisms for Rebound Effects of Solar Electricity Prosuming in Germany, FCN Working Paper No. 7/2021, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June. (in preparation)

Contact:
Hschmitz@eonerc.rwth-aachen.de
Tatasoy@eonerc.rwth-aachen.de
Rmadlener@eonerc.rwth-aachen.de

BACK-UP SLIDES

Back-up Slides: Difference Between Prosumers and Consumers (w/o grid price)

Effect	Prosumers	Consumers	Difference	t-value
Without matching	3,995	3,598	397	2.83
ATT	3,995	3,750	245	1.07
ATU	3,598	3,821	223	-

- ATT: If prosumers in the sample were consumers, they would consume 245 kWh more in a year on average

- ATU: If the consumers in the sample were prosumers, they would consume 223 kWh less in a year on average

Short conclusion: After matching the difference is no longer statistically significant.

What are the reasons for observing a difference in total consumption?

Back-up Slides: Difference Between Prosumers and Consumers (w/o grid price)

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- ATT: If prosumers in the sample were consumers, they would consume 245 kWh more in a year on average

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Short conclusion: After matching the difference is no longer statistically significant.

Matching:Results without Self-Consumption

(Full Sample)

Effect	Prosumers	Consumers	Difference
Without matching	3,323	3,624	**-300*** **
ATT	3,323	3,772	**-448*** **

(PV Systems Installed Before and in 2011)

Without matching	3,347	3,624	-277
ATT	3,347	3,493	-146

(PV Systems Installed After 2011)

Without matching	3,309	3,624	**316**
ATT	3,309	3,670	**361**

Theoretical model for consumers

$$V = u \cdot g - p \cdot g$$

u = utility per kWh consumed
p = electricity price per kWh
g = amount of electricity consumed from the grid

- Consuming one kWh from the grid has the cost p
- Maximizing overall utility V leads to u = p (marginal benefits = marginal costs)
- Households choose the optimal value for g

Theoretical model for prosumers including self consumption tax or bonus

$$V = u \cdot q - p \cdot g + t \cdot f + b \cdot s$$

u = utility per kWh consumed
q = total electricity consumed
p = electricity price per kWh
g = amount of electricity consumed from the grid
t = Feed in tariff received per kWh
f = Feed in amount in kWh
s = self consumption amount in kWh
b = bonus/tax for self consumption per kWh

- Depending on the installation date, some prosumers get paid (b > 0) or taxed (b < 0) for their self consumption
- The new equilibrium condition is then t – b = p
- The bonus (tax) increases (decreases) the incentive to self consume

Theoretical model for prosumers

$$V = u_s \cdot s + u_g \cdot g - p \cdot g + t \cdot f$$

u = utility per kWh consumed
q = total electricity consumed
p = electricity price per kWh
g = amount of electricity consumed from the grid
t = Feed in tariff received per kWh
f = Feed in amount in kWh

- Consuming one kWh from the grid has the cost p
- One additional kWh of self consumption has opportunity cost t
- If t < p, the incentive to consume is higher compared to consumers
- If t > p, the incentive to consume is identical as for consumers