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RECONCILING WTP TO ACTUAL ADOPTION OF GREEN ENERGY TARIFFS: A DIFFUSION MODEL OF AN INDUCED ENVIRONMENTAL MARKET

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Abstract

This paper develops a formal model that links the willingness to pay (WTP) literature with the established innovation diffusion literature. This concern arises from an attempt to reconcile the large disparities that have been observed between actual adoption of green energy tariffs and WTP for such tariffs. These disparities have often been attributed to upward response bias and the free rider problem. However, empirical research indicates that other factors have hindered the development of green energy markets, including supply side problems and poor regulation. Using an epidemic diffusion framework our model shows how increasing consumer environmental concern driven by word of mouth and mass media communication channels results in a growing number of people who state they are WTP for green energy. The presence of upward response bias and the free rider problem result in 'feasible adoption' being below stated WTP. Feasible adoption is, in turn, differentiated from actual adoption by the extent of market imperfections. It is concluded that; (1) the potential of such markets may take time to reap and that the low penetration rates of today may reflect a conventional diffusion trajectory and (2); low and stable energy prices appear to be a precondition if consumers are to contribute substantively to the funding of renewables investments through green tariffs.

Keywords

Willingness-to-pay, innovation diffusion, green energy, environmental valuation

1. Introduction*

This paper develops a 'Diffusion Model of an Induced Environmental Consumer Market' in an attempt to link the willingness to pay literature with the established innovation diffusion literature. This concern arises from an attempt to reconcile the large disparities that have been observed between actual adoption of green energy tariffs and willingness to pay for such tariffs. These disparities have often been attributed to upward response bias and the free rider problem. However, empirical research indicates that other factors have hindered the development of green energy markets, including supply side problems and poor regulation. Thus, by linking the willingness to pay and innovation diffusion literatures, the model presented in this paper provides a framework with which to conceptualise the various factors that can explain the empirically observed differences between actual take-up of green energy tariffs and consumers stated preference to do so (i.e. the number of consumers claiming a willingness to pay for a premium for green energy tariffs). These distinctions should help policymakers make more accurate assessments of the role that green energy markets can play in the funding of new renewable investments over time.

1.1. The WTP literature

Mirroring government attempts to tackle environmental decay, the last three decades have witnessed the emergence of a substantial body of work that can best be described as the willingness to pay (WTP) literature. Recent contributions range from efforts to understand the WTP for energy-saving measures in residential buildings (Banfi *et al.* 2008) to attempts to ascertain the WTP for environmental improvements in hydropower regulated rivers (Kataria 2009). Contributions have emanated principally from environmental economics and environmental management (including the consumer psychology end of marketing) though a sizable literature has evolved in healthcare research and heath economics (See Diener *et al.* 1998; Olsen and Smith 2001 for reviews). The literature has used survey methods to explore two 'non-market' concerns, namely, (1) valuing externalities and (2) measuring of the 'pre-market' potential of induced (environmental) markets.

The latter is the least cited application and relates to markets that do not yet exist but which policymakers believe offer potential to internalise externalities and/or reap the benefits of green consumerism, should government provide the right regulatory and incentive framework. In the former case the valuations obtained are used in cost-benefit analyses that determine whether technologies such as wind energy merit government support. Thus, these valuations can be used to determine whether, once all externalities are internalised, positive externalities outweigh negative externalities and, if they do, they can also help determine the extent of support. Since policy decisions can rest on the use of willingness to pay estimates, it is critical that these valuations are valid and reliable (Diamond and Hausman 1994; Carson *et at.* 2001).

A lively debate concerning the validity and reliability of willingness to pay estimates has surrounded the development of this literature. The debate is involved and has dragged on for well over a decade (See Carson *et al.* 2001; Spash 2008; Venkatachalam 2004). On the one hand, critics argue that willingness to pay estimates are inherently flawed by, *inter alia*, the presence of upward response bias and 'embedding effect' that bring in to question both their reliability and validity (See Diamond and Hausman 1994). On the other hand, advocates argue that careful study design and implementation and the use of a contingent valuation approach can overcome these problems (Carson *et al.* 2001).

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Contingent valuation (CV) approaches have become the preferred survey-based method approach of carrying out willingness to pay surveys. Such has been the importance of non-market valuation on issues like pollution control that US's National Oceanic and Atmospheric Administration commissioned a panel headed by eminent economists to explore the controversies surrounding contingent valuation (Arrow *et al.* 1993). The panel concluded that contingent valuation surveys can provide estimates reliable enough to be of some use when considering non-market valuation. However, on the issue of validity, they cautioned that:

> "The Panel is persuaded that hypothetical markets tend to overstate willingness to pay for private as well as public goods... All surveys of attitudes or intentions are bound to exhibit sensitivity of response to the framing of questions and the order in which they are asked. No automatic or mechanical calibration of responses seems to be possible. The judicial process must in each case come to a conclusion about the degree to which respondents have been induced to consider alternative uses of funds and take the proposed payment vehicle seriously." (Arrow et al. 1993, p.44)

The existing empirical evidence on green energy markets points to a large and persistent divergence between actual adoption rates and the number of consumers claiming a willingness to pay (See Section 2). Thus, the nature of the subject would understandably seem to lead to upward response bias, whether such bias can be corrected for by current advances in CV methodology is no doubt open to ongoing debate (Spash 2008). Either way the 'Diffusion Model of an Induced Environmental Consumer Market' presented here can be adapted for alternative views in this debate and as such is principally concerned with the other reasons, such as the free rider problem, market imperfection and supply constraints that may lead to differences between WTP and actual adoption of green energy tariffs.

1.2. Innovation diffusion literature

Diffusion research has developed over the past few decades as a specialist but well established field of research in marketing and economics (see Geroski 2000; Lissoni and Metcalfe 1994; Rogers 1995; Stoneman 2002). Rogers (1995, p.5) defines diffusion as

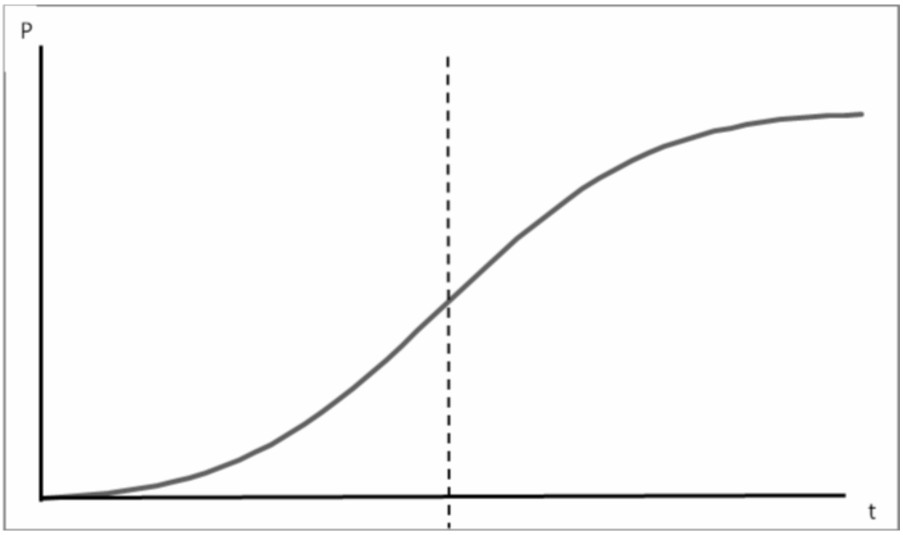
> "the process by which an innovation is communicated through certain channels over time among members of a social system. It is a special type of communication, in that the messages are concerned with new ideas".

Stoneman (1995, p.5), on the other hand, defines diffusion as occurring when

> "new products and processes spread across the potential market."

These slightly different definitions emphasize differences in focus of the economics and marketing traditions of diffusion research.

Figure 1: The innovation diffusion process



In the marketing tradition, epidemic models are emphasised, while in economics diffusion tradition, probit or hurdle rate models have become increasingly popular (See Geroski 2000; Lissoni and Metcalfe 1994). The reason for these different approaches are that epidemic models are better suited to model the process of diffusion where individuals are the unit of measurement. By way of contrast economists have found that probit/hurdle-rate models are better suited to ascertain the various determinants, including the profitability of the innovation, at the firm level (Kemp 1997; Lissoni and Metcalfe 1994; Rogers 1995).

Rogers (1995) observes that the rapid expansion of diffusion research in marketing in the 1970s is largely attributable to applicability of the Bass (1969) model of innovation diffusion to new product development. This model is an epidemic model of diffusion that emphasises communication channels as the key factor in the 'S' shaped diffusion process (See Figure 1). In the model, diffusion is the result of two types of communication processes; namely, the mass media and interpersonal word-of-mouth communication channels. The mass media communication channels play a large role in persuading earlier adopters (innovators) to adopt, while word-of-mouth begins to dominate adoption decision of those that follow (imitators). Since the concern in this paper is with developing a model of an induced environmental market for consumers the Bass model will be used as the point of departure in linking the diffusion and WTP literatures.

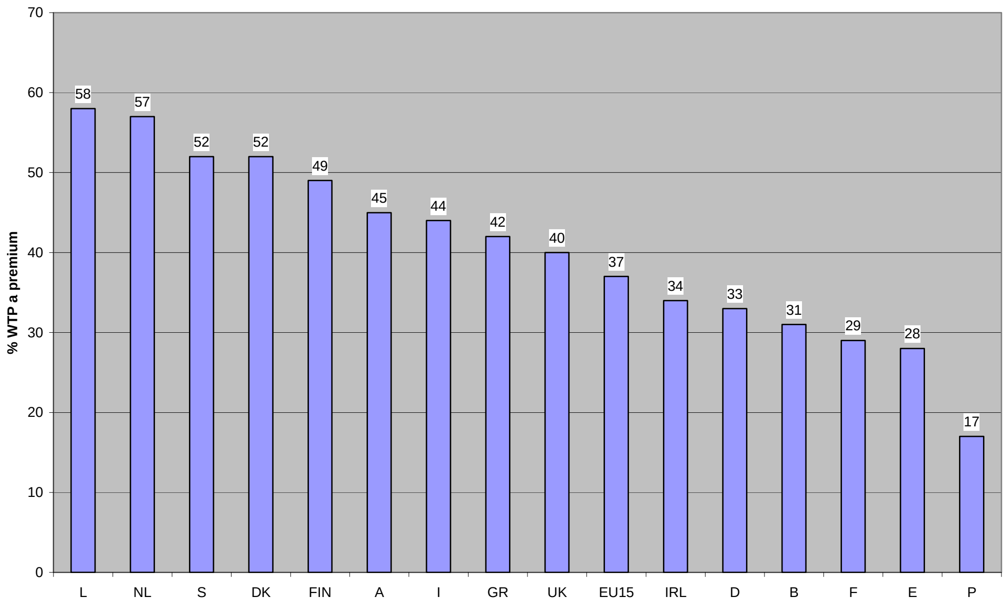
Having briefly introduced the literatures that provide the grounding for the 'Diffusion Model of an Induced Environmental Consumer Market', the rest of the paper develops the model in the following way. Immediately following is a summary of the empirical research on green energy markets that has explored the divergence between WTP and actual adoption of green energy tariffs and which inspired the model. The subsequent section provides a discussion of the use of WTP estimates to measure market potential in green energy markets. Section 4 presents the model itself, while the final section provides some concluding remarks.

2. Empirical context: Green energy markets

The emergence of modern environmentalism has been accompanied by a desire to reap commercial benefits from individuals' growing concern for the environment. This has resulted in a dramatic growth in green consumerism. Ottman (1993, cited by Zarnikau 2003), provided valuable insights into the demographic characteristics of green consumers; namely, that they are educated, affluent and under 55 years of age. The desire to further harvest green consumerism has seen a dramatic growth in the contributions to the WTP literature to asses pre-market potential of, *inter alia*, green energy markets.

The willingness of consumers to pay for green energy has been examined in numerous countries including Finland, USA, Canada, Germany and the UK. WTP surveys have implied that there is consumer demand for innovative green energy products. These surveys have therefore played a major role in justifying the development of markets for green energy tariffs and the associated processes of liberalisation (See Farhrar and Houston 1996; Fouquet 1998). Research on green energy markets has focused on two broad issues. First, the research has been concerned with measuring consumers' stated willingness to pay a premium for green energy and to ascertain the differentiating characteristics of willing individuals. Second, the literature has sought to explain differences between stated willingness to pay and actual take-up of green energy tariffs. As will be apparent in the following discussion, the former has tended to find high stated willingness to pay for green energy (Section 2.1.), while the latter has observed a large divergence between stated and actual adoption of green energy tariffs (Section 2.2.) with a number of reasons being mooted for this large divergence (Section 2.3.).

Figure 2: European WTP a premium ranging from 5% to over 25%[1]



2.1. WTP for green energy

US surveys of willingness to pay for green energy have found that between 40% to 70% of respondents are willing to pay a premium for green energy (Fahrar and Houston 1996; Zarnikau 2003). High levels of willingness to pay for energy from renewable sources are also presented in the European research. Devries (2004) recorded that substantial differences between consumers' willingness to pay exist across the European Union nations. Figure 2 which shows that over half of consumer in Luxembourg, The Netherlands, Sweden and Denmark claim to be WTP a premium (ranging from 5% to over 25%) for green energy. Generally speaking stated WTP in Europe would seem to be higher in the northern countries of the EU.

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1 Complied from Devries (2004)

Over the year there have been various attempts to measure WTP in the UK green energy market context allowing for an understanding of how WTP has evolved over time. Within this literature Fouquet (1998), Batley *et al*. (2001), Tinch *et al.* (2003), Devries (2004), Graham (2006) and Akcura (2008) report that 20%, 35%, 42%, 40%, 64% and 35% of UK customers respectively are willing to pay for green energy at different time periods. As the first UK green tariffs were introduced in 1997 (Boardman *et al.* 2006), it is apparent that differences over time in WTP may be linked to familiarity with the concept of green tariffs and increasing awareness of environmental issues, though this trend appears to have reversed in the last few years due to large rises in energy prices.[2]

This evidence points to an ever changing valuation consumers attach to green energy tariffs linked to heightened ecological concern and current energy prices. The link between ecological concern and WTP has been confirmed in the empirical literature on green energy (Rowlands *et al*. 2003). Ecological concern is defined as

> "general environmental attitude and [individual's] perception of the necessity for societal change commensurate with the concept of sustainable development" (Scott 1999 cited in Rowlands et al. 2003, p.39)

2.2. Adoption estimates

Despite this high level of customer intent, the actual take-up of green energy tariffs is relatively low in most counties where the choice exists. In the US average rates estimated to be at or below 2% (Bird et al. 2002; Wiser 2003; Wiser and Pickle 1997; Zarnikau 2003), though some of the best performing programmes have achieved penetration rates of between 5 and 17% (Bird et al. 2007, p.6). European nations have also appreciated only modest levels of green energy tariff adoption by consumers, with the Netherlands providing a notable exception. Markard and Truffer (2006) find that up to 2001 only the Netherlands had reached a level of retail customer adoption that exceeded 1.5%.

UK estimates for the take-up of green tariffs have seen a rising trend but are still far below the UK WTP estimates discussed earlier. For instance, Bird *et al*. (2002, p.531) indicated approximately 0.2% of households in 2001 had taken up a green energy tariff, Graham (2006, p.2) estimated that this had grown to just under 1% of households by 2006, while Diaz-Rainey and Ashton (2008) estimate adoption to have potentially reached up to 1.5% by 2007. The low penetration levels achieved in the UK contrast markedly to those in the Netherlands. For instance Markard and Truffer (2006) estimated that, within the Netherlands, take-up of green energy tariffs in 2001 was approximately 11%, a figure rising to 26% in 2003. The increased take-up of green energy tariffs in the Netherlands has been attributed to (1) tax exemptions that made green electricity of broadly equivalent cost when compared to conventional tariffs and (2) heavy advertising by utilities (Bird *et al*. 2002; van Rooijen and van Wees 2006). Indeed, there is some anecdotal evidence that when the tax breaks were removed after 2003 and the price advantage of conventional tariffs was restored, there was considerable switching away from green tariffs.

[2] Though survey design is likely to account for some of these WTP differences over time there appears to be a clear trend. The notion that consumers valuation of green tariffs is dynamic is consistent with the Efficient Market Hypothesis in finance where assets prices repeatedly adapt to constant news flow and tend to trend based on fundamentals (i.e. the random walk with a trend found in asset prices). In this case the fundamental driving valuation is ecological concern; however, this may be offset, say by rising energy prices and or lowered incomes. The former, rising energy prices, may explain the fall in WTP reported by Akcura (2008), since UK retail energy prices rose dramatically from 2006 to 2008 (Gas 80% and electricity 60%) (BERR 2009). Indeed, in Akcura (2008, p.25) 60% of respondents that claimed not to be willing to pay for green energy gave the reason that energy prices had gone up too much already in the past few years.

2.3. Explaining the divergence between WTP and adoption

A range of explanations for this large divergence between stated and actual behaviour has been forwarded by the international literature exploring green energy markets. The most often cited reasons have been the free rider problem and upward bias in WTP surveys (Diaz-Rainey and Ashton 2008; Gossling *et al*. 2005; Wiser 2003; Wiser and Pickle 1997). A broader range of explanations have been mooted in recent years as researchers have examined the peculiarities of individual markets, including

- **Lack of knowledge as to green power availability**: Mentioned in the context of Finland, UK and the US markets (respectively Salmela and Varho 2006; Ipsos MORI 2008; Wiser 2003)
- **Hesitancy in switching electricity supplier and high search costs:** Again in the context of Finland, UK and the US (respectively Salmela and Varho 2006; Diaz-Rainey and Ashton 2008; Wiser 2003)
- **Distrust of energy product suppliers and their motives for introducing green energy tariffs:** Finland, UK and the US (as above though Boardman *et al*. 2006 also found this in the UK context)
- **Consumer confusion due to a complex regulatory structure and the absence of effective green energy guidelines for green power retailers:** Mentioned in the UK literature on numerous occasion and relates to the complex interaction between green tariffs and the supply side incentive system for renewables, the Renewable Obligation (Boardman *et al.* 2006; Diaz-Rainey and Ashton 2008; Graham 2006)
- **A lack of renewables supply:** Mentioned in the UK context and leading incumbents to innovate and provide green offerings that did not derive their energy from renewables, thus adding to customer confusion (Diaz-Rainey and Ashton 2008)
- **Failure to meet customer expectations:** UK the public opinion clearly associates green tariff with electricity from renewables, yet many product offerings do not meet this expectation, this has not only caused confusion but it has also put consumers off taking up existing offerings (Diaz-Rainey and Ashton 2008; Ipsos MORI 2008)

3. Market potential and pre-market valuations

When exploring the potential of green energy tariffs and the characteristics of potential green energy consumers in Ontario, Rowlands *et al.* (2003, p.39) noted that

> "Ideally, we would have investigated actual consumer behaviour. However, given the only recent introduction of green electricity, few opportunities exist to study this phenomenon".

Even in countries where green tariffs have existed for some time, the low levels of adoption that are evident in most countries mean that studies of actual adopters would need to have extremely large samples or would need to overcome confidentiality issues and the reluctance of utility companies to release details of their green consumers. These challenges are not insurmountable since two recent studies have explored actual adopters in the US (Kotchen and Moore 2007) and the Netherlands (Arkesteijna and Oerlemans 2007).

In both studies, customer contact information was obtained from utility companies. In Kotchen and Moore (2007) customer information was obtained from two green power programmes in Michigan, a state where competition has not been introduced at the retail level (Bird *et al.* 2007). Hence, the companies involved could not have been concerned that the results of the study would facilitate a competitor. In the Netherlands, there has been retail competition since 2001 for those customers who wish to opt for green power; however, most customers that have switched to a green tariff have done so with their incumbent utility supplier (Bird *et al.* 2002; Markard and Truffer 2006).

More fundamentally, however, where adoption is low, as is the case in the most countries that have liberalized their retail electricity markets, exploring actual adopters has two problems. First, it reveals nothing about the market potential. Second, any investigation of consumer characteristics is likely to explore the characteristics of early adopters who will display different characteristics to subsequent adopters. Thus, the results are likely of limited use in targeting future marketing campaigns. The alternative to investigating actual adopters is to use a willingness to pay approach. This approach also has limitations; not least the potential for upward response bias and the free rider problem discussed earlier. As will become apparent in the depiction of the Diffusion Model of Induced Markets (Section 4), exploring both actual adopters and willingness to pay prove to be complementary to understanding the adopter environment and, hence, being able to make more accurate assessment of the role that green tariffs can play in funding new renewables generating capacity.

4. The Model

In this section a ‘Diffusion Model of Induced Markets’ is developed in an attempt to link the WTP and innovation diffusion literatures introduced in Section 1. The aim of the model is to provide a framework with which to conceptualise differences between actual take-up and WTP observed empirically (Section 2). Our model is based on Bass (1969) and extends this model in two ways. First, it accounts for the upward response bias and the free rider problem discussed in section 2.3. Second it accounts for various other ‘market imperfections’ such as supply side problems or customer confusion (also discussed in section 2.3) by introducing a variable which incorporates those imperfections.

4.1 Assumptions of the model and willingness to pay

The model starts from the assertion that WTP estimates offer some information as to the potential of green energy markets (see Section 3). Further, consistent with empirical findings, it is asserted that the increasing individual concern for the environment (‘environmental or ecological concern’) leads to a gradual increase in the number of individuals reporting a WTP (See Section 2.1.). Environmental or ecological concern can itself be seen as a function of numerous social and psychological factors driven by the spread of information about the environment and climate change. One other assumption implicit in the model is that energy prices are constant (See discussion in Section 2.1.)

Further, the model, following Bass (1969), assumes that adoption is influenced by two types of communication channels that disperse information related to ecological concern, the mass media, we call this type of influence m, and interpersonal word-of-mouth communication, we call this type of influence w. We assume that both m and w are aggregate influences so that for example it is not information on the news today that affects m but rather a total effect of what’s been on the news over a period of time. We define the probability of an initial purchase been made at time t given that no purchase has been made up to t as $p(t) = m + \frac{w}{N}Y(t)$ [3] so that this probability is equal to a constant $p(0) = m$ at time $t = 0$ (this is the probability of a purchase at time $t = 0$ when there is no word-of-mouth effect and all purchases are due to the influence of the mass media) plus an additional term

[3] Note that since this is an induced market, adoption is not possible until government provides the legal and regulatory framework for the creation of the market. In energy markets this has meant liberalization of retail energy provision and de-regulation of tariffs. For simplicity in notation and exposition, we consider that for our model time $t=0$ is when the legal and regulatory framework is provided so as to induce the market.

$\frac{w}{N}Y(t)$ which captures adoption due to the influence of word-of-mouth as the number of previous buyers increases[4]. In the term $\frac{w}{N}Y(t)$, $Y(t)$ is the number of buyers up to time t and N is the population of potential buyers.

At this stage we define our population of potential buyers as $N = N_0 v_0$, where N_0 is our country population and v_0 represents the fraction of consumers who are potential adopters. It will be the case that not all consumers will be adopters due to a number of factors which include low income (therefore they cannot afford the premium) and low or no endowed environmental motivation (their natural concern for the environment is so low they will never voluntarily adopt or state they will pay a premium price for green energy). As a result consumers will be prepared to state a willingness to pay for green energy represented by a percentage price premium p_i. Whether $p_i > 0$ or $p_i = 0$ will determine whether a consumer will be included in the fraction of the population which can be adopters of green energy. We assume that v_0 represents the fraction of citizens who's stated willingness to pay for green energy is $p_i > 0$.

Let $f(t)$ be the likelihood of a purchase at time t with $F(t) = \int_0^t f(x)dx$ and $F(0) = 0$ so that the likelihood of a purchase at time t given that not purchase has been made yet is

$$p(t) = \frac{f(t)}{1 - F(t)} = m + \frac{w}{N}Y(t) = m + wF(t) \tag{1}$$

with $Y(t) = NF(t) = N\int_0^t f(x)dx$ being the total number of buyers up to time and $Nf(t)$ being the number of purchases at time. This number of purchases at time t is given by

$$Nf(t) = N[1 - F(t)]p(t) = \left[m + w\frac{\int_0^t S(x)dx}{N} \right]\left[N - \int_0^t S(x)dx \right] \tag{2}$$

which can be written as

$$Nf(t) = mN + (w - m)Y(t) - \frac{w}{N}[Y(t)]^2 \tag{3}$$

From the total number of purchases we can solve for the likelihood of a purchase at time t as

4 Alternatively we can say that w is a parameter which is influenced by both the mass media and word of mouth so that the mass media influences initial purchases as well as later purchases. This is consistent with assuming that the

$$f(t) = m + (w - m)\frac{Y(t)}{N} - \frac{w}{N^2}[Y(t)]^2 = m + (w - m)F(t) - w[F(t)]^2 \qquad (4)$$

which together with $\frac{dF(t)}{dt} = f(t)$ yields the differential equation for $F(t)$

$$\frac{dF(t)}{dt} = m + (w - m)F(t) - w[F(t)]^2 \qquad (5)$$

Together with the initial condition $F(0) = 0$ the differential equation, as in Bass (1969), has a solution

$$F(t) = \frac{1 - e^{-(m+w)t}}{\frac{w}{m}e^{-(m+w)t} + 1} \qquad (6)$$

From this we get

$$f(t) = \frac{(m+w)^2}{m}\frac{e^{-(m+w)t}}{\left[\frac{w}{m}e^{-(m+w)t} + 1\right]^2} \qquad (7)$$

As a result the number of buyers up to time t is

$$WTP(t) = Y(t) = NF(t) = N\frac{1 - e^{-(m+w)t}}{\frac{w}{m}e^{-(m+w)t} + 1} \qquad (8)$$

4.2 Achievable adoption

However, as discussed in section 2, stated willingness to pay for a new product is often higher than actual willingness to pay. To account for this problem we introduce an upward response bias variable u [5] which we subtract from the stated percentage price premium p_i. As a result the actual price premium that the consumer is willing to pay is $p_i - u$ [6]. So the actual fraction of consumers who are potential adopters (those for whom $p_i - u > 0$) which we call v will be smaller than v_0. Also, to account for the free rider problem, as discussed in section 2, we introduce an additional effect on the population of potential buyers such that

(Contd.) coefficient of imitation in Bass (1969) is influenced by both mass media and word-of-mouth.

5 The model assumes that a single reliable WTP CV methodology is used. The model is flexible enough, however, to accommodate to differing opinion about the validity of WTP estimates as represented by different values of u (upward response bias). u is, however, assumed to be constant over time

6 Note that the upward bias in the model is introduced as a percentage of price. Since energy prices are assumed to be constant so is u.

$$N(t) = N_0 v e^{-r(t)} \tag{9}$$

where $r(t)$ captures the effect of the free rider problem. We assume that the upward response bias effect is constant over time while the free rider problem effect reduces over time $r'(t) < 0$ and ultimately disappears as network and reciprocity effects gradually dilute individuals' concerns about free riding by others. The effect of defining $N(t)$ as above means that the population of potential buyers now increases over time,

$$\frac{dN(t)}{dt} = N_0 v \frac{d\left(\frac{1}{e^{r(t)}}\right)}{dt} = -N_0 v \frac{e^{r(t)} \frac{dr(t)}{dt}}{[e^{r(t)}]^2} > 0 \tag{10}$$

Substituting N with $N(t)$ and following the same steps as above yields the same differential equation for $F(t)$ as in (5) which together with the initial condition $F(0) = 0$ has the same solution as in (6). As a result the number of buyers up to time t now becomes

$$K(t) = Y(t) = N(t)F(t) = N(t) \frac{1 - e^{-(m+w)t}}{\frac{w}{m} e^{-(m+w)t} + 1} \tag{11}$$

Comparing $K(t)$ with $WTP(t)$ we find that $K(t) < WTP(t)$ as $N(t) < N$.

4.3 Actual adoption

Besides the upward response bias and the free rider problem various 'market imperfections' have been identified to affect actual adoption levels and thus the diffusion of new product, such as consumer confusion, lack of supply or lack of consumer trust (See Section 2.3.). At this point we further extend our model to take account of one such market imperfection, namely supply side problems. By doing this we can incorporate differences in the market environments in different countries. We therefore assume that of the population of potential buyers only one constant fraction can have their demand satisfied[7] so that if the population potential is $N(t)$ then the actual population of buyers for the product is $\bar{N}(t) = dN(t)$, where $d \in (0,1)$ [8]. Substituting $N(t)$ with $\bar{N}(t)$ and following the same calculations as above yields the same differential equation for $F(t)$ as in (5) which together with the initial condition $F(0) = 0$ has the same solution as in (6). As a result the number of buyers up to time t becomes

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[7] Alternatively we could use Jain *et al.* (1991) and introduce a number of Waiting Applicants $D(t)$ who would like to consume the product but their demand cannot be met due to lack of supply. In this case $N(t) - D(t)$ would be the actual population of potential buyers. The merit of using our approach is that our differential equation characterizing the diffusion process has an explicit solution which is not the case in Jain et al. (1991).

[8] To account for different 'market imperfections', d can also reflect for example poor regulation or consumer confusion or mistrust.

$$A(t) = Y(t) = \overline{N}(t)F(t) = dN(t)\frac{1-e^{-(m+w)t}}{\frac{w}{m}e^{-(m+w)t}+1} \tag{12}$$

Comparing $A(t)$ with $K(t)$ and $WTP(t)$ we find that $A(t) < K(t) < WTP(t)$ as $\overline{N}(t) < N(t) < N$.

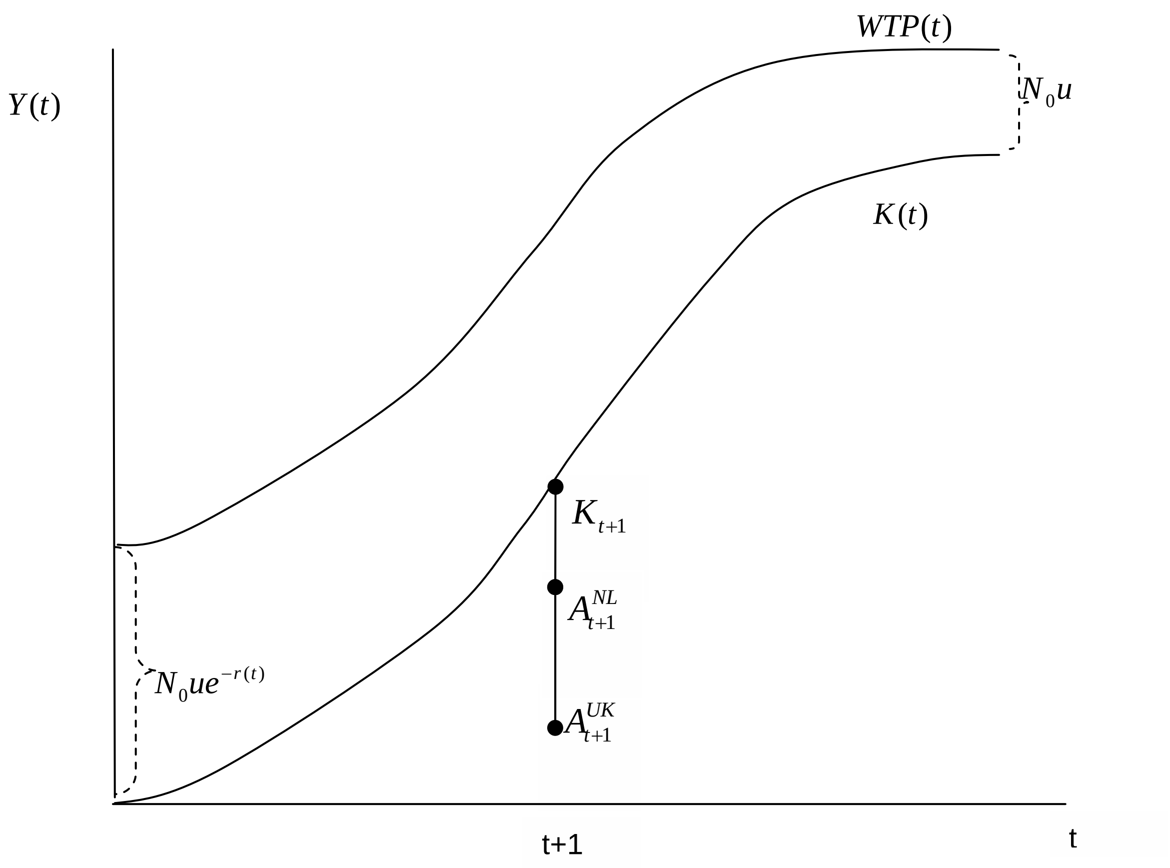
The framework provided above links willingness to pay ($WTP(t)$), the concept of 'achievable adoption' ($K(t)$) and actual adoption ($A(t)$) with the aim to conceptualize the various factors (u, $r(t)$ and market imperfections as captured by d) that can explain differences between actual take-up and willingness to pay. We can see how incorporating the different factors leads to different levels of adoption of the product and how actual adoption can be related to achievable adoption and stated willingness to pay.

A graphical representation of the model is depicted in Figure 3 using the examples of the green energy markets in the Netherlands and the UK (See Section 2). This depiction further assumes that the UK and the Netherlands have identical 'diffusion' trajectories for $K(t)$ and $WTP(t)$. This implies that both countries are culturally identical since u would have to be the same in both countries. This means that citizens of one country are no more likely to over-report their propensity to adopt green tariffs than those of the other country or indeed that citizens of both report equivalent WTP at any point in time[9].

It is apparent that both countries at time t+1 have not achieved their shared penetration ceiling (K_{t+1}); however, the UK underperformed relative to the Netherlands ($A_{t+1}^{NL} > A_{t+1}^{UK}$). The differences between K_{t+1} and A_{t+1}^{NL}, and between K_{t+1} and A_{t+1}^{UK} arise as a result of the type of market imperfection in the adopter environment, such as supply constraints, discussed earlier. If we take d as a composite effect of the market imperfections it is evident that $d_{t+1}^{NL} > d_{t+1}^{UK}$ so that market imperfection and supply constraint are more pronounced in the UK than the Netherlands. From Figure 3 it is clear UK market imperfections are large (a small d) and they have held back the development of the market. Interestingly, one of the assumptions that underlies the Bass (1969) model is that supply constraints do not limit diffusion (Rogers 1995, p.83). As discussed in Section 2.3, supply constraints have been seen as an impediment to the development of the green energy markets in the UK. Supply constrains became an issue also in the Netherlands, but only after a high level of tariff penetration was achieved.

9 Note: Our model can be easily modified to account for country differences in over-reporting of propensity to adopt green tariffs.

Figure 3: Diffusion model of induced environmental market



5. Conclusions and Policy Implications

By linking the willingness to pay literature with the established innovation diffusion literature this paper has provided a conceptual framework with which to understand the large disparities that have been observed between actual adoption of green energy tariffs and stated willingness to pay for such tariffs. Further and most important of all, the empirical context and the model highlight that $WTP(t)$ and, therefore, achievable adoption ($K(t)$) is not constant and is likely to change over time as ecological concern rises. This is consistent with the notion in the Efficient Market Hypothesis in finance that though markets trend based on fundamentals, prices are constantly changing in response to news flow. Indeed, the notion that penetration ceilings are not constant is recognised in the innovation diffusion literature (Griliches 1980; Kemp and Volpi. 2008). This may highlight to policymakers that the potential of such markets may take time to reap and that the low penetration rates of today may reflect a conventional trajectory of a diffusion process.

Further, for the model to have greater policy benefits a methodology for estimating $K(t)$ is required. Since $WTP(t)$ and $A(t)$ can be estimated then estimates of $K(t)$ would give researchers some idea as to the relative importance of u and r versus market imperfections (d) in explaining large differences between $WTP(t)$ and $A(t)$. It would, therefore, facilitate an assessment of the value of the market imperfections. This would allow policymakers to conduct cost-benefit analyses of policies aimed at correcting the market imperfections.

A critical assumption in the model is that energy prices are constant. This does not hold in practice. It is clear from the evidence presented in Section 2.1. that the relative price of energy is important and that, as in the UK, significant rises in energy prices are likely to be associated with a drop in WTP. This indicates that green tariff may have counter-cyclicality to generators investment incentives. When energy prices are high generators will be incentivised to invest in RES while consumers will be put off contributing to RES investment via green tariffs. The opposite is true; a low price environment will imply poor incentives for generators to invest which is offset somewhat by greater WTP/take-up of green tariffs. It is, however, unlikely that this greater WTP will replace all, or indeed to large extent, the lost generating inventive thereby implying that more support may be needed for RES from supply side support mechanisms (e.g. higher FITs/subsidies). This interaction between demand (green energy tariffs) and supply (FIT, GCM) side incentive systems in differing price environments would appear to offer an interesting avenue for further research. Further, it is likely that a volatile price environment will cause commitment problems for green energy markets. Consumers may be reluctant to switch to green tariff in low price environments if they fear a high likelihood of price hikes in the near future, as this would force them to switch and incur switching cost (real or informational).

Notwithstanding the above need for more research, it is clear that a high energy price environment may be inconsistent with policies to support voluntary consumer contributions towards renewables investment through green energy. If a self-selecting group of consumers are to contribute to the funding of renewables investments through green tariffs it appears that low and stable energy prices may be a precondition.

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