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Adoption of alternative fuel vehicles: Influence from neighbors, family and coworkers

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A B S T R A C T

During the last years, many governments have set targets for increasing the share of biofuels in the transportation sector. Understanding consumer behavior is essential in designing policies that efficiently increase the uptake of cleaner technologies. In this paper we analyze adopters and non-adopters of alternative fuel vehicles (AFVs). We use diffusion of innovation theory and the established notion that the social system and interpersonal influence play important roles in adoption. Based on a nationwide database of car owners we analyze interpersonal influence on adoption from three social domains: neighbors, family and coworkers. The results point primarily at a neighbor effect in that AFV adoption is more likely if neighbors also have adopted. The results also point at significant effects of interpersonal influence from coworkers and family members but these effects weaken or disappear when income, education level, marriage, age, gender and green party votes are controlled for. The results extend the diffusion of innovation and AFV literature with empirical support for interpersonal influence based on objective data where response bias is not a factor. Implications for further research, environmental and transport policy, and practitioners are discussed.

1. Introduction

With emissions from the transport sector growing more rapidly than other sectors and with an estimated doubling of these emissions by 2050, the transport sector is of key importance in climate change mitigation (Creutzig et al., 2015). As the problems become ever more pressing, alternative technologies that rely less on fossil fuels are being developed and diffused in markets. Alternative fuel vehicles (AFVs) are vehicles that can be fueled by alternatives to fossil gasoline and diesel in part or in full. Among the most common ones today are different types of electric vehicles (i.e., battery-electric, hybrids, and plug-in hybrids) but there are also cars available to consumers that can be fueled by ethanol, biodiesel, biogas and hydrogen. The total environmental impact of the car fleet is likely to decrease if fossil conventional vehicles (CVs) are replaced by AFVs and alternative fuels, by large consumer groups (Rezvani et al., 2015; Schäfer et al., 2009). Thus under-

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standing consumer adoption of new technologies is an important condition for the long-term success of a future less environmentally harmful transport system and for crafting policies to that effect (Axsen and Kurani, 2011; Mau et al., 2008; Ozaki and Sevastyanova, 2011).

In the literature that is developing with the purpose of better understanding consumer adoption of AFVs several frameworks and theoretical models have been used (for comprehensive reviews see Rezvani et al., 2015; Turcksin et al., 2013). For example several studies have highlighted the importance of actual and perceived vehicle attributes using conceptualizations such as perceived relative advantage, compatibility, trialability, observability, and risk (Jansson, 2011; Moons and De Pelsmacker, 2015; Peters and Dütschke, 2014; Petschnig et al., 2014) as well as other related aspects such as vehicle use, fuel consumption, tax incentives and pollution reduction (He et al., 2012; Hidrue et al., 2011; Mannberg et al., 2014). Other studies have looked into attitudinal psychological factors such as values, beliefs, norms and environmental awareness and responsibility, influencing intentions to adopt or actual adoption (Caperello and Kurani, 2011; Egbue and Long, 2012; Jansson et al., 2010). Yet other studies focus on the influence of sociodemographic factors (such as age, gender and education) on the adoption decision (Jansson, 2011; Potoglou and Kanaroglou, 2008, 2007; Ziegler, 2012). Several studies combine factors and also rely on theoretical frameworks (or parts thereof) such as the theory of planned behavior (Egbue and Long, 2012; Lane and Potter, 2007; Moons and De Pelsmacker, 2012), the value-belief-norm-theory (Jansson et al., 2010; Petschnig et al., 2014), and the diffusion of innovation theory (Jansson, 2011; Peters and Dütschke, 2014; Petschnig et al., 2014). In spite of this quickly developing literature, and thus increasing understanding of AFV adoption factors, a detailed understanding of interpersonal influence on the adoption decision is still lacking. This is somewhat surprising given that cars are highly visible products (Jansson, 2011; Johansson-Stenman and Martinsson, 2006) and that marketing theory (Bearden and Etzel, 1982; Buttle, 1998; Chevalier and Mayzlin, 2006; Childers and Rao, 1992), as well as diffusion of innovation theory (Rogers, 2003; Young, 2009), view influence from others as a key factor in consumer behavior. This deficiency in the AFV adoption literature has been noted by others as well. For example, according to Axsen and Kurani (2011), transportation researchers are only beginning to explore interpersonal influence as a driver for adoption. Therefore, although other factors are important for AFV adoption, the focus in this paper is on interpersonal influence.

Although there is a lack of studies on interpersonal influence on AFV adoption, it does not mean that it's a new idea as such. In fact, a fundamental pillar of diffusion of innovation theories is the influence from the social system in one's spatial vicinity (Hägerstrand, 1967; Rogers, 2003, 1962). This effect has sometimes been termed the neighbor effect (Axsen et al., 2009; Mau et al., 2008) and the neighborhood effect (Hägerstrand, 1965; Zhu and Liu, 2013). The few empirical studies that exist have found that potential AFV adopters are more likely to purchase AFVs when exposure to them is high in the surrounding areas (Mau et al., 2008; Zhu and Liu, 2013) proving that the value or utility of these vehicles become higher as more people close by adopt. Axsen and Kurani (2011) also found that most households ranked at least one social interaction as being highly influential of their assessment of the AFV in a demonstration project type setting. From an environmental psychology perspective there are many studies pointing to the importance of interpersonal influence in the form of social and personal norms on AFV adoption (Jansson, 2011; Ozaki and Sevastyanova, 2011; Petschnig et al., 2014). However, these studies generally do not specify from where the social influence comes, just that it is an influential factor in adoption.

In much of the developing literature on interpersonal influence and AFV adoption there is a heavy reliance on consumer reported information using for example interviews in demonstration projects and different types of self-administered questionnaires. Although valuable for understanding the influence of attitudinal factors and previous experiences, relying only on self-report interviews and surveys in researching interpersonal influence runs the risk of the respondents over- or underestimating these types of influences based on what information is currently salient in their minds (i.e., the availability bias, Tversky and Kahneman, 1973). In addition, most studies investigating social normative influence do not explicitly examine from where in the social system this influence comes. This is problematic since good communication strategies rely on segmentation and understanding target groups in order to communicate with the relevant groups regarding new environmental innovations or policies.

The study conducted here aims to overcome the theoretical as well as empirical problems of the extant literature on AFV adoption discussed above. Thus, the main purpose of this paper is to explore how membership in social domains is related to AFV adoption. Although the main focus is on interpersonal influence from three domains (neighbors, family and co-workers), based on the literature, we also control for sociodemographic factors that have been found in previous studies to be important. In addition, instead of relying on self-report data, we use a national database of the entire car owning population in a country. Since the database contains actual, objective data on car ownership, place of residence, family ties, and work location, together with sociodemographic and voting data, we are able to investigate interpersonal influence without asking respondents to remember who influenced them to do what in their adoption decisions. Thus, based on diffusion of innovation theory, and previous survey based studies, we develop a model of interpersonal influence incorporating influence from neighbors, family and co-workers. Using logistic regressions on the data set covering car purchases in 2008 (the year most flex-fuel cars were sold) in Sweden, we test the relationships and also add sociodemographics as controls. We then compare our results with previous research and draw conclusions and implications relevant for researchers, practitioners and policymakers. As such we add a novel perspective of interpersonal influence measured objectively to the insights from previous survey-based adoption studies.

2. Background

In this section we first discuss the diffusion of innovations framework and interpersonal influence concerning car choices and then introduce the market for AFVs in Sweden where the study was conducted. In this presentation we place specific emphasis on flex-fuel vehicles (ethanol/E85 and gasoline compliant cars) as these are the types of AFVs we use as the empirical example.

2.1. Diffusion of innovations and interpersonal influence

A fundamental tenant of how innovations diffuse on a market is that they spread unequally fast in different social systems. The rate of consumer adoption is influenced by the innovation at hand, communication channels, time, and, the social system, according to diffusion of innovation theory (Rogers, 2003). The importance of the social system is also emphasized studying diffusion from a spatial perspective by for example Hägerstrand (1967). Stating that diffusion essentially is about communication, he argued that innovation adoption is more likely to happen in the vicinity of existing adoptions, naming this relation the neighborhood effect (Hägerstrand, 1965). The effect essentially stems from potential consumers becoming aware and learning about innovations from neighbors close by and thereby becoming more likely to adopt these innovations themselves. Innovation adoption then occurs in a way which indicates that a new adoption is more likely to follow in the vicinity of existing adoptions than further away from them. Thus, the saturation stage may be reached in the central area of dispersal while the density of adoptions is still low in peripheral areas (Hägerstrand, 1965). "The importance of the neighborhood effect suggests that the links between individuals in circles of acquaintances and friendship play a remarkably important role for directing information and influence." (Hägerstrand, 1965, page 28) This neighbor/hood effect has since its initial conceptualization been incorporated explicitly or implicitly in much theorization on diffusion of innovation and innovation adoption and as such has been linked to how interpersonal influence in general affects awareness and adoption of new innovations (Rogers, 2003; Wejnert, 2002; Young, 2009). The explanation for the effect relates to that support from influential others has an important influence on what action a potential adopter chooses to take since individuals adapt their attitudes and behaviors to their social context (Lu et al., 2005). This is due to that innovations create uncertainty about their expected consequences for potential adopters. Individuals interact with the social network to consult on their adoption decisions since they are uncomfortable with uncertainty (Burkhardt and Brass, 1990; Lu et al., 2005). In many areas there is wide support for the importance of interpersonal influence in adoption and diffusion. Electronic services such as banking, online gifts and wireless internet (Kim and Park, 2011; Lee et al., 2002; Lu et al., 2005), high-tech innovations such as personal digital assistants (Kulviwat et al., 2009) and new drugs and health risk perceptions (Morton and Duch, 2001; Prosser et al., 2003), are a few examples.

In addition to interpersonal influence having a general effect on adoption, the influence of strong and weak ties to other individuals and networks has also been discussed (Granovetter, 1973). In this vein it has been argued that the stronger the ties connecting two individuals the more similar they are. Since first adopters (called innovators) have been considered as having marginal influence, the speed of the diffusion of an innovation does not pick up until the next group (early adopters) begin to adopt and spread the innovation (Rogers, 2003). This is because early adopters are a more integrated part of the social system than innovators. Thus an innovation to be diffused can reach a larger number of people (called early majority and late majority), and traverse greater social distance, when passed through weak ties rather than strong ties, since more weak ties exist than strong in larger social systems (Granovetter, 1973). This can account for the fact that diffusing innovations to innovators in the social system is not enough in order for the innovation to be widely adopted. Thus, influence from different parts of the social system, where a spread of adopter types exist, is important for the diffusion at an aggregate level.

In the developing literature investigating the diffusion of AFVs, relative to the amount of studies, only a few attempts have been made to understand the role of interpersonal influence. Axsen and Kurani (2011), using a qualitative explorative approach find that interpersonal influence plays an important role in participants' assessment of plug-in hybrid vehicle (PHEV) technology. In another study, using a combination of stated and revealed preferences, Axsen and colleagues settle the existence and importance of the neighbor effect in simulating technological changes (Axsen et al., 2009). In addition, in a simulation, Struben and Sterman (2008) show that word of mouth is important in stimulating diffusion of AFVs. Furthermore, in another simulation, Mau et al. (2008) find support for their hypothesis that changes in the degree of market penetration of "clean" vehicle technologies had impact on people's preferences, which they also refer to as the neighbor effect. Zhu and Liu (2013) also found evidence of a neighbor effect researching the adoption of hybrid electric vehicles (HEVs) in Florida. They mean that these findings indicate that potential buyers are more likely to purchase HEVs when HEV exposure is high in the surrounding areas (both urban and rural), and that this measurement of exposure proved useful for the neighbor effect (Zhu and Liu, 2013).

In terms of the AFV being an eco-innovation, which purports to lessen environmental harms compared to conventional cars, the attitudes and behaviors of others function as a moral compass showing the direction towards moral rightness (Nyborg et al., 2006). Thus, there is also a wealth of studies attesting to the general importance of pro-environmental norms (a form of interpersonal influence) for AFV adoption (e.g., Jansson, 2011; Ozaki and Sevastyanova, 2011; Petschnig et al., 2014). However, these studies do not point at from what social domains this influence comes, or from where it is strong or weak. There is also survey evidence pointing at the importance of interpersonal influence adoption. For example it was found that 75% of adopters of AFVs in 2006 and 80% in 2008 in Sweden were acquainted with other adopters, whereas non-adopters to 30% and 47% respectively, had these acquaintances (Jansson et al., 2009). Although the results accounted for above point to the significance of the social network for innovation adoption and the neighbor/hood effect, these findings rely to a large extent on simulations and respondent self-reports; the latter being susceptible to recall bias. As pointed out by Nyborg et al. (2006), these recollections might be susceptible to the availability bias (e.g., Tversky and Kahneman, 1973) and effects of personal influence overestimated by the respondents (knowingly or unknowingly). Furthermore, although valuable, these studies do not point to where in the social context the influence can be found with statistical certainty.

Based on the above discussion we expect that interpersonal influence in social domains will have an impact on AFV adoption. Although interpersonal influence can occur through many types of relationships, it is likely that relations and ties in some social domains have stronger influence than others. Thus, to investigate what type of social influence is stronger in the consumer decision between a conventional vehicle (CV) and an alternative fuel vehicle (AFV) we make use of three social domains: neighbors, family and coworkers.

2.1.1. Influence from neighbors, family and coworkers

Due to the novelty of exploring interpersonal influence using an objective dataset we do not develop directional hypothesis in this study. Instead, based on previous studies, we put forth propositions regarding the three social domains. In addition, also due to our explorative purpose, we introduce several sociodemographic controls, discussed further below.

The first social domain we focus on refers to the neighborhood. We propose that individuals in the person's immediate neighborhood will have an effect on adoption. This is in line with previous research and the neighbor effect (Axsen et al., 2013; Mau et al., 2008; Zhu and Liu, 2013). This group of people represents the geographical context where the individual is likely to spend time and display driving habits and choice of car. As a consumer product, cars are extremely visible to others, in fact much marketing of cars is focused on design and image aspects that purport to convey status of the driver (Johansson-Stenman and Martinsson, 2006). In addition, most urban areas are segregated in terms of socioeconomic characteristics and ethnicity (e.g., Forrest and Kearns, 2001), and thus people living nearby are likely to be similar to each other and this may also be the case for AFV ownership. The fundamental tenant is that the more neighbors that adopt AFVs, the more desirable it becomes for other neighbors to do the same (e.g., Zhu and Liu, 2013).

The second domain we focus on is the family. It is proposed that both immediate family (i.e. spouse, parents and children) and relatives outside the nuclear family may have an influence on adoption. Research in moral development (e.g., Gilligan, 1982; Kohlberg, 1981) point to the importance of the immediate family as an important reference point for values and moral beliefs to develop. Thus it is likely that the family also influences decisions that are perceived to have positive or negative effects on the environment. In their study Axsen and Kurani (2011) showed that interactions between family members played an important role in buyer's assessments of plug-in hybrid vehicle technology.

The third domain concerns the individual's coworkers that were also identified in the Axsen and Kurani (2011) study. Cars are visible products when parked outside offices and factories and are likely often topics of discussion among coworkers (e.g., Jansson, 2011; Johansson-Stenman and Martinsson, 2006). For example, previous research has discussed that one factor behind the relative success of the Toyota Prius (gasoline/electricity hybrid) was its design, making it more visible in the community (Kahn, 2007; Ozaki and Sevastyanova, 2011). Many AFVs have design elements signifying their environmental aspects, but several makes and models also look very similar to ordinary CVs. Thus, interaction among car owners is to some degree required in order for information of fuel type to spread in a social system. In Sweden it is quite common for white collar workers to have cars as subsidized company cars which might generate discussions among coworkers especially since the regulations and financial incentives regarding these cars have been altered several times as AFVs have been introduced. This makes the coworker domain particularly interesting to study.

2.1.2. Sociodemographic factors

Many studies focusing on the influence of personal and social norms in the adoption of AFVs, have also analyzed the influence of other factors in relation to the studied behavior. For example sociodemographic factors, such as age, education length, gender and income level have been found to have different effects in different studies (e.g., Jansson, 2011; Johansson-Stenman and Martinsson, 2006; Mannberg et al., 2014; Petschnig et al., 2014; Potoglou and Kanaroglou, 2007). However, due to ambiguous results in earlier studies, it is not possible to state beforehand what effects social influence might have when control factors are introduced. However, due to the explorative nature of our study we are interested in controlling for as many factors as possible. For this purpose we control for income, education level, marriage, age, gender, and green party votes. Green party votes in an area, is used due to the effect that people with similar characteristics tend to self-select into certain geographical areas (Massey and Denton, 1988). In line with previous studies (e.g., Kahn, 2007), we assume that green party support is likely related to AFV adoption. Since we primarily are interested in the relation between AFV adoption and the three social domains we sought a way to control for other confounding factors. By controlling for green party votes in the neighbor domain we, to some extent, control for the self-selection into neighborhoods and thus the fact that similar people (with similar voting preferences) gather together.

2.2. Policy initiatives and the market for AFVs in Sweden

Road transport contributes about 20% to the European Union's (EU) total emissions of carbon dioxide (CO2), the main greenhouse gas. Of the CO_2 emissions, light-duty vehicles (cars and vans) produce approximately 15% of the EU's total emissions (EC, 2014). In addition to the CO_2 problem which follows from the almost exclusive use of fossil fuels (gasoline and diesel), the current situation is in conflict with goals concerning renewable energy in the EU. To come to terms with these problems, the EU established the goal of reaching a 5.75% share of renewable energy in the transport sector by 2010 (EC, 2003). In 2009, this share was increased to a minimum of 10% in every member state by 2020. Another directive also aimed to ensure the use of sustainable biofuels only, defined as generating clear and net greenhouse gas savings without negative impact on biodiversity and land use (EC, 2009). As such the greenhouse gas emissions must be at least 35% lower than from the fossil fuel they replace currently; from 2017 this increases to 50%. Policies like these form the basis for national policies in the EU member states, however countries can decide on faster implementation.

In Sweden the focus was put on introducing ethanol for cars (both blending 5% ethanol in ordinary gasoline, but also on supplying E85 which is a blend of 85% ethanol and 15% gasoline) after a directive was enacted in 2004 in which AFVs were defined in order to promote government agencies to procure them to a higher degree (SFS, 2004). This also impacted the private market where flex-fuel cars (cars with the possibility to be fueled by E85 ethanol and gasoline in different blends) became the most common AFV in Sweden (see Fig. 1).

With the aim of securing supply and infrastructure development, the first of April 2006 a filling station mandate was enacted requiring filling stations above a certain size to supply at least one alternative fuel (SFS, 2005). In a few years this meant that Sweden had the largest ethanol (E85) distribution network outside Brazil (Pacini and Silveira, 2011) with more than 1300 E85 pumps in 2008 (see Fig. 2). Another effect of the filling station mandate, together with more fuel efficient cars thus needing to be filled less often, was that outdated and very small filling stations closed down, especially in rural areas with low population density. The sales of ethanol/E85 in Sweden has varied over the years, however in 2008 a total of 207,364 cubic meters were sold which was 4.3% of all fuels sold in Sweden that year.

Furthermore, in 2006, alternative fuels were highlighted in a report aiming at breaking Sweden's fossil oil dependence by 2020 (Commission against oil dependence, 2006) and in the same year it was decided to further investigate a coordinated climate and energy framework which also brought up alternative fuels (Swedish government, 2006). In 2009 it was proposed that Sweden should aim for a fossil oil independent car fleet by 2030 (Swedish government, 2009).

The different policies promoting AFVs in general and flex-fuel ethanol cars in particular, together with other factors, led to that the sales of these cars kept climbing from about 2% of all new cars sold in Sweden in 2004 to more than 21% in 2008. Thus in 2008, consumers were given a relatively open choice of car models and fuel types to choose from since there were many models available in all car model sizes. The same, or similar, car model would often be available in an AFV version and with traditional gasoline and diesel engines. The infrastructure for distributing E85 was also in place in most of Sweden by 2008. As a consequence E85 was widely available. Since flex-fuel vehicles can be fueled by both gasoline and ethanol to varying degrees without any alterations to the engine, the environmental impact varies depending on how consumers decide to fuel their cars. According to the Swedish Road Administration, in 2008, 90% of the fuel used in flex-fuel cars was ethanol, which is the highest proportion reported for a single year before or after (Swedish Transport Administration, 2014). No estimate for how the increase in ethanol sales affected the emission of greenhouse gases (GHG) is available for 2008. However, in 2011 when sustainability and origin reporting was commenced due to the EU directive, the average GHG reduction of ethanol in Sweden compared to fossil fuels was 66% according to the Swedish Energy Agency (2014).

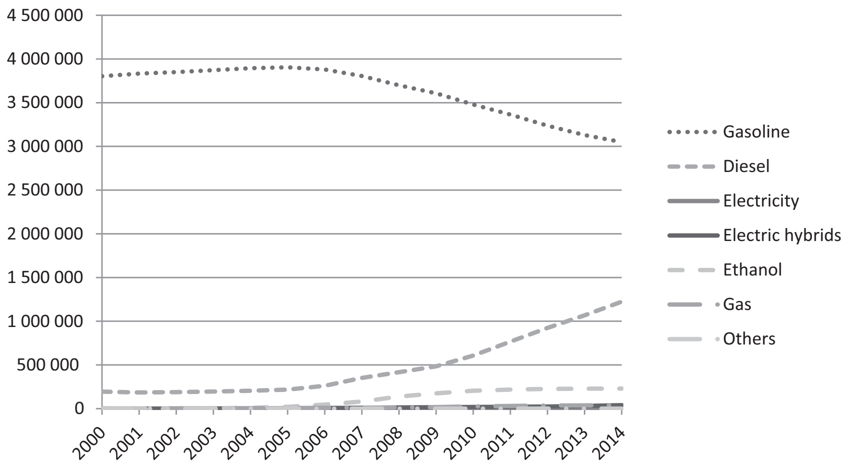

Fig. 1. Number of cars in Sweden and fuel type. *Source:* Trafikanalys, 2015.

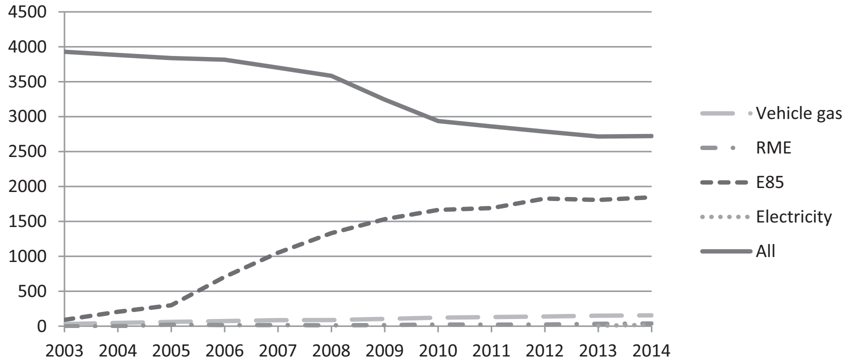

Fig. 2. Fueling stations and types of alternative fuels. *Source:* SPBI, 2015.

3. Method

In order to analyze the influence of the three social domains (neighbors, family relations and coworkers) on AFV adoption several methodological choices were necessary. Due to the wide availability of car makes and models, and the relatively high sales of AFVs and fuels in 2008 in Sweden this year was chosen as the year of analysis. Another factor behind this choice was that it takes several years for data to be read into, and controlled for accuracy, in the databases of the type we use, which makes analyzing more current data more prone to error sources.

Due to our interest in interpersonal interactions, we chose to focus on private consumers rather than corporate purchasers. Considering that some makes and models of flex-fuel cars were developed with significantly different features than their conventional counter-parts we decided to look for a car model that was available as flex-fuel as well as gasoline and diesel types during 2008. This choice was made to avoid the risk that consumers primarily choose the flex-fuel car based on other reasons than the engine type and environmental aspects. Furthermore, in order to control for status and image effects as much as possible, we wanted to use a make and a model that was neither a luxury, nor a budget alternative. Finally, since brand loyalty is an influential factor in car replacements (e.g., Lambert-Pandraud et al., 2005) we wanted to control for this factor as well. If adopters of different makes and models were to be analyzed, the proposed relations could be brand effects rather than tied to the social domains in focus for the study.

After going through the sales figures for all cars in Sweden for 2008 with the above criteria in mind, we arrived at the Volkswagen Golf as the best fitting example of a vehicle fulfilling our criteria. Volkswagen Golf is one of the most well-known cars and is continuously one of the most sold cars in Sweden year after year. Furthermore, the Golf is neither a budget alternative nor a luxury car, although with extra equipment and more powerful engine, it can be equipped as some of the more expensive cars on the market. There was thus a substantial sample to work with as well. According to official sales numbers a total of 11,198 new Golfs were registered in Sweden in 2008 and of these 5610 were registered to private individuals (Bil Sweden, 2009). During that year the Golf came in flex-fuel versions (1684 new registrations to individuals), diesel versions (1181 registrations) and gasoline versions (2745 registrations), and all these cars make up our sample. The price differences between the different engine versions were in general small. For example, the average price of the flex-fuel versions were 15% cheaper than the average price of the gasoline versions, whereas the diesel versions on average were 11% more expensive compared to the gasoline versions (based on sales price averages as reported by resellers in November 2008 to Bil Sweden, made available in personal communication, own calculations).

3.1. Data source

For the purpose of this research, we make use of register data collected by Statistics Sweden (SCB). The database covers the entire population registered in Sweden and it includes individual level demographic and socioeconomic indicators such as age, sex, education level, income and employment. Moreover, the data set also consists of information on car ownership. For those individuals who own a car (or several cars) there is also a set of variables describing the characteristics of the car, e.g., make and model of car, registration day, fuel type, engine power in kilowatts, weight, environmental class, etc.

Having access to the link between individuals and their cars is an important feature for this research, but available data also provide relational information between individuals. This makes it possible to incorporate the notion of social domains which means that social interaction is not a random process between individuals residing in a region, country or any other spatial entity. A particular person's social interaction is to a large extent restricted to a variously small subset of the total population with weaker or stronger ties to different individuals (Granovetter, 1973). Our available register data makes it possible to, for each of the individuals, identify a particular group of other people that this specific individual is exposed to and thus will likely have some connection to.

As introduced above, these connections are subdivided into three different social domains related to neighbors, family, and coworkers. Neighborhood is defined as the immediate vicinity around the place of residence. Neighbors living within the same hectare grid ($100 * 100$ m) represent the neighborhood population. Our data does not carry any information about individuals' perceived neighborhoods, which may be more narrow or extensive than the defined squares. Admittedly, the use of a distance decay function would have solved this problem, but we could not get access to data needed to estimate the non-linear slope of the decay function. Therefore, we decided to investigate the potential of utilizing high resolution spatial data, which enables the portrayal of small geographies and human interactions close to the place of residence. Data sets for research that combine characteristics like small geographies and country-wide population register data are rare and may make a good contribution in this respect. Furthermore, family refers to bonds bringing parents and children together excluding more distant family relations e.g. uncles, aunts, cousins, etc. Coworkers are individuals that are interacted with on the workplace. Firms and organizations sometimes organize their economic activities in different workplaces found at different locations. Here we have access to data on workplace level, which means that an individual's coworkers at work can be found in the data set and their characteristics in relation to car ownership can be observed.

As may be noted from the above presentation, the number of people involved in the three social domains is subject to variation according to different definitions. However, our guiding principle when deciding on the size of the domains is that the chances for accepting a new innovation leading to the adoption of new technology (e.g. purchasing an AFV) is probably at its strongest close to the individual and weakens further away (Hägerstrand, 1953; Wolf, 2010). Based on this line of thought, the social domains should only incorporate those people that stay close to the individual, i.e. nearest neighbors, closest family, and coworkers at the same firm localization. By using this dataset we are able to identify individuals who purchased a new Volkswagen Golf in 2008 and we can map owner characteristics as well as similar characteristics of their neighbors, family members, and fellow workers. Moreover, this procedure makes it possible to use reliable data and avoid reliance of self-reports on interpersonal influence and, for example, income (considered by many to be a sensitive issue in Sweden resulting in bias and non-responses in self-report surveys).

3.2. Measures

All Volkswagen Golf purchases in 2008 were used in the analyses. In total this meant that 5,610 Golfs made up the sample and of these 1,690 were AFVs and 3,920 CVs (gasoline and diesel).

In order to measure the effects of interpersonal influence the three social domains were operationalized in different ways. The neighbor domain variable represents the vicinity of the individual's place of residence. Individuals living nearby do not necessarily socialize with each other on a regular basis, but they are likely to have ties as many are superficially acquainted and know their neighbors (Granovetter, 1973). A car is a visible product constantly exhibited on the driveway or in the parking lot in full view of everybody to notice and comment upon. It may be argued that this setting between neighbors quickly fades away as the distance from the place of residence increases. For example, you are likely to talk to or notice the neighbor across the street but you will most likely not pay attention to the person living ten blocks away. In this interpersonal influence respect, the neighborhood is a very local phenomenon. The spatial resolution of data enables us to zoom in as close as hectare grids ($100 * 100$ m squares), which represents a relevant vicinity for this purpose. Thus, the neighbor domain variable is defined as the share of AFVs of any type in percent, of all cars owned by neighbors in this vicinity in 2007. Choosing 2007 as the year is done since this will allow for time from one individual's adoption and interpersonal influence to have an impact on another person's actual adoption decision in 2008.

The variable family domain is defined as the share of AFVs among nuclear adult family members (i.e. father, mother, sibling, children, grandparents, and, grandchildren) in percent residing in the same municipality in 2007. AFVs owned by family members do not necessarily have to be Volkswagen Golfs, but any make meeting the AFV definition. We decided to omit family members living outside the municipality because of the distance decay effect, i.e., social interaction tend to decline as distance increases (Hägerstrand, 1953). Irrespective of family ties, social exchange on an everyday basis is likely to be smaller when residing in different parts of the country. In order to obtain reasonable time logic, the family domain variable was observed the year before the purchase of a new Volkswagen Golf in 2008. In this way we take into account that exposure is preceded by the purchasing decision. Thus, the variable family domain shows the share of family members owning an AFV in 2007.

The coworker domain refers to the workplace where the individual was employed in 2007. For individuals with more than one job contract during the year, data pertains to the employer paying the highest salary, which is an indicator of length of stay in the job. Employers running operations in more than one location have two or more workplaces which employees are connected to. Available data identifies the other coworkers in the particular workplace and this link makes it possible to observe their individual characteristics like car ownership. The coworker domain variable indicates the share of coworkers owning an AFV (Volkswagen Golf or any other AFV) in 2007 in percent.

In the analyses we control for income, education level (university degree), marriage, age, gender and green party votes. For the control factor green party votes we calculated the share of green party votes in the national election in 2006 (last previous election before 2008) for each of the approximately 6100 voting areas and used the percentage as a control variable. Percentage green party votes ranged from 0% to 24% across voting areas.

4. Results

In order to fulfill the purpose of exploring how interpersonal influence is related to choices of AFVs, several analyses were carried out. Firstly, descriptive data were analyzed for the sample of Golf owners and thereafter two logistic regressions were run with type of car (CV or AFV Golf) purchased as the dependent (categorical) variable. Thus the analyses build on the fact that Golf cars were chosen in 2008 by the studied individuals.

In Table 1 the descriptive statistics for our sample are presented. The descriptives pertain to the year 2007 since we are interested in how these influence the choice of type of Golf in 2008. Studying these numbers it is clear that 2008 adopters of AFVs (in this case the Golf flex-fuel ethanol version) have higher levels of neighbors, immediate family, and coworkers owning AFVs the year before compared to owners of conventional vehicles (CVs, i.e., gasoline and diesel fueled Golfs). In these calculations the Golf-owning individual her/himself (and other possible AFVs this person might own) are excluded so as not to confound the data. As presented in Table 1, 1.46% of all people in the neighborhood square own an AFV in the AFV adoption group (the year before adoption), whereas in the CV group, this percentage is 0.89. In the family domain the difference is even larger where 2.34% of the family members own an AFV in the AFV adoption group, whereas the corresponding figure is a mere 1.14% in the CV group. In the coworker domain 1.66% of all coworkers in the AFV group have adopted an AFV before, whereas in the CV group this number is down to 1.00%. In addition, the year before adoption, AFV owners have higher income, higher percentage of university degrees, are slightly older, are to a higher extent female, and vote to a higher degree for the green party, compared to CV owners. However, AFV adopters are to a lesser extent married than CV owners.

Next, the logistic regressions were run using AFV/CV owner as the dependent variable (Table 2). In Model 1, effects of the social domains were tested by themselves. All three domains were found to be statistically significant correlates of AFV adoption ($p < 0.05$) with the coefficient for the neighbor domain being the strongest (OR = 1.053, $p = 0.009$) and for the family domain the weakest (OR = 1.032, $p = 0.046$). The co-worker domain fell in the middle of the two (OR = 1.032, $p = 0.033$). Using odds ratios for the neighbor domain, the results can be interpreted so that a one percentage point increase in the percent of individuals owning an AFV in the defined neighborhood (in the year before adoption), would increase the odds of a person in that neighborhood adopting an AFV by 5.3%. The model achieved a Nagelkerke R-square of 0.018 ($p < 0.001$, N = 5,610).

In Model 2, the control variables were added to the three social domains. The neighbor domain is still significant ($p < 0.05$) and the family domain is significant at the 90% confidence level. The coworker domain is no longer significant. Of the controls, education level, age and gender are significant correlates (all $p < 0.05$). The effect of income and green party votes are significant at the 90% confidence level. Thus, individuals with neighbors and family members owning AFVs, higher education level, older, females and green party voters are more likely to choose an AFV (Golf) according to this model. It was also noted that although influence from two of the social domains were significant, the effects from education level and gender were stronger measured as odds ratios. This model achieved a Nagelkerke R-square of 0.056 ($p < 0.001$, N = 5,610). The main conclusion from Model 2 is that even when controlling for common sociodemographic factors, and green party votes (in order to control for self-selection to some extent), two of the three social domains are still significantly related to AFV adoption but the neighbor domain is the strongest and significant at the 95% confidence level.

5. Discussion

The main purpose of this paper was to explore how membership in social domains is related to AFV adoption. Based on previous literature concerning diffusion of innovations, interpersonal influence and AFV studies (Axsen and Kurani, 2011; Granovetter, 1973; Hägerstrand, 1965; Jansson et al., 2009; Ozaki and Sevastyanova, 2011; Rogers, 2003) we chose to explore influence from three domains: neighbors, family and coworkers. In the utilized dataset, car ownership was linked

Table 1
Descriptive statistics.

	AFV owner		CV owner	
	Mean	SD	Mean	SD
Neighbor domain, share of AFVs in percent[a]	1.46	5.03	0.89	3.15
Family domain, share of AFVs in percent[a]	2.34	13.65	1.14	9.17
Coworker domain, share of AFVs in percent[a]	1.66	6.30	1.00	3.36
Income, in thousands of SEK[b]	285.76	334.15	243.98	223.44
University degree, share of individuals in percent	35.56	47.88	28.10	44.96
Married, share of individuals in percent	56.50	49.59	57.38	49.46
Age, mean	53.20	13.92	52.35	14.51
Female, share of individuals in percent	38.00	48.70	33.00	46.90
Green party votes in percent, 2006 national election	5.18	3.21	4.63	2.54
n	1,690		3,920	

[a] Excluding own AFV.
[b] 1 SEK = 9.25 Euro (2007).

Table 2
Results of logistic regression models with AFV/CV owner as dependent.

	Model 1			Model 2		
	B	*OR*	*sig.*	*B*	*OR*	*sig.*
Independent variables						
Neighbor domain	0.051	1.053	0.009	0.039	1.040	0.044
Family domain	0.009	1.009	0.046	0.008	1.008	0.075
Coworker domain	0.032	1.032	0.033	0.017	1.017	0.157
Income				0.000	1.000	0.053
Education level				0.368	1.445	0.004
Married (1 = Married)				−0.007	0.993	0.953
Age				0.014	1.014	0.008
Gender (1 = Female)				0.487	1.628	0.000
Green party vote				0.039	1.040	0.061
Constant	−0.954	0.385	0.000	−2.286	0.102	0.000
Model -2 LL	2047.712		0.000	1974.857		0.000
Nagelkerke R^2	0.018			0.056		
N = 5,610						
OR = Odds Ratio						

to the domains and as an AFV we used the flex-fuel version of the 2008 VW Golf. We proposed that individuals being exposed to higher levels of AFVs, and thus interpersonal influence from these owners in the three different social domains would adopt an AFV to a higher degree than other car buyers. Based on logistic regressions our results show an effect of interpersonal influence from all three social domains when analyzed without control variables. The interpersonal influence from neighbors was the strongest, followed by the coworker influence and then the family influence. However, when controlling for sociodemographic factors and green party votes, the influence from the neighbors and family members become weaker, but still hold, but the influence from the coworker domain disappears. The overall result point to the importance of interpersonal influence as an innovation diffuses, and is in large part in line with previous literature, both within an outside the empirical area of AFVs (Hägerstrand, 1965; Mau et al., 2008; Zhu and Liu, 2013). The contribution of our study is that we are able to show the impact of interpersonal influence in relation to AFV adoption from three sources using observable data (as opposed to respondent self-reports) from three domains simultaneously. For example, whereas Zhu and Liu (2013) point to interpersonal influence from one domain (neighbors) our method allows us to compare this effect to influence from family and coworkers and distinguish that it is the most pronounced effect. Furthermore, whereas Mau et al. (2008), use market penetration rates of AFVs to simulate changing preferences, we are able to go beyond preferences and draw conclusions on actual adoption data. Finally, whereas Axsen and Kurani (2011), using an ambitious multi-method approach, investigate 275 social interactions in a demonstration project, we are able to analyze interpersonal influence and control for important sociodemographic factors in a generalizable sample of actual car buyers consisting of 5,610 primary agents.

A relevant question that the results raise is why the neighbor effect is the strongest of the interpersonal influences (with and without the controls) in our results. Based on previous research regarding the neighbor/hood effect however, the results are to some extent expected (Hägerstrand, 1965; Mau et al., 2008; Zhu and Liu, 2013). Cars are visible products, which has been pointed out in previous research (Egbue and Long, 2012; Jansson, 2011; Ozaki and Sevastyanova, 2011; Petschnig et al., 2014), and this visibility is likely one reason behind the strength of the effect. Since there might be other factors in the neighborhood behind this relation that are difficult to control for, we used green party voting as a proxy for pro-environmental attitudes to partially control for these factors. Even when controlling for this, our results point to the neighborhood as the most important domain for the diffusion of these types of products. So, although individuals with pro-environmental attitudes gather in certain neighborhoods (e.g., Kahn, 2007) there is still an effect of observing or being in contact with others close to one's home before the adoption decision is made. This is also in line with the exploratory results of Axsen and Kurani (2011) who found that neighbor interactions are important. So, what has been shown using other methods holds true even when using actual observable factors. Similar results have been found studying the adoption of another eco-innovations such as residential solar photovoltaics (i.e., Bollinger and Gillingham, 2012; Palm, 2017).

The influences from family and coworker domains are weaker, and for the co-worker the relation does not hold when controls are introduced. The weaker influence from the family domain might be explained by this domain's relation with the control variables introduced. Voting preferences can to some extent be assumed to be inherited from parents to children meaning that the family effect on AFV adoption is not separable from the green party voting preference. In addition the concepts of weak and strong ties might explain this finding. According to Granovetter (1973), in a social system, there are more weak ties than strong, and thus although the influence from family members might be stronger, due to their numbers, their effect is weaker in total. Since there is a more limited amount of family members to be influenced by, than for example neighbors (for most people) the effect of the strong ties of the family is actually weaker in the aggregate. Also the effect of coworkers on AFV adoption is insignificant when controls are introduced. A likely explanation for this is the coworker domain's relations with educational level and income which possibly accounts for some of the variance, but it might also be related to that cars are not that frequently discussed or noticed by coworkers compared to neighbors.

The results pertaining to the sociodemographic control variables are partly supported by previous research, which has shown that older people, in comparison to younger people, are more interested in the environmental performance of the car (Johansson-Stenman and Martinsson, 2006). Similar patterns have been observed among women who prefer AFVs to a larger extent than men (Johansson-Stenman and Martinsson, 2006; McCarthy and Tay, 1998). Moreover, in previous studies people with a higher education level appear to be more positive towards AFVs (Jansson et al., 2011; Potoglou and Kanaroglou, 2007). Finally, there are studies that find that higher income is related to higher likelihood for AFV adoption/intention to adopt (Jansson et al., 2010; Zhu and Liu, 2013), but there are also studies that find no such relation or present ambiguous results (Egbue and Long, 2012; Mannberg et al., 2014; Petschnig et al., 2014). The effect we find of income is weak which might be attributed to the fact that the price of the Golf caters to a wider target group than other types of cars where there are more price differences.

6. Conclusions and implications

Our findings point to significant effects of interpersonal influence using observed data in a large sample. Primarily the influence comes from neighbors, but also from immediate family and coworkers (although the influence from the two latter domains, weaken or disappear, when controls are introduced). Based on our empirical analyses we conclude that interpersonal influence and thus the neighbor effect is an important factor of innovation adoption in general, and for AFV adoption specifically. These findings have several implications.

From a diffusion of innovation perspective, our study puts focus on the importance of the social system as an influencer in the consumer adoption process. The study also relates to the discussion on weak and strong ties and the level of perceived interpersonal influence (e.g., Axsen and Kurani, 2011; Granovetter, 1973). As ties to neighbors in general can be assumed to be weaker than with immediate family and coworkers our study implies that the weaker social ties might be more important for innovation diffusion. Thus, the neighbors might be less strongly tied to the individual, but since the ties are weaker, and as it has been argued, there are more weak ties in a social system than strong ones (e.g., Granovetter, 1973), the neighbors are more influential on the adoption decision. The results also carry implications in general for the theoretical understanding of influence on consumer behavior. Based on this study and others (Axsen et al., 2009; Mau et al., 2008; Zhu and Liu, 2013) it becomes clear that as the adoption of an innovation picks up, and thus becomes more common and observable in for example a neighborhood, the perceived non-monetary value of this innovation increases and the rate of adoption keeps on increasing. Thus, when something, like an AFV becomes more normal, preferences change and the product, or the utility derived from the product also becomes more attractive for the majority. Thus risk of adoption decreases (Lu et al., 2005). From a marketing theory perspective this might be common knowledge, however, as Axsen and Kurani (2011) point out, as transportation researchers are only in the beginning of exploring interpersonal influence, this finding is an important addition to the transportation and policy literature.

From a policy perspective, our results signify the importance of social and normative influence on cleaner transportation technology adoption by consumers. As has been previously pointed to using other methodologies, there are different social influences and they exert different levels of pressure on the potential adopter but in general social influence is a significant factor (e.g., Axsen and Kurani, 2011; Griskevicius et al., 2008). This knowledge is important when developing polices for decreasing greenhouse gas emissions and lessening the fossil oil dependence of the car fleet. For example, policymakers can use social marketing campaigns and communicate the speed and rate at which an eco-innovation such as the AFV is spreading in a region or country. This could influence adopters and non-adopters to interact and share experiences on adoption that might also spill over into discussions on environmental issues with a wider focus. By considering the adoption decision more from a social interaction perspective (e.g., Chevalier and Mayzlin, 2006; Childers and Rao, 1992), social media technologies of today also come into focus. Policymakers could utilize these media to a larger extent in order to stimulate discussion and interpersonal influence. Another policy implication concerns the importance of demonstration projects in order to stimulate discussion and thus also adoption. Policymakers utilizing knowledge from this study could target demonstration projects concerning AFVs such as electric vehicles at certain neighborhoods and places of employment in order to generate more discussion in specific social systems. Although demonstration projects might reach a small target group only (e.g., Caperello and Kurani, 2011), the discussion generated could be picked up in the different social domains and thus influence adoption. It also becomes important to not only stimulate social interaction but also ponder what types of benefits this communication could be about. It might be that some attributes are more important to communicate in certain social domains than others. For example studies have found that AFV adopters are motivated both by environmental attitudes and novelty seeking, as well as possible image effects of being opinion leaders in the market (Jansson, 2011; Jansson et al., 2017).

Implications for practitioners, such as manufacturers and marketers of AFVs of this study concern the importance of stimulating interpersonal influence, the design elements of AFVs and the possibility of targeting certain consumer groups specifically in communication. Although car manufacturers already are using social media and interpersonal influence in order to stimulate AFV adoption, our study points to that the neighborhood could be more important in this endeavor. Using local marketing campaigns targeting close neighbors of adopters might be a successful strategy to further discussion and eventual adoption. In addition, developing AFVs with prominent design elements, or radically new designs, might also be a successful strategy given our results, which are also pointed to in previous research (Jansson, 2011; Ozaki and Sevastyanova, 2011). Less radical approaches might be to develop labeling standards that clearly signify on cars what environmental impact they have. Finally, based on our findings it might also be advantageous to target female, slightly older and more highly educated individuals in communication campaigns for AFVs in order to increase the rate of diffusion. Another segmentation approach would be to target specific "green" neighborhoods and increase consumer adoption in these and thus subsequently influence adoption in other areas as well.

7. Limitations and further research

Although our study and results to a large extent are in line with other findings using other methods we had to make some methodological choices which lead to limitations. The most obvious problem of our study design concerns causality. The way the study is set up limits our ability to show that the interpersonal influence is the main influence on adoption of all possible factors; rather we show it is an important one. Although controlling for green party voting, we cannot either totally rule out the possibility of people having self-selected into the neighborhood domain, i.e. that similar people choose neighborhood based on similar attributes or preferences and then buy similar cars in general (e.g., Manski, 1993). Partly this relates to the fact that segregation in geographical areas is a well know phenomena (e.g., Forrest and Kearns, 2001) and that this is closely related to the interpersonal interaction (desired or not) taking place in that area. We have tried to account for this self-selection bias to some extent by controlling for green party votes in the neighborhood and also by defining and measuring domains in 2007, and adoption in 2008. As such we were interested in the interpersonal influence on adoption but cannot fully rule out other effects from for example attitudes, emotions and previous experiences. However, due to that our results are in line with other studies reviewed above using simulations, interviews, and stated preference methods, we argue that our models are robust in the population chosen. In any case, research replications in other contexts and countries, using other types of purportedly pro-environmental innovations are important as well.

Another limitation of our study design is the relatively low explanatory power of the models. Many other factors that are not included in our models, due to limitations in the data set, might be influential as well. For example, we did not have access to information on the friend domain which previous research has proved to be important for AFV assessments (Axsen and Kurani, 2011). Further research with information on all these four social domains would be valuable in advancing our understanding on AFV adoption and innovation diffusion.

Other limitations of our study concern the focus on one car make and model only; the VW Golf, and it's AFV type diffusion in one single market; Sweden. However, our results are to a large extent supported by previous findings and theorization so it is likely that further studies using a more diverse set of AFVs, and conducted in more countries, would corroborate our findings. In relation to this it is also important to point to the fact that our study shows that preferences for AFVs change over time, and that different types of AFVs might increase or decrease in popularity given policy and market factors. Thus, it is important to continuously follow and research the development and effects of policy and market initiatives on actual adoption, social interaction, attitude formation and change, among adopters and non-adopters.

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