Three forms of energy prosumer engagement and their impact on time-shifting electricity consumption

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Abstract

Focusing on households' micro-generation, in this case solar photovoltaic (PV) systems, and the role as prosumers, this paper identifies three distinctive forms of engagement as energy prosumer. These forms are based on responses to statements on being prosumer, and refer to becoming (1) more environmentally conscious, (2) focused on own financial gain, and (3) less concerned about electricity consumption. By applying an ordered logistic regression, we investigate how these different types of engagement influence the self-stated tendency to time-shift electricity consumption according to peak loads in the energy system and to own electricity production.

We find that prosumers, who state that being prosumer make them more environmentally conscious, are more likely to time-shift electricity consumption according to peak demands in electricity grid as well as to own production. Prosumers, who express focus on own financial gain, seems more likely to time-shift according to own production, whereas prosumers, who state that they have become less concerned with own consumption, tend to time-shift less according to own production.

Furthermore, the results show that the accounting scheme ('hourly or immediate accounting' or 'annual accounting') has a strong impact on the tendency to time-shift. As could be expected, prosumers with hourly or immediate accounting, are much more likely to time-shift energy consumption to own production compared to prosumers with annual accounting.

This paper contributes with new knowledge on the extent to which having PVs, and being an energy prosumer, change and reconfigure the everyday practices of households. The findings suggest that how people see themselves as prosumers and engage in energy-consuming activities have an impact on the tendency to time-shift everyday electricity practices. Moreover, the results also problematize that the present available accounting scheme encourage prosumers to adjust everyday practices to own production, whereas from a system perspective, it would be more sustainable to adjust to the peak loads of the electricity grid.

Introduction

In a future energy system based on fluctuating renewable energy production such as wind and solar photovoltaic (PV), it becomes increasingly important that energy consumption is adjusted to the fluctuating patterns of production. One strategy to achieve this is to raise the energy awareness of the consumers by transforming them into engaged and active prosumers; A term that was originally coined by Alvin Toffler in the 1980s (Toffler, 1980), and refers to overcoming the general separation of consumption and production in the modern capitalist society. The term has, however, in recent years been introduced specifically within the energy agenda, as a termed used to describe consumers who produce energy themselves through micro-generations technologies, e.g. solar PV panels.

Studies show that being involved in energy production influences everyday life and that households with micro-generations technologies change their patterns of energy consumption. For example, a UK study by Keirstead (2007) indicates that PV systems encourage households to reduce their overall electricity consumption and time-shift to when generation peaks. Reid and Ellsworth-Krebs (2017) find that solar PV panels give households a sense of satisfaction by being involved in production of electricity or shifting electricity-consuming practices. Similarly, Christensen et al. (2017a) find high commitment to time-shifting electricity consumption among households that have installed solar panels. Together, these studies suggest that micro-generation technologies engage households in energy-saving activities and somehow encourage households to change patterns of consumption. Using the case of automated meter reading, Löfström (2014) also illustrates how a new technology in itself, rather than feedback and economic incentives, may lead to increased awareness and interest in energy consumption among the occupants, who thereby maybe become a more active and flexible part of the energy system.

However, households might engage as prosumers and become active in different ways, which might relate to their tendency to time-shift energy consumption practices. Theories of practices argue that shared, yet differentiated, engagement in practices can explain the processes and nature of consumption (Warde, 2005), and that technologies such as PVs can influence the engagement in practice and hence potentially reconfigure practices (Gram-Hanssen, 2010). In this paper, we, therefore, investigate the impact of different forms of engagement as prosumers on time-shifting of electricity consumption practices. Based on a representative survey of Danish households with solar PV panels, we use factor analysis to identify three forms of engagement as prosumer, and investigate the correlation with self-reported tendency to time-shift electricity consumption according to own production and to peak demands in the electricity grid. We control for impacts of solar panels characteristics (e.g. accounting scheme and size of the solar panel), general environmental concern, personal and household characteristics (e.g. gender of respondent, income, family composition), and house characteristics (e.g. building year, housing type) that presumably also relate to the tendency to time-shift electricity practices.

Individualistic approaches to energy consumption behaviour focusing on individual consumer choices have been criticized from a practice theoretical approach for not paying attention to the social and material configuration of human conduct (Shove, 2010; Southerton, 2013). Hence, instead of focusing on motivating the individual to make better choices by given the right information and economic incentives, practice theoretical accounts, in domains like energy consumption, argue for transforming collective everyday practices in order to achieve more sustainable consumption patterns (e.g. Shove, 2003). Most practice theoretical scholars suggest that practices are held together by recognisable and intelligible elements, denoted as some kind of combination of material objects, shared understandings and meanings or engagement (Gram-Hanssen, 2011, 2010; Shove et al., 2012; Warde, 2005). Where the individualistic approaches focus on stronger economic incentives and better information as a mean to change consumption patterns, the practice theoretical perspective points at technological innovations and cultural processes. For example, new technologies may reconfigure practices and thereby also energy consumption patterns (Gram-Hanssen, 2010), and Warde (2005) introduces processes like social differentiation as a change mechanism in which groups of people engage in the same practices in different ways.

Inspired by practice theoretical accounts, this article study how a micro-generation technology (in this case PV systems) can create different forms of engagement in energy consumption practices, which might influence the likelihood of time-shifting these practices.

The paper continues with presenting the data, variables and methods applied in the paper, which is followed by a presentation of the results, and finally the results are discussed.

Data, variables and methods

DATA

The analysis is based on a representative web survey among Danish households who have installed solar PV panels. The survey was conducted during the fall of 2018 and carried out by Statistics Denmark on behalf Aalborg University. 4,567 prosumers were selected out of a population of 72,900 Danish prosumers. 54.9 % responded, which gave 2,505 responses, but due to missing data on some questions, the number of observations in the models is 2,121 and 2,154. The survey data were combined with data from the Danish administrative registers and data from Energinet.dk. The survey focused on the everyday life of people living in households with PV systems.

DEPENDENT VARIABLES

In the survey, we asked the prosumers to what extent they time-shift their electricity consumption on hourly basis to the production of their own PV system, for example by time-shifting to daytime, and to the electricity peak demand, for example by time-shifting to night time.

Table 1 shows that a little more than one fourth of the prosumers responded that they do not adjust consumption to own production, whereas almost half responded that they do not adjust to peak demands in the electricity grid. Moreover, half of the prosumers stated that they adjust to own PV production to some or large extent, and very few did this for adjustment to peak demands (16.7 %).

Although the percentage of prosumers that state that they 'not at all' are time-shifting their electricity consumption seems high, the results indicate that prosumers are somewhat likely to adjust their electricity consumption, primarily to own production, but also to some extent to peak demands in the electricity grid.

These two variables are used as dependent variables in the analysis. However, we need to remove the 'Do not know' responses in order to transform them into ordinal variables that we are able to model using ordered logistic regression model. Such a model use a non-observable 'latent' variable y^* as indication of the responses to the ordinal variable, and thereby estimate the correlation between the dependent variable and independent variables (Wooldridge, 2010, p. 504). Thus, we use an ordered logistic regression to model the likelihood of time-shifting electricity consumption, and the coefficients can then be interpreted as in a binary logistic regression, for example using odds ratios.

FACTOR ANALYSIS AND EXPLANATORY VARIABLES

The explanatory variables is three forms of prosumer engagement. In order to identify these different forms of engagement, we apply a factor analysis with obligue promax rotation on a list of questions from the survey on how the respondents think

Table 1. To what extent do your household adjust your electricity consumption to … (N=2,533).

	… own PV production	…peak demands in electricity grid
To a great extent	22.0 % (556)	1.9 % (48)
To some extent	28.1 % (711)	14.8 % (374)
To a small extent	17.8 % (451)	31.8 % (805)
Not at all	28.2 % (713)	45.4 % (1,152)
Do not know	4.0 % (102)	6.1 % (154)

Table 2. Factor loadings after oblique promax rotation.

	Pattern matrix			Scoring coefficients		
How do you agree or disagree with the following statements? Having solar panels make me …	**1**	**2**	**3**	**1**	**2**	**3**
… keep an eye on whether the sun is shining	0.085	**0.623**	-0.051	0.175	**0.363**	0.010
… think of making money when I see the sun shining	0.017	**0.635**	0.053	0.131	**0.341**	0.085
… more environmentally conscious	**0.697**	-0.006	0.021	**0.356**	0.143	-0.013
… more aware of saving energy	**0.680**	0.049	-0.017	**0.386**	0.180	-0.039
… think less about what I use electricity for	0.022	-0.016	**0.647**	-0.016	0.044	**0.412**
… less aware of turning off unnecessary electricity consumption	-0.022	0.014	**0.641**	-0.030	0.050	**0.412**
*Proportion of variance accounted for **after** rotation*	*0.722*	*0.698*	*0.419*	*0.722*	*0.698*	*0.419*

Prosumers survey (N=2,413)

that being energy prosumer influences them. The questions were inspired by previous qualitative research on being energy prosumer. Thus, we used six question items from the a question battery, which ask "Having solar panels make me…" as the overall question and with the response categories being 'Strongly disagree', 'Slightly disagree', 'Neither agree or disagree', 'Slightly agree', and 'Strongly agree'. As with the dependent variables, it was necessary to remove the category 'Do not know' prior to performing the factor analysis to use them as ordinal variables.

Table 2 present the factor loadings (pattern matrix) and the scoring coefficients for each of the question items and the three factors identified after a factor analysis with oblique rotation using the promax rotation method. It shows that three interpretable factors can be detected and constructed into continuous variables using the regression scoring method (Thomson, 1951). These three factors were interpreted as *more environmentally conscious* (factor 1), *focused on own gain* (factor 2), *less concerned with electricity consumption* (factor 3). The pattern matrix shows that the three factors are all supported by relatively strong correlations (above 0.6) (Vaus, 2002).

As the promax rotation allows the three factors to correlate[i], the factors should not be seen as indicating separate types of prosumers, but merely indicating three distinctive forms of engagement that the prosumers' everyday practices are characterized more or less by.

CONTROL VARIABLES

The control variables used in the models include variables based on recoded survey questions, variables based on register data, and variables based on data from Energinet.dk.

The control variables were grouped in three categories. The first group was characteristics of the PV system. These included accounting scheme ('Hourly or immediate accounting' or 'Annual accounting'), size of the PV system (in kW), year of registration (with 'Before 2012' as reference category), household battery for energy storage. The second group was personal and household characteristics. These included gender (here as 'Male'), age, household income, technical education in household (e.g. electrician or engineer), highest attained education in household, and child (under 13 years) in household, teenager (13 to 19 years) in household. As electricity consumption is in most cases a household matter, these variables were at household level, where possible. In addition, we also controlled for self-reported general environmental concern (see Appendix I for further). The third group was dwelling characteristics. These included housing type, building period, electrical or hybrid car, air-condition, ground source heat pump system, air-to-water heat pump, air-to-air heat pump, electrical heating, and solar heating.

Unfortunately, it was not possible to get updated data from the registers. Therefore, data on income was from 2015 and data on education and houses was from 2017. The full list of control variables can be found in appendix II.

Analytical strategy

Following practice theoretical accounts, micro-generation technologies such as PV systems, can create different forms of engagement in energy consumption practices, and thereby reconfigure or change the timing and rhythm of everyday practices.

This paper investigates the extent to which time-shifting of electricity consumption according to own production and peak demands vary due to different forms of engagement as prosumer. However, as there is evidence suggesting that prosumers are socially different and live in different types of houses (Hansen et al., 2018), it is important to control for factors that might have an impact on the correlation between the explanatory variables and dependent variables. Such characteristics have also proven important for time-shifting energy consumption practices, for example controlling for children in the household is important because it is associated with the flexibility of everyday practices (Christensen et al., 2017; Nicholls and Strengers, 2015), and gender also seems to play an important role (Christensen et al., 2017).

Therefore, as illustrated in Figure 1, we investigate the correlation between engagement and time-shift of electricity consumption and control for PV characteristics as well as type of house and household. In the models this means that we model in two steps; first without control variables, and second, with control variables, to see if the estimates change.

Results

THREE FORMS OF ENGAGEMENT AND TIME-SHIFTING ELECTRICITY CONSUMPTION

As described in the section on dependent variables, we look at two different types of time-shifting; first, time-shifting according to peak demands in the electricity grid (Model I and II), and second, time-shifting according to own production (Model III and IV). For each dependent variable, we model in two steps; first, a model only with the different types of engagement (Model I and III), and second, a model that includes relevant control variables (Model II and IV). In the second step, we only present the reduced model, since the full model is very large.

Table 3 shows that prosumers who agree to a larger extent state that being prosumer make them more environmentally conscious are more likely to time-shift to peak demands in the electricity grid, but also to own production. The odds ratios (OR) are reduced from Model I to Model II, but still significant, when we control for general environmental concern and other characteristics. However, the OR increases from Model III to Model IV, when control variables are added to the model. This indicates that the direct correlation between engagement in the form of more environmentally conscious and time-shifting is strong, and not just a matter of general environmental concern or other conditions.

Table 3 also shows how engagement, in the form of being more focused on own gain, seems more likely to time-shift according to own production, whereas engagement in the form of less concerned with energy consumption are less likely to time-shift to own production. Finally, Table 3 shows that the models get a better fit when adding more variables because log likelihood increases from Model I to Model II and especially from Model III to Model IV.

Full models can be found in Appendix III. However, we highlighted two of the control variables of special attention. Self-stated environmental concern is a measure indicating how much the prosumers in general are concerned by environmental issues (see Appendix I for details). This is relevant to distinguish between being environmentally concerned in general, and consider oneself increasingly environmentally conscious by being prosumer. As expected, it shows that being generally environmentally concerned is related positively to both time-shifting to peak demands and own production.

Accounting scheme is also showed in Table 3 with a very strong correlation with time-shifting according to own production. Thus, prosumers with hourly or immediate accounting of the difference between production and consumption compared to annual accounting are 12.08 times more likely to adjust electricity consumption according to own production to a larger extent, given that all of the other variables in the model are held constant. This is expected as the accounting scheme may reflect different meanings of energy consumption practices, where the prosumers that are accounted hourly or immediately have a stronger incentive to consume energy when the sun is shining and the PV system is producing electricity compared to those that are annual accounted. Moreover, we control for differences in socio-demographic characteristics (e.g. household income, gender, age, family type), and house characteristics (e.g. building year, housing type in the models).

Discussion and conclusions

The results show that approximately two third of Danish PV owners state that they time-shift electricity consumption to adjust to production of their own PVs and approximately half of them time-shift to adjust to peak demands in the energy system. However, this also point out that a little more than one fourth never adjust to own production, and almost half of the prosumers do not adjust electricity consumption to peak demands in the electricity grid.

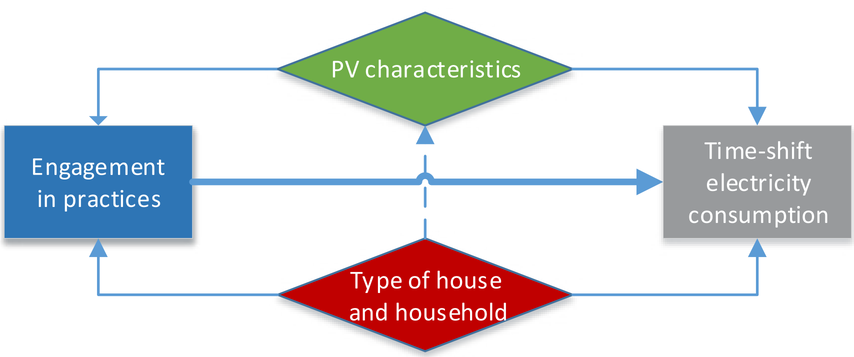

Figure 1. Analytical strategy.

Table 3. Ordered logistic regression on the correlation between forms of engagement as prosumer (factors) on self-reported time-shifting of electricity consumption according to peak demand in the grid (a) and to own production (b). Odds ratios reported. See Appendix III for full model.

	Peak demand in grid (a)		Own production (b)	
	Model I	**Model II**	**Model III**	**Model IV**
Forms of engagement as prosumer				
1. More environmentally conscious	1.814***	1.562***	1.413***	1.701***
	(0.215)	(0.196)	(0.159)	(0.213)
2. Focused on own gain	0.878	0.921	1.956***	1.546***
	(0.107)	(0.117)	(0.228)	(0.196)
3. Less concerned with energy consumption	1.073	1.084	0.727***	0.802***
	(0.0712)	(0.0737)	(0.0463)	(0.0543)
Environmental concern		1.246***		1.154***
		(0.0705)		(0.0637)
Hourly or immediate accounting		1.073		12.08***
		(0.249)		(2.803)
PV controls	NO	YES	NO	YES
Personal and household controls	NO	YES	NO	YES
House controls	NO	YES	NO	YES
Number of observations	2,121	2,121	2,154	2,154
Log likelihood	-2,233	-2,202	-2,765	-2,388

*Standard deviation in parentheses, *** p<0.01, ** p<0.05, * p<0.1. YES and NO refer to whether the controls are included in the model or not.*

Based on a factor analysis of survey data, we identified three forms of engagement as energy prosumer. These refer to being 1) more environmentally conscious, 2) focused on own financial gain, and 3) less concerned about electricity consumption.

Looking at the correlation between these forms of engagement and the tendency to time-shift electricity consumption practices, we show that prosumers who state that being prosumers make them more environmentally conscious are more likely to time-shift according to peak demands in the electricity grid as well as to own production. Prosumers that to a higher degree state they are focused on own financial gains are also more likely to time-shift according to own production, whereas households that state they have become less concerned with electricity consumption as prosumer are less likely to time-shift according to own production.

Furthermore, the results shows that the accounting scheme is an important factor in order to time-shift electricity consumption practices according to own production. Prosumers, who are hourly or immediately accounted for the difference between production and consumption instead of annual accounted, seems much more likely to time-shift consumption practices according to own production. This suggests that the accounting scheme, and thereby the potential economic gains of consuming own electricity, change the meanings of time-shift practices and thereby the daily rhythm of everyday routines. However, the difference between the accounting schemes might also relate other factors related to the way of accounting and giving information about consumption and production. As regards time-shifting electricity consumption, this is interesting as it indicates a quite high interest in changing rhythms of practices. However, from an overall system and sustainability perspective, it is more desirable if prosumers time-shift according the peak loads of the grid rather than to their own production. This (unintended) incentive of the accounting scheme thus seems to promote an unwanted time-shifting from a sustainable perspective. Changing the economic incentive may work for own gain, but it does not necessarily make the practices performed by prosumers more in line with what is good for the system, e.g. to avoid peak demands in the electricity grid.

This paper indicates that there are different ways of practicing energy prosumption and engaging as energy prosumer, and that these relate to the tendency to time-shift electricity practices. Therefore, having a PV system installed does not necessarily in itself activate consumers, but some probably will become more environmentally conscious, and thereby be more likely to actively engage in time-shifting practices according to peak demands in the grid. Consequently, campaigns and information directed energy prosumers might benefit from taking into account that energy prosumers engage in different ways and practice prosumption accordingly. However, as this paper also show that accounting scheme is the most influential factor, information campaigns might not be as effective as changing the meanings of practices in order to get households to time-shift everyday practices, for example by develop clear incentives to how to perform practices.

Generally, it seems that the PV systems have the potential to engage and activate energy consumers in very different ways with very different outcomes, and that time-shifting everyday practices to peak demands in the electrictiy grid mainly relates to how environmentally conscious the prosumers are or have become by getting PV systems.

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Endnotes

[i] Especially factor 1 and factor 2 correlate strongly, but factor 2 and factor 3 also correlate significantly.

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Appendix I. Environmental concern factor

To construct a measure of general environmental concern, we conducted a factor analysis on three question items from the survey. The response categories of the questions were 'Not at all', 'To a lesser extent', 'To some extent', and 'To a large extent'. The factor analysis showed that all three question items correlate with the underlying factor, which we interpreted as environmental concern.

Table I. Factor loadings.

	Pattern matrix	Scoring coefficients	Uniqueness
To what extent does it matter to you that Denmark's climate effort is among the most ambitious in the world?	0.689	0.290	0.526
To what extent do you personally feel obliged to do something for a sustainable future?	0.782	0.442	0.388
To what extent are you willing to change your current lifestyle in favor of the environment?	0.675	0.276	0.545

Prosumers survey (N=2,353)

Appendix II. Control variables

Table II. Control variables in the models.

PV characteristics	
E	Hourly or immediate accounting (instead of annual)
E	Size of PV system (kW)
E	Year of registration
S	Household battery for energy storage
Personal and household characteristics	
S	Male
R	Age
R	Household income
R	Technical educated in household
R	Highest attained education in household
R	Child (under 13 years) in household
R	Teenager (13 to 19 years) in household
House characteristics	
R	Housing type
R	Building period
S	Electrical or hybrid car
S	Air-condition
S	Ground source heat pump system
S	Air-to-water heat pump
S	Air-to-air heat pump
S	Electrical heating
S	Solar heating

Note: Variables based on survey data is marked with S, variables based on register data is marked with R, and variables based on data from Energinet.dk is marked with E.

Appendix III. Full models

Table III. Full Table 3: Ordered logistic regression on the impact of ways of practicing prosumption (factors) on self-reported time-shifting of electricity consumption according to peak demand in the grid or to own production. Odds ratios reported.

	Time-shift to peak demand in grid		Time-shift to own production	
	Model I	**Model II**	**Model III**	**Model IV**
Change in engagement as prosumer (factor analysis)				
1. More environmentally conscious	1.814*** (0.215)	1.562*** (0.196)	1.413*** (0.159)	1.701*** (0.213)
2. Focused on own gain	0.878 (0.107)	0.921 (0.117)	1.956*** (0.228)	1.546*** (0.196)
3. Less concerned with energy consumption	1.073 (0.071)	1.084 (0.074)	0.727*** (0.046)	0.802*** (0.054)
Environmental concern		1.246*** (0.071)		1.154*** (0.064)
PV characteristics				
Hourly or immediate accounting (instead of annual)		0.915 (0.194)		10.87*** (2.321)
Size of PV system (kW)		0.990 (0.036)		1.027 (0.037)
Year of registration (Ref. "Before 2012")				
2012		1.183 (0.321)		2.155*** (0.634)
2013		1.217 (0.376)		2.096** (0.688)
2014		1.322 (0.466)		2.346** (0.864)
2015		1.589 (0.547)		1.931* (0.694)
2016		1.541 (0.560)		2.041* (0.771)
Household battery for energy storage		1.283 (0.271)		0.935 (0.190)

The table continues on the next page … →

Table III. Full Table 3: Ordered logistic regression on the impact of ways of practicing prosumption … (continuation).

	Time-shift to peak demand in grid		Time-shift to own production	
	Model I	**Model II**	**Model III**	**Model IV**
Personal and household characteristics				
Male		0.948 (0.089)		0.886 (0.083)
Age		1.014*** (0.005)		1.015*** (0.005)
Household income		1.000 (0.000)		1.000*** (0.000)
Technical educated in household		0.929 (0.098)		0.907 (0.094)
Highest attained education in household (ref. “Elementary or high school”)				
Vocational		1.314 (0.257)		1.139 (0.216)
University college		1.249 (0.241)		0.810 (0.152)
University		1.199 (0.251)		0.879 (0.182)
Child (under 13 years) in household		1.534*** (0.225)		1.001 (0.144)
Teenager (13 to 19 years) in household		0.983 (0.124)		0.955 (0.118)
House characteristics				
Housing type (Ref. “Single-family dwelling”)				
Terraced house		1.443 (0.345)		0.556** (0.137)
Farm house		0.771* (0.106)		1.074 (0.145)
Building period (Ref. “Before 1961”)				
1961–1978		0.921 (0.099)		0.988 (0.106)
1979–2006		1.027 (0.125)		1.120 (0.136)
After 2006		0.907 (0.143)		0.945 (0.150)
Electrical or hybrid car		1.405* (0.283)		1.371 (0.278)
Air-condition		1.106 (0.129)		1.152 (0.134)
Ground source heat pump system		1.343** (0.191)		1.059 (0.150)
Air-to-water heat pump		1.155 (0.160)		0.901 (0.126)
Air-to-air heat pump		0.961 (0.121)		1.069 (0.131)
Electrical heating		1.105 (0.159)		0.824 (0.118)
Solar heating		1.309** (0.169)		1.190 (0.154)
Cut point 1	0.937 (0.042)	3.352** (1.644)	0.372*** (0.019)	3.361** (1.683)
Cut point 2	5.072*** (0.297)	18.84*** (9.309)	0.918* (0.042)	10.92*** (5.498)
Cut point 3	65.46*** (11.35)	248.6*** (129.7)	4.007*** (0.219)	76.43*** (38.90)
Number of observations	2,121	2,121	2,154	2,154
Log likelihood	-2233	-2202	-2765	-2388

Standard deviation in parentheses, *** p<0.01, ** p<0.05, * p<0.1