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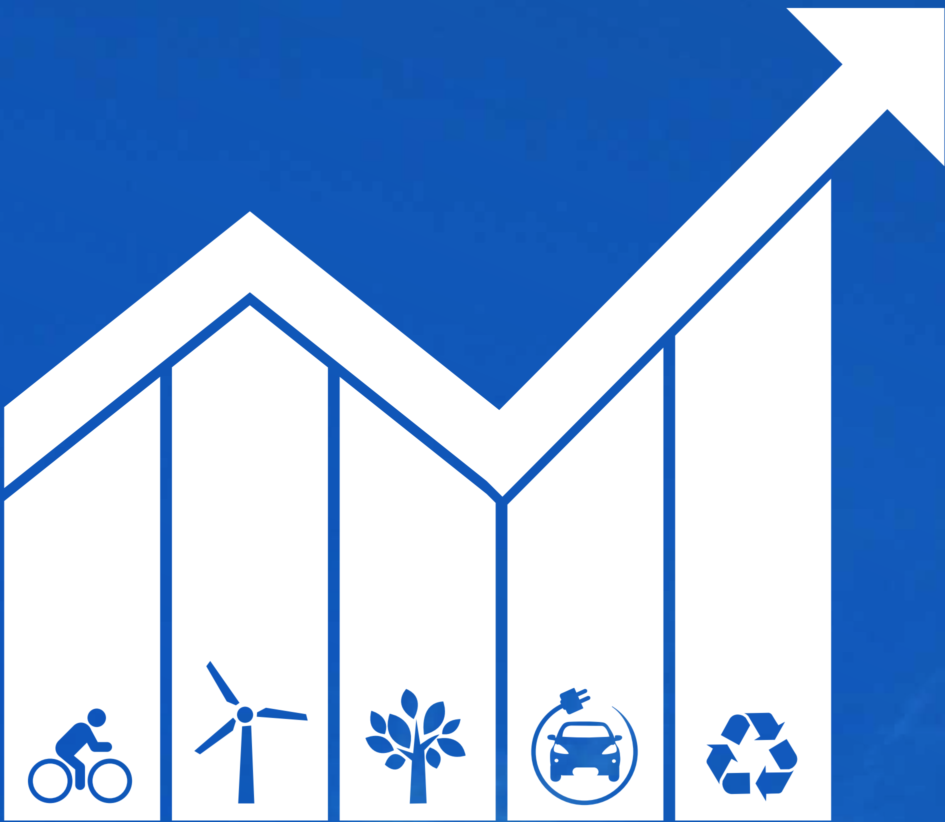

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THE DIFFUSION OF SOLAR PANELS IN GERMANY, SPAIN AND THE NETHERLANDS

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ABSTRACT

This paper empirically examines what drives the diffusion of solar panels in Germany, Spain and the Netherlands. We look at institutional processes that shape firms' behaviour with respect to the generation of sustainable innovations as well as cost-benefit considerations of consumers in purchasing the innovations. Key contributions of the paper are the connection between economics and institutional theory in explaining diffusion, and the novel method for quantification of institutional processes. We find that next to energy payback time play, mimicry amongst solar companies plays an important role in the diffusion of solar panels, whereas other institutional processes seem to play a lesser role.

KEYWORDS: innovation, technology diffusion, energy-efficiency paradox, institutional change, sustainability

INTRODUCTION

The question 'what drives the diffusion of sustainable innovations?' is an important one. Policy makers around the world have set sustainability targets. Sustainable innovations such as energy-saving technologies can play an important role in achieving the goals. However, these targets are difficult to attain. The adoption of energy-efficient technologies is usually slower than could be expected from straightforward cost-benefit analysis (Blok, Groot, Luiten, & Rietbergen, 2004). These technologies, though appearing to be attractive on the basis of net present value calculation, may not be adopted in practice, or only after considerable delays (Groot, Hofkes, Mulder, & Smulders, 2004). This phenomenon is known as the energy-efficiency paradox (Shama, 1985).

This paper empirically examines what factors drive the diffusion of sustainable innovations.[1] The paper analyzes the impact of institutional processes shaping firms' behaviour with respect to the generation of sustainable innovations. Institutional processes are the deeper and more resilient aspects of social structure: the processes by which, e.g., norms, values and habits become established as authoritative guidelines for behaviour (Scott, 2004). Institutional theory is not traditionally applied in innovation studies: its main conceptualization is as a theory of stability rather than change. However, institutional theory is strong in explaining isomorphic change, i.e., the process by which actors within the same field adopt novelty in similar ways (Dimaggio and Powell, 1983). In other words, it explains how innovation diffusion accelerates through different and often complementary isomorphic processes. DiMaggio and Powell (1983) describe how adoption of novelty takes place through processes of coercive isomorphism resulting from, e.g., governments' rules and regulations; normative isomorphism initiated by processes of professionalization and knowledge exchange; and mimetic isomorphism between actors looking for 'the seemingly best thing to do' under conditions of uncertainty.

[1] We define innovation as the generation, acceptance and implementation of new ideas, processes, products or services (Thompson, 1965), with 'sustainable' referring to the fact that these innovations should reduce the negative impacts, or increase the benefits, to people, planet and profit (Hart, 1995).

This paper analyzes the effect on diffusion from different types of institutional pressure. Mizruchi and Fein (1999) find that out of 160 studies in institutional theory, only two operationalize all three forms of institutional isomorphism distinguished by DiMaggio and Powell. Mizruchi and Fein's principal objection is that "the focus on one isomorphic process leads to a failure to consider that an alternative process might be operative" (1999: 664). This criticism is in line with DiMaggio and Powell's (1983) observation that the mechanisms of isomorphism are not necessarily independent: each is a separate process, but there will also be interactions between processes. Hence, a complete and integral picture of the (interactive) effect of various institutional pressures is lacking.[2] As stated by Heugens and Lander (2009: 76), "researchers have only barely begun to understand the field-level mechanisms through which isomorphic pressures accelerate and co-ordinate collective action."

We examine the role of institutional processes on the basis of the 'Waves of Change Database' (Klein Woolthuis, 2014). The database combines time series on the diffusion – in terms of sales or installed capacity – of electric cars, solar panels and energy-efficient lighting in Germany, Spain, the Netherlands and the UK. The explanatory variables, i.e., the institutional pressures leading to, or hampering diffusion, have been operationalized and coded over a period from roughly 1990 to 2013, leading to a database of around 5000 historical events.

This paper examines the diffusion of solar panels in Germany, Spain and the Netherlands. Previous studies on the success of wind turbines, focused mainly on field actors in promoting the new technology (Garud & Karnoe, 2003; Wesley D. Sine & Brandon H. Lee, 2009). Being a consumer product, the diffusion of solar panels depends strongly on consumers as well, and makes it possible to examine the role of (microeconomic) cost-benefit considerations by consumers and explanations from institutional theory in a

[2] Competitive pressures have not at all been considered in these studies (Mizruchi and Fein, 1999). Yet, DiMaggio and Powell (1983) start their article with competitive isomorphism as a driver of change. Institutional isomorphism is introduced as complementing the 'invisible hand'. DiMaggio and Powell argue that especially in the early phases of an innovation's diffusion, as well as in fields with free and open competition, market competition, niche change, and fitness measures, play a large role. Institutional processes become more important as the innovation spreads.

complementary fashion. The link between economics literature and institutional theory in explaining the diffusion of sustainable innovation and institutional change has so far been ignored.

The remainder of this paper is organized as follows. In section 2 we discuss the existing literature on the diffusion of new technologies. We also develop a number of hypotheses regarding the effect of different types of institutional pressure on diffusion. Section 3 describes the method used for empirical analysis, and section 4 the estimation approach. The main results from our regressions are given in section 5. Section 6 concludes.

THEORY AND HYPOTHESES

The diffusion pattern of new technologies is often S-shaped: adoption increases at a slow pace when a technology has just been introduced; after the initial period the rate of increase picks up. When time has elapsed and the market is nearly saturated, the rate of increase falls again (Rogers, 1962).

In the economics literature, the focus in innovation diffusion is on choices by individual adopters (consumers), based primarily on relative prices and information. The literature distinguishes by and large two explanations for the S-shaped diffusion pattern. Epidemic models (see, e.g., Griliches, 1957; Stoneman, 1983) emphasize the importance of endogenous learning effects and/or information. Knowledge about a new technology, or its potential savings, is considered to be limited on the outset of the diffusion. Yet, as more adopt the technology, more learn about the new technology (by word of mouth or demonstration) through contact with adopters. They may subsequently adopt the technology as well. Probit or rank models (see, e.g., Karshenas and Stoneman, 1995) combine heterogeneity among adopters with the gradual improvement of the technology over time. This leads to different adoption dates (Stoneman, 2002). In the early stages of development of the technology only actors (here consumers) with relatively high returns from adoption will adopt. As the technology improves (in terms of performance or lower costs), actors with lower returns will also adopt.

From an institutional theory's perspective, the focus is on the processes by which actors in the same field adopt novelty in similar ways. Institutions are the conscious and unconscious rules, such as routines, shared opinions, and explicit rules, that guide behaviour. This paper focuses on institutional processes shaping firms' behaviour with respect to adopting, i.e., generating, sustainable innovations.

DiMaggio and Powell (1983) emphasize **professionalization** as a process that drives isomorphic behavior to adopt novelty. Professionalization is the process by which actors merge towards similar worldviews through, e.g., education, socialization, and through interaction with others (Dimaggio & Powell, 1983). If such a worldview is supportive of a sustainable innovation, professionalization will help the innovation diffuse. Several routes for professionalization have been distinguished in the literature. Professionals can contribute to the creation of new technical and behavioural norms in a field by introducing new norms and standards (Bansal, 2005). Similar pressures result from the development and publication of new insights and knowledge, such as status reports, market reviews, or special issues in leading journals on socially responsible behaviour (Campbell, 2007; Scott, 2008). Norms are strengthened if publicly expressed expert opinions support new development – for instance, where engineers and scientists push for better environmental practices (Matten & Moon, 2006; Radaelli, 2000; Sharfman, Ellington, & Meo, 1997) – and when knowledge is extensively shared in personal networks, conferences and stakeholder meetings (Van Everdingen & Waarts, 2003). Training and education, e.g., through the development of new curricula or in-company training, also contribute to institutionalizing new norms through the process of professionalization (Campbell, 2007; Dimaggio & Powell, 1983). In a similar fashion, the spread of management models (Rao & Sivakumar, 1999), such as the 'Cradle to Cradle' philosophy, spur companies to change. Through, e.g., rankings and benchmarking companies are compared with regard to their sustainability performance (Sustainable top 50, Dow Jones Sustainability Index), and stimulated to take up innovations (Scott, 2008).

Hypothesis 1: *Professionalization increases the rate of sustainable technology diffusion.*

Mimicry is a response to uncertainty, which makes a particular organization mimic behaviour of more successful organizations. "When organizational technologies are poorly understood (March and Olson, 1976), when goals are ambiguous, or when the environment creates symbolic uncertainty, organizations may model themselves on other organizations" (Dimaggio and Powell, 1983: 151) to be "no better or worse than any organization" in the field (Kondra and Hinings, 1998: 745-8). The wider practices are spread through a field, the greater the pressure to conform, by which this pressure becomes self-reinforcing as it leads to rationalized standard practices (Leblebici, Salancik, Copay, & King, 1991). An increase or decrease in the number of innovations is a signal as to the direction that the front-runners are moving in. This can be through companies announcing new products or showing prototypes at tradeshows (Burns & Wholey, 1993; Haunschild & Miner, 1997). The more firms adopt, and the more successful in doing so, as measured in terms of capacity build up (hiring employees) and profitability, this will stimulate others to model themselves on this success (Haveman, 1993). The same happens when more prestigious firms adopt an innovation, or when emerging firms become more prestigious. This increases the legitimacy and visibility of new solutions (Burns & Wholey, 1993).

DiMaggio and Powell (1983) acknowledge field connectivity as an important predictor of mimetic isomorphism, as networks are an important vehicle for exchanging and structuration. Hence, if the degree of industry interconnectedness increases – e.g., through interlocking directories or inter-firm partnerships – this will also increase mimetic pressures (Palmer, Jennings, & Zhou, 1993; Ramanath, 2009).

Hypothesis 2: *Mimicry increases the rate of sustainable technology diffusion*

More recent work on institutional theory focuses on how novelty can be created and stimulated by **institutional entrepreneurship**, i.e., the process in which entrepreneurs, large organizations, NGO's or other actors create an impetus for change by individual and/or collective action (Battilana, Leca, & Boxenbaum, 2009; Dimaggio, 1988; Greenwood, Suddaby, & Hinings, 2002; Leblebici et al., 1991). Such actions can be in response to developments as they evolve, e.g., jolts (Sine & David, 2003), in anticipation of new, expected institutions such as future rules and regulations, or because they are convinced that it is 'the right thing to do' (Bansal and Roth, 2000). With their actions, institutional entrepreneurs contribute to the establishment of new institutions (Klein Woolthuis 2013).

Important activities of institutional entrepreneurs are framing and theorizing, the development of new business models, development of new knowledge and technological standards, and for instance lobbying ((Henriques & Sadorsky, 1996; Oliver & Holzinger, 2008). Companies can either do this individually, or through industry associations (Campbell, 2007; Delmas & Toffel, 2004) or by forming coalitions (Garud & Karnoe, 2003). Another way is self-regulation. In this case members of industry install voluntary standards instead of being forced to do so by the state. For instance, they set standards on fair practices, product quality or workplace safety. Good examples are Cradle to Cradle and LEEDS certification in the construction industry (Senge, Smith, Kruschwitz, Laur, & Schley, 2008). These industry-based certification systems provide strong technical and behavioural norms that can pave the way for, e.g., wider industry adoption or more stringent government regulation, thereby increasing the pace of technology diffusion.

Hypothesis 3: *Institutional entrepreneurship increases the rate of sustainable technology diffusion*

Another growing body of literature in the field of institutional theory looks at the role of **social movement** in stimulating societal change and sustainability (De Bakker & Den Hond, 2008a; Senge et al., 2008). Recent studies have investigated the influence of consumers, citizens and NGOs on corporations in general, and more specifically on the adoption of sustainable innovations (de Bakker & den Hond, 2008b). These social movements can be defined as (loosely) organized yet sustained effort in support of a social or environmental goal, and the embedding of this in society's institutions. The essence of social movement is that actors clarify their wishes, demands, expectations and dislikes and thereby influence the institutions that guide behaviour. As such, they can influence other actors directly and indirectly to adopt innovations. For instance, the public can call attention to certain topics or expressing dismay at undesirable behaviours (Greening & Gray, 1994; Rao & Sivakumar, 1999). This can be done, e.g., by organizing campaigns directed at companies, consumers or 'the system' (Etling et al., 2010; Campbell, 2007; Stolle et al., 2005), or through information disclosure (Ramanath, 2009; Stolle, Hooghe, & Micheletti, 2005). Through advocacy the public and NGOs can, just like industry actors, attempt to influence political decisions to introduce rules and regulations that favours the adoption of sustainable innovations. They can invite politicians to their meetings, give speeches, and organize social meetings to influence opinions and build towards new norms (Doh & Guay, 2006; Ramanath, 2009).

NGOs and companies can also work together in NGO/corporate partnerships to help establish new norms (Senge et al., 2008) or work with governments to do so (Ramanath, 2009). Lastly, customers can enforce adoption of new models by political consumerism, as seen, e.g., in buycotts or boycotts. Buycotting refers to the increased buying of particular products by consumers, whereas boycotting refers to abstaining from buying in order to express certain preferences or ethics (de Bakker & den Hond, 2008b; Greening & Gray, 1994; Micheletti, 2003; Sharfman et al., 1997). Through shareholder activism, members of the public can obtain shares in corporations and file shareholder resolutions at a firm's meetings (De Bakker & Den Hond, 2008a) and in that way can directly influence decision-making processes.

Hypothesis 4: *Social movement increases the rate of technology diffusion*

In this paper we do not test the effect of government interventions on diffusion. This is because, in terms of the diffusion of innovations, the role of governments is an indirect one. Governments do not influence the diffusion of innovations directly, but indirectly through the stimulation of industry (inter)action, stakeholder dialogue, or customer demand. For this reason, we do not formulate hypotheses regarding government actions here. In our discussion we do pay attention to this.

DATA

The data for this research comes from the Waves of Change database (Klein Woolthuis, 2014). For the analysis in this paper we chose solar panels as representation of the sustainable technology. Solar panels are consumer products and hence the diffusion is dependent on actions taken by all actors, including consumers, or 'the public'. This would not be the case for the diffusion of, say, wind turbines; these are seldom purchased by individual consumers. Moreover, the innovation can be considered roughly the same for all three countries, as the technological maturity of the products is the same across the countries. Lastly, solar panels do not require additional infrastructure. Electric cars, e.g., require charging points, the availability of which may affect their diffusion. The model specification for solar panels used in the empirical analysis in Section 4 is therefore relatively simple.

Below, we describe the construction of the database and its descriptive statistics relating to the diffusion of solar panels.

First, an extensive literature survey was conducted to identify the activities constituting the processes. The data consists of archival data such as news releases, secondary research reports, annual reports, and official government publications on solar panels in each country.[3] The data were gathered by native speakers to ensure that articles were fully understood and could be placed within the context of the country concerned.[4] The time frame is 1989 to 2012. A broad range of data sources was chosen to prevent reporting bias and to allow for triangulation (Saunders, Thornhill, & Lewis, 2009).

The data events were coded and analyzed using process analysis (Langley, 1999). This approach allows us to collect comparative and contextual data (Saunders et al., 2009). To verify the reliability of the coding process, an inter-rater reliability test was conducted to determine the degree of agreement among multiple observers. The Kappa score was 0.76, indicating substantial reliability (Landis & Koch, 1977). The institutional processes are operationalized as events that influence the diffusion of innovation in a non-financial way, those influences other than price that guide behaviour of actors in the field. In our study, we examine the effect of professionalization, mimicry, institutional entrepreneurship and social movement. Below we describe how these processes were operationalized on the basis of previous literature.

Professionalization is defined as the process by which actors merge towards similar worldviews through education, socialization, and, e.g., through interaction with others (Dimaggio & Powell, 1983). Hence, it defines what is (non) norm behaviour and what is technically feasible from a professional point of view. The professionalization process is operationalized by activities of knowledge development, knowledge sharing and expression of expert opinions (Campbell, 2007; Scott, 2008), training and education (e.g., development of new curricula at universities, but also in-house training (DiMaggio and Powell, 1983), introduction of new norms and standards (Matten & Moon, 2006; Radaelli, 2000; Sharfman et al., 1997), the spread of new knowledge/sustainable management models (Van Everdingen

[3] Using solely secondary sources has both advantages and disadvantages (Saunders et al., 2009). An advantage is that fewer resources in terms of time and money are needed than when gathering primary data (Ghauri and Grønhaug, 2005). Using secondary data also allows us to triangulate the findings. Finally, secondary data are likely to be of a higher quality than primary data (Stewart and Kamins, 1993). A disadvantage of using secondary data is that they have been gathered for a different purpose than that of the study, and biases can occur in news sources. Another disadvantage is that processes taking place 'behind the scene' can only be captured to a limited extend.

[4] After determining the data sources, key words and search terms were specified in order to gather comparable data for all three countries (Benders et al., 2007). The terms chosen were 'solar panels' and solar energy', plus the names of the dominant actors within industry in each of the countries. These keywords were translated in the native language of each country.

& Waarts, 2003), and the publication of rankings and benchmarks (e.g., the percentage of companies that have adopted a norm, or the sustainability top 50).

Mimicry is defined as the process by which actors merge in adopting similar innovations as a reaction to uncertainty. In conditions of uncertainty, actors mimic those organizations that seem successful. Thus, we operationalize mimicry as those activities that signal that adoption of the sustainable innovation is the right thing to do. These signals include front runners adopting the innovation (Haunschild and Miner, 1997; Burns and Wholey, 1993), increased industry interconnectedness (Galaskiewicz and Burt, 1991; Palmer et al., 1993, Ramanath, 2009; DiMaggio and Powell, 1983), hiring or firing of employees, increase of industry turnover or profit, increase of front-runner firms' prestige and visibility, and the number of innovations presented in magazines, trade shows and the like (Haveman, 1993; Burns and Wholey, 1993).

Institutional entrepreneurship is defined as the process by which entrepreneurs, large organizations, NGO's or other actors create an impetus for change by individual and/or collective action (Dimaggio, 1988; Greenwood et al., 2002; Leblebici et al., 1991; Leca et al., 2008). From the literature survey, activities were identified such as advocacy of innovation, through processes of framing and theorizing (Greenwood et al., 2002; Pacheco, York, Dean, & Sarasvathy, 2010), membership of industry associations and campaigns (De Bakker & Den Hond, 2008a), coalition forming and bricolage (Garud & Karnoe, 2003), self-regulation (Senge et al., 2008), boycotting contractors and/or suppliers, and lawsuits to resist or enforce innovation.

Social movement is defined as the process by which individuals, for the sake of the social good, create an impetus for change by individual and/or collective action. Activities that characterize social movement processes are events such as interest groups that organize public demonstrations etc. (Greening & Gray, 1994), engagement in lobbying activities (Doh & Guay, 2006; Ramanath, 2008), bringing certain topics onto a political agenda or into public awareness (Campbell, 2007) and tactics such as revealing information, public disclosure, or civil disobedience, but also actions with direct financial consequences such as buycotts, boycotts and shareholder activism (De Bakker & Den Hond, 2003; Ramanath, 2008).

TABLE 1. Diffusion and number of events in different institutional processes, solar panels

	Netherlands	**Germany**	**Spain**	**Total**
Years in sample	1990 – 2011	1990 – 2011	1990 – 2011	
Diffusion (% of sales in 2011)	0.09%	3.2%	2.53%	
Professionalization	45	59	31	135
Mimetic industry	165	166	69	404
Institutional entrepreneurship	13	26	15	54
Social movement	18	29	20	67
Normative government	37	16	29	82
Coercive government	42	27	66	135
Total	320	323	230	873

Table 1 shows that a total of 873 events have been registered with regard to solar panels in Spain, the Netherlands and Germany, covering the period 1990–2011. The table also shows the distribution of these activities across the different institutional processes. The data measure the number of events within a certain institutional process. This does not take into account the 'size' or 'quality' of the events. This should be borne in mind when interpreting the results below. An advantage of using count data is that the institutional processes are comparable across countries. The most frequently observed type of process is mimetic pressures from the industry. However, we could also conclude that this type of pressure is most easily observable. The table also shows the diffusion rate in 2011, i.e., sales of solar panels (thermal and photovoltaic) as a percentage of the total market capacity. Germany, Spain and the Netherlands show large differences in their uptake of renewable energy in general, and of solar panels in particular. Whereas Germany has made an 'energy turn-around' ('Energiewende'), the Netherlands lags behind in its share of renewables. Still, the overall results indicate that diffusion of solar panels is still at an early stage.

We chose solar panels as these are consumer products and hence the diffusion is dependent on actions taken by different actors, including firms and consumers, or 'the public’. This would not be the case for the diffusion of, say, wind turbines; these are seldom purchased by individual consumers. Moreover, the innovation can be considered roughly the same for all three countries, as the technological maturity of the products is the same across the countries. Lastly, solar panels do not require additional infrastructure. Electric cars, e.g., require charging points, the availability of which may affect their diffusion. The model specification for solar panels used in the empirical analysis below is therefore relatively simple.

The diffusion rate differs considerably in the various countries as can be seen from the following graphs. In Germany, well known from its solar success, we see a steady and fast increasing diffusion (Figure 1). This is especially after a large ‘wave’ of institutional pressures from around 2001 to 2008. Mimetic actions by industry actors form the majority of events in that period. We have to interpret this against a background in which the German government has followed through on very consistent policies stimulating both solar and solar PV from 1990 onwards. Around 2008 the supportive schemes are slowly reduced.

In Spain, diffusion progresses in two stages (Figure 2). From around 2003 to 2008, the Spanish solar industry is characterised by a huge boom. In this period all institutional processes play a role, but like in Germany, certainly in the ’boom’ years, mimetic processes dominate as companies jump on the solar bandwagon, innovate, grow and promote solar to the public as well as other institutional actors. The boom ends abruptly with the 2008 financial crisis, after which solar diffusion slowly recovers around 2010 but is based on solar panel imports rather than own industry production.

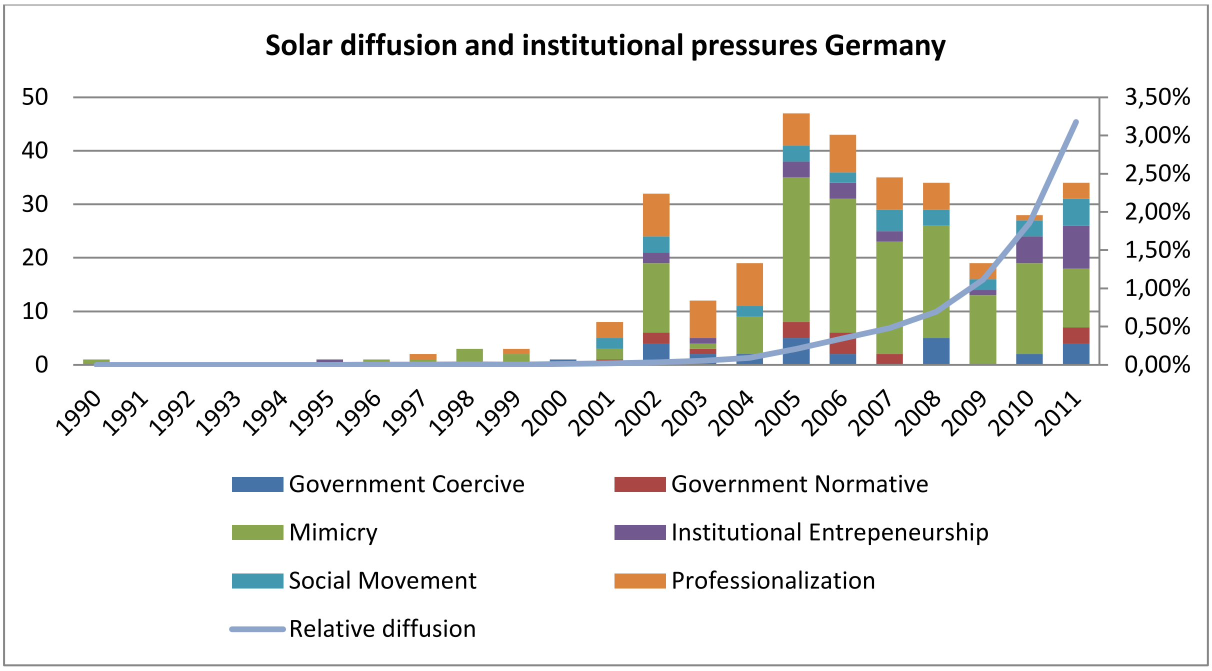

FIGURE 1. Solar diffusion and institutional pressures, Germany

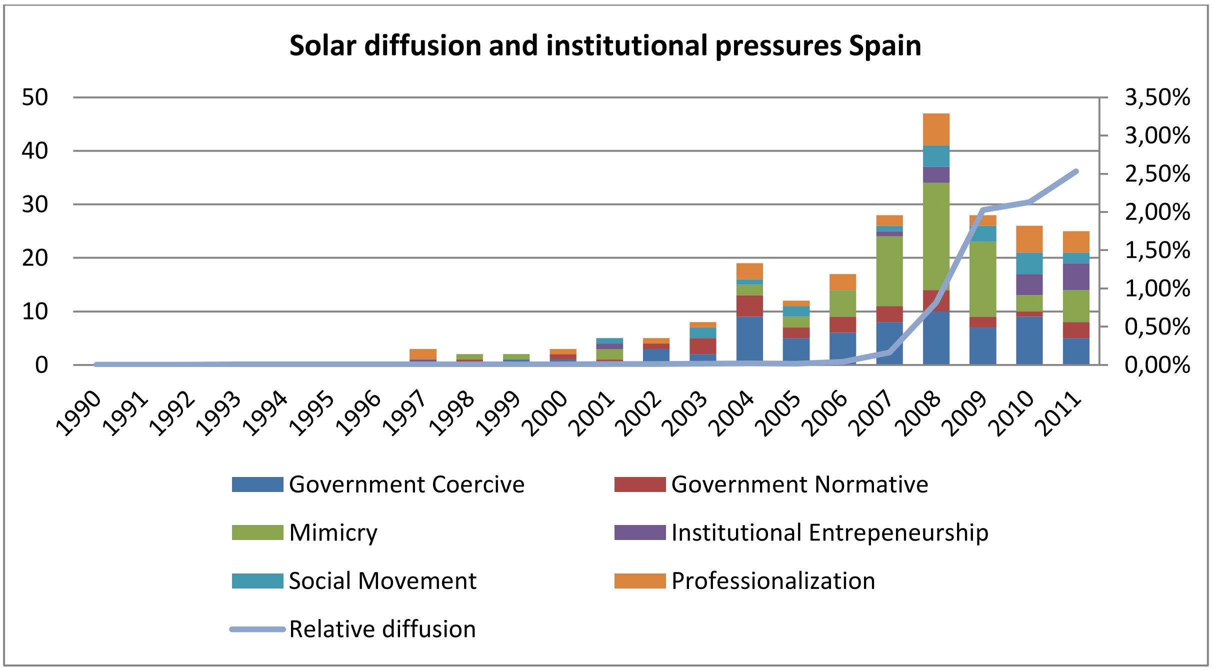

FIGURE 2. Solar diffusion and institutional pressures, Spain

The Netherlands (see Figure 3) shows a very different picture. Whereas the institutional processes were equally as lively as in the other countries, the diffusion of solar remained low. A large difference between the countries is that where Spain and Germany installed the Feed-In Tariff, The Netherlands had a chop and change policy in which short term subsidies were given e.g. for the purchase of solar panels. It is furthermore striking that

NGO's, political parties and companies alike have lobbied the government for more sustainable energy policies since the 1990's (which can be seen in the large percentage of institutional entrepreneurship and social movement events) but that clear and consistent policies have not been implemented.

In the remainder of this paper we will focus on the effect of the various processes on the diffusion of the innovation.

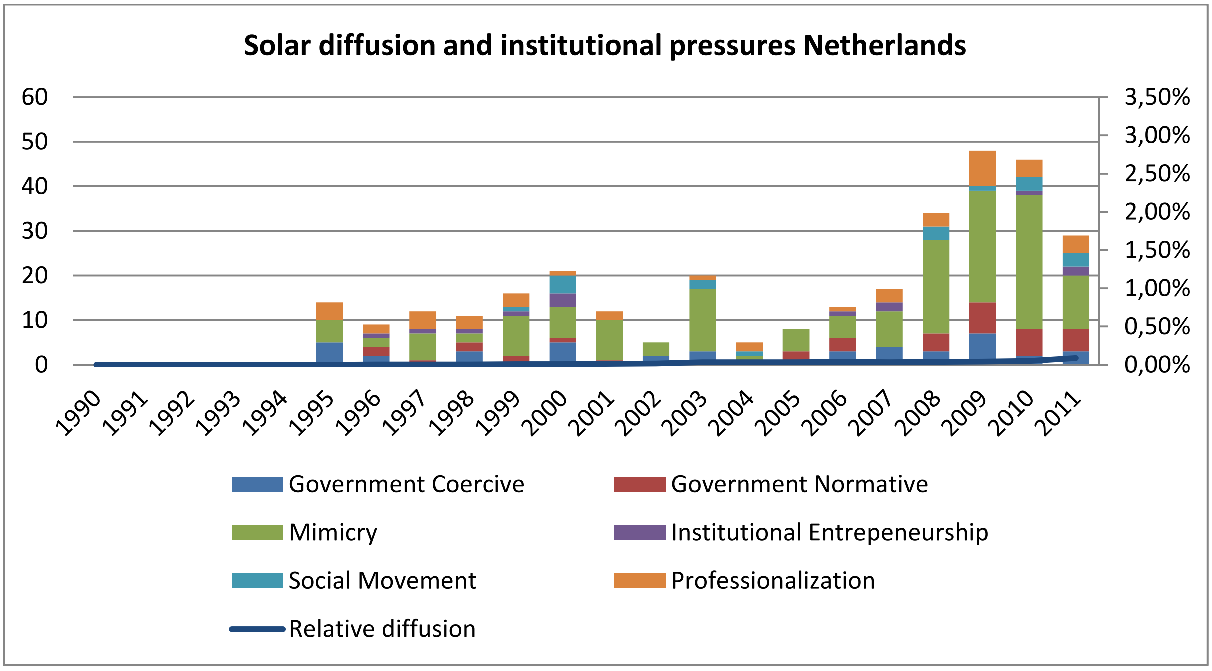

FIGURE 3. Solar diffusion and institutional pressures, Netherlands

ESTIMATION MODEL

The change in the stock of adopters of a consumer technology over time usually follows an S–shape, see Section 2. We define D_t^j as the total number of products sold up to time t in country j.[5] That is,

$$D_t^j = \sum_{t=T^j(1)}^{t} y_t^j, \tag{1}$$

[5] We assume that each adopter buys only one unit of the technology and that there is no replacement demand (*cf.* Stoneman, 2002).

where y_t^j denotes the number of new purchases of solar panels in country $j \in X_c$ at time $t \in T^j$.[6] By dividing D_t^j by the total number of potential owners N^j in country j, we obtain our measure for diffusion

$$S_t^j = \frac{D_t^j}{N^j}, \tag{2}$$

i.e., the degree of market penetration S_t^j. The diffusion process, the relative change in diffusion $\frac{\mathrm{d}S_t^j}{\mathrm{d}t}$, is represented by a Gompertz growth curve.[7] To enable the use of OLS the Gompertz curve is divided by $S_{t-1}^j ln\left(\frac{1}{S_{t-1}^j}\right)$ *cf.* (Stoneman, 2002). The resulting regression equation then becomes:

$$ln\left(\frac{\Delta S_t^j}{S_{t-1}^j ln\left(\frac{1}{S_{t-1}^j}\right)}\right) = a_p + a_c + \sum_{i=1}^{l} a_i \ln(Z_i) + \varepsilon_t, \tag{3}$$

where Z represents the set of l explanatory variables. a_p and a_c represent (additive) technology- and country-specific effects respectively. ε_t is an i.d.d. disturbance term.

We estimate the model for the diffusion of solar panels in Spain, the Netherlands and Germany.[8] The saturation level N^j for solar panels is approximated by the number of dwellings in 2011. Data are from national statistics offices.

Our main explanatory variables are the four institutional processes: professionalization (*PR*), mimicry (*MI*), institutional entrepreneurship (*IE*) and social movement (*SM*). The data on processes include zero's, i.e., when no actions (events) are undertaken. Taking the natural logarithm of the data would drop these observations from the regressions. We deal with zero events by creating two variables for each event: a dummy variable indicating whether the event is zero or positive, and a variable for the log event.

[6] T^j is the vector with years for which we have complete observations on both events and diffusion for country j. That is, $T^{PV,NL} = \{1990, 2004, \dots, 2013\}$.

[7] As part of a sensitivity analysis we also apply alternative functional forms.

[8] This means that the technology-specific effects a_p in equation (3) are not part of our regressions.

Next, we take the interaction of the two variables. The interaction term takes on the value zero when the dummy variable equals zero. When the dummy variable equals one, the interaction term takes on the value of the log event. The interaction measures the difference in the effect of no action versus action of a given amount. We expect the coefficient of the interaction terms to be positive. The sum of the coefficients of both variables gives the effect of positive events. We expect this effect to be positive. There is no clear theoretical underpinning for the coefficient of the dummy variable. However, our hypothesis is that not doing anything will have no effect on the diffusion.

The explanatory variable energy payback time is used to capture the notion that the adoption of solar panels will speed up as the technology improves (in terms of performance or lower costs). The energy payback time is directly related to the net-present-value (NPV) (Blok et al., 2004). Hence, this variable captures the traditional (microeconomic) cost-benefit considerations of consumers for adoption. We *a priori* expect energy payback time to have a negative coefficient: as the payback time becomes shorter it becomes more attractive to adopt solar systems, which will be reflected in higher sales. Data on the energy payback time of photovoltaic (PV) systems are from EPIA (EPIA, 2011) and De Wild-Scholten (Wild-Scholten, 2013).

As residuals are serially correlated, we estimate the model with Cochrane-Orcut AR(1) so as to remove first order autocorrelation.

RESULTS

Table 2 gives the baseline results from estimating equation (3). Preliminary analysis indicated that the best lag structure involves variables in time t in most cases. Only for social movement (*SM*) the best lag structure is t–1.

Column (1) gives the results for the energy payback time (*EPBT*). The results indicate that costs/benefits to individual consumers play an important role in explaining the adoption of solar panels. The coefficient of *EPBT* is negative, indicating that a lower energy payback time increases the diffusion of solar systems. This result is consistent with theoretical expectations: the adoption of solar panels fastens when the technology improves in terms of performance or lower costs. The coefficient is statistically significant as well.

Columns (2) – (5) show the effects on diffusion from the separate institutional processes. As mentioned above, most studies so far have considered the effect of only one or two institutional pressures. Furthermore, competitive pressures were not considered at all. We repeat these analyses in columns (2) – (5). Specification (2) tests *hypothesis 3* (*cf*. section 2) that institutional entrepreneurship (*IE*) increases the rate of technology diffusion. The coefficient of the dummy variable *D_IE* is almost zero, indicating that no action in terms of institutional entrepreneurship has no effect on the diffusion of solar panels. This is consistent with our *a priori* expectations. The coefficient of the interaction term is positive. This means that there is a positive difference between (positive) institutional entrepreneurship and taking no action. However, this difference is not statistically significant. So, we cannot rule out the possibility that the effect of institutional entrepreneurship on diffusion is almost zero as well. We conclude that there is little support for *hypothesis 3* in our data.

Column (3) shows similar results for social movement (*SM*). The results suggest that social movement has a positive effect on the diffusion of solar panels. However, neither the dummy variable *D_SM* nor the interaction term is statistically significant. Hence, we find little empirical support for *hypothesis 4*, too.

Column (4) gives the results for mimicry (*MI*). Here, the interaction term has a positive sign and it is statistically significant, indicating that there is a statistically significant difference between mimicry and no action. The coefficient of the dummy variable *D_MI* is positive but it is not statistically significant, consistent with our ex ante expectations. These results support *hypothesis 2*. The effect of mimicry on the diffusion of solar panels according to column (4) is 0.23.

TABLE 2. Results for baseline specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ln(*EPBT*) $_t$	−1.08***					−0.98**	−1.02**	−0.79*	−0.99**
	(2.69)					(2.27)	(2.36)	(1.92)	(2.39)
D_IE $_t$		−0.00				−0.00			
		(0.03)				(0.03)			
D_IE *ln(*IE*) $_t$		0.16				0.08			
		(1.27)				(0.59)			
D_SM $_{t-1}$			0.03				−0.01		
			(0.23)				(0.08)		
D_SM *ln(*SM*) $_{t-1}$			0.11				0.06		
			(0.88)				(0.51)		
D_MI $_t$				0.06				0.03	
				(0.39)				(0.21)	
D_MI *ln(*MI*) $_t$				0.17**				0.13*	
				(2.57)				(1.92)	
D_PR $_t$					−0.05				−0.07
					(0.45)				(0.62)
D_PR *ln(*PR*) $_t$					0.16*				0.13
					(1.70)				(1.35)
Intercept	−2.04***	−2.81***	−2.79***	−3.04***	−2.83***	−2.15***	−2.11***	−2.46***	−2.17***
	(5.50)	(8.83)	(8.56)	(10.40)	(8.48)	(5.28)	(5.16)	(5.86)	(5.34)
Adjusted R–squared	0.16	0.06	0.05	0.16	0.07	0.14	0.13	0.20	0.16
Observations	60	60	60	60	60	60	60	60	60
ρ	0.70	0.72	0.72	0.68	0.73	0.69	0.69	0.69	0.69
DW (transformed)	1.59	1.54	1.47	1.66	1.49	1.59	1.57	1.70	1.57

Notes: dependent variable: Gompertz growth curve. Absolute robust *t*-statistics in parentheses. * significant at 10%, ** significant at 5%, *** significant at 1%. Specifications include country-specific fixed effects.

Column (5) gives the results for professionalization (*PR*). The coefficient of the interaction term is positive and statistically significant (at the ten percent level). The coefficient of the dummy variable *D_PR* is not statistically significant similar to the dummy variables for the other events. The results indicate that *hypothesis 1* is supported by the data. The effect of professionalization on the diffusion of solar panels is 0.11.

So, we find empirical support for mimicry and professionalization when we look at the effect on the diffusion of solar panels from individual institutional processes. However, the coefficients of the institutional processes in specifications (2) – (5) will most likely suffer from omitted variable bias, as no additional control variables are included. Paraphrasing DiMaggio and Powell (1983), focussing on only one process may conceal the fact that an alternative process is at work. Also, the specifications above do not take into account that institutional pressures may operate alongside competitive pressures. These issues are addressed subsequently.

First, specifications (6) – (9) in Table 2 include *EPBT* along with each of the respective institutional processes. These specifications allow us to investigate the effect on diffusion from both straightforward cost-benefit considerations by individual actors and institutional processes. The results indicate that the effect of *MI* is robust for the inclusion of *EPBT*. As for *PR*, we find that the interaction term is no longer statistically significant in a specification with *EPBT*. Specification (8) yields the best result in terms of explanatory power. We note that the effect of energy payback time *EPBT* becomes smaller in the specification with *MI*.

The results in Table 2 suggest that mimicry in particular is an important driver of diffusion. However, as observed by DiMaggio and Powell (1983) and Mizruchi and Fein (1999), isomorphic processes should be considered in their full complexity. We therefore investigated whether the observed effect of *MI* changes when other institutional processes are included together with *EPBT*. Columns (1) – (3) in Table 3 show the results for combinations of *MI* and one of the other institutional processes. The results indicate that the effect of *MI* is robust for the inclusion of other processes.[9] Likewise the results for *IE*, *SM* and *PR* in columns (1) – (3) are qualitatively similar to columns (6), (7) and (9) in Table 2.

Overall, the fit of the Gompertz curve is relatively low. We therefore estimated a different model as well. Following (Jenn, Azevedo, & Ferreira, 2013) we regress annual sales on sales in the previous year plus our set of explanatory variables. The model was estimated using simple OLS. Column (4) in Table 3 gives the results. We find that this model is largely dominated by sales in the previous year. Still, the effect of *MI* is robust: the interaction term has a positive sign and is statistically significant, whilst the dummy variable *D_MI* is not statistically significant, consistent with our ex ante expectations. We also find that *EPBT* has no statistically significant impact on sales of solar panels. As this is also the case in a specification with just *MI*, i.e., the equivalent in terms of explanatory variables of specification (8) in Table 2, we ran a regression with (the log of) GDP as an explanatory variable rather than *EBPT*. The results are presented in column (5). The coefficient of GDP has the expected, positive, sign and is statistically significant. So, this variable adds some power to the test. Nevertheless, we find that the effect of *MI* is robust.

[9] The results for *MI* are robust for the inclusion of more processes, too. The low statistical significance of the processes adds little power to the test. These results are available upon request.

TABLE 3. Sensitivity analyses

	(1)	(2)	(3)	(4)	(5)
$\ln(EPBT)_t$	−0.69	−0.70	−0.77*	−0.44	
	(1.59)	(1.59)	(1.83)	(1.08)	
D_IE_t	0.00			0.02	0.03
	(0.02)			(0.18)	(0.22)
$D\_IE*\ln(IE)_t$	0.06			0.09	0.17
	(0.50)			(0.73)	(1.05)
D_SM_{t-1}		−0.02		−0.05	−0.14
		(0.14)		(0.28)	(0.77)
$D\_SM*\ln(SM)_{t-1}$		0.09		0.09	0.19
		(0.68)		(0.40)	(0.97)
D_MI_t	0.03	0.02	−0.00	0.10	0.00
	(0.23)	(0.15)	(0.01)	(0.85)	(0.04)
$D\_MI*\ln(MI)_t$	0.13*	0.13*	0.12*	0.19**	0.18**
	(1.86)	(1.96)	(1.75)	(2.44)	(2.23)
D_PR_t			−0.08	−0.02	−0.10
			(0.64)	(0.18)	(0.82)
$D\_PR*\ln(PR)_t$			0.09	0.03	0.07
			(0.93)	(0.20)	(0.63)
$\ln(Sales)_{t-1}$				0.85***	0.86***
				(11.50)	(17.16)
$\ln(GDP)_t$					1.28*
					(1.84)
Intercept	−2.55***	−2.55***	−2.46***	1.29*	−17.89*
	(5.66)	(5.61)	(5.54)	(1.75)	(1.79)
Adjusted R−squared	0.18	0.18	0.18	0.99	0.98
Observations	60	60	60	63	60
ρ	0.68	0.68	0.69		
DW (transformed)	1.70	1.68	1.67		

Notes: dependent variable in columns (1) – (3): Gompertz growth curve; in columns (4) – (5): natural logarithm of annual sales. Absolute robust *t*-statistics in parentheses. * significant at 10%, ** significant at 5%, *** significant at 1%. Specifications include country-specific fixed effects.

CONCLUSION

This paper has examined what factors drive the diffusion of sustainable innovations. We focus on the diffusion of solar panels in Germany, Spain and the Netherlands in particular. Our results support the notion from the economics literature that adoption of solar panels will fasten as the technology improves in terms of performance or lower costs. However, cost-benefit considerations are complemented by less rational, institutional considerations.

We find that mimicry, in particular, is a dominant isomorphic process driving the diffusion of solar panels. This confirms earlier theoretical contribution in which it was conveyed that with the diffusion of novel technologies, markets are characterized by high uncertainty and technologies are poorly understood and goals are ambiguous, and as a result organizations will mimic other organizations to be "no better or worse than any organization" in the field (Kondra and Hinings, 1998: 745-8). In this study we see that the role of this industry driven process towards homogenization plays an important role in pushing solar into the market. In the events we see how companies are quick to follow each other in promoting the products, increasing production, introducing new technologies, start new companies, take-over other companies and similar activities that propel the industry forwards. Contrary to theoretical expectations, our results do not provide much support for the other institutional processes: the role of institutional entrepreneurship (Battilana et al., 2009; Pacheco et al., 2010), professionalization or social movement (De Bakker & Den Hond, 2008a; W. D. Sine & B. H. Lee, 2009). The importance of these processes has been greatly emphasized in recent years, as being crucial in setting agenda's, creating room for experimentation and thereby paving the way for wider diffusion of novelty in general and renewable energy in specific (Sine & David, 2003; Wesley D. Sine & Brandon H. Lee, 2009). Whereas this may still be true, we find no direct effect on innovation diffusion. Further research could examine how these processes impact on e.g. mimicry and professionalization as processes that effect innovation diffusion in a more direct manner.

We contribute to the existing literature in two manners. First, this article connects the previously unconnected economics and institutional literature. Previous literature has studied the role of institutional processes on innovation diffusion (Wesley D. Sine & Brandon H. Lee, 2009), however, without taking competitive processes into account. In our study we see that the importance of the role of institutional processes as described in earlier studies, decreases when it is studied relative to the influence of price, with a marked exception of industry mimicry. This is an important finding as it points to the important role of price and industry engagement, and implies that sustainability policies focusing on social movement, awareness campaigns and other forms of bottom up involvement, may be less effective.

Second, we present a novel method of studying institutional processes which enables to study institutional processes across products (solar, cars, lighting) and across countries (Netherlands, Spain, Germany, UK). Whereas this study is only a first step, further cross-analysis of different diffusion paths should lead to improved insight and concrete policy recommendations for sustainable innovation. It will help the field, that is often characterized by highly detailed and contextualized cases, to move forwards by offering a more quantitative, testable and generalizable method.

Limitations and notes for further research

The results presented in this paper represent a first step in the empirical analysis of how economic and institutional forces explain the diffusion of sustainable products. Next studies should also take into account the dynamic interactions between these processes. Previous literature has emphasized how, e.g., social movements influence coercive processes (e.g., government regulation), that in turn create space for institutional entrepreneurs after which 'big industry' will follow (mimicry), e.g., (Wesley D. Sine & Brandon H. Lee, 2009). Insights into to what extent, and how, institutional forces correlate in driving innovation diffusion would be hugely beneficial to understanding and guiding the transition towards more sustainable energy systems. Furthermore, this paper has focussed on the diffusion of solar panels only. The analysis can be extended to other types of sustainable technologies, e.g., electric cars and energy-efficient lighting (as can be found in the Waves of Change Database).

Appendix A

This appendix provides details of data used in this paper.

Table A1. Descriptive statistics

	Mean	SD	Min.	Max.	Obs.
Gompertz growth	−3.19	0.70	−4.24	−1.19	63
Ln (*Sales*) *t*	4.86	2.75	0	11.15	66
Ln(*EPBT*) $_t$	0.71	0.41	−0.17	1.19	72
D_IE *ln(*IE*) $_t$	0.21	0.48	0	2.08	66
D_SM *ln(*SM*) $_{t-1}$	0.33	0.51	0	1.61	66
D_MI *ln(*MI*) $_t$	1.14	1.20	0	3.40	66
D_PR *ln(*PR*) $_t$	0.60	0.73	0	2.08	66

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